Working Draft, Standard for Programming Language C++

Note: this is an early draft. It’s known to be incomplete and incorrect, and it has lots of bad formatting.
# Contents

1 General  
1.1 Scope ............................................. 1  
1.2 Normative references .................................. 1  
1.3 Definitions ........................................... 2  
1.4 Implementation compliance ................................ 4  
1.5 Structure of this International Standard .................... 5  
1.6 Syntax notation ......................................... 5  
1.7 The C++ memory model .................................. 5  
1.8 The C++ object model ................................... 6  
1.9 Program execution ....................................... 6  
1.10 Acknowledgments ...................................... 9  

2 Lexical conventions  
2.1 Phases of translation ................................... 11  
2.2 Character sets .......................................... 12  
2.3 Trigraph sequences ..................................... 13  
2.4 Preprocessing tokens .................................... 14  
2.5 Alternative tokens ...................................... 14  
2.6 Tokens ................................................ 15  
2.7 Comments ............................................. 15  
2.8 Header names .......................................... 15  
2.9 Preprocessing numbers .................................. 16  
2.10 Identifiers ........................................... 16  
2.11 Keywords ............................................ 17  
2.12 Operators and punctuators ............................... 17  
2.13 Literals .............................................. 18  

3 Basic concepts  
3.1 Declarations and definitions .............................. 25  
3.2 One definition rule ..................................... 27  
3.3 Declarative regions and scopes ........................... 29  
3.4 Name lookup .......................................... 34  
3.5 Program and linkage .................................... 48  
3.6 Start and termination .................................... 51
3.7 Storage duration .......................................................... 54  
3.8 Object Lifetime .......................................................... 56  
3.9 Types ........................................................................... 60  
3.10 Lvalues and rvalues ....................................................... 65  

4 Standard conversions .................................................. 67  
4.1 Lvalue-to-rvalue conversion ........................................... 68  
4.2 Array-to-pointer conversion .......................................... 68  
4.3 Function-to-pointer conversion ...................................... 68  
4.4 Qualification conversions .............................................. 68  
4.5 Integral promotions ...................................................... 70  
4.6 Floating point promotion .............................................. 70  
4.7 Integral conversions ..................................................... 70  
4.8 Floating point conversions ............................................ 70  
4.9 Floating-integral conversions ....................................... 71  
4.10 Pointer conversions .................................................... 71  
4.11 Pointer to member conversions ................................... 71  
4.12 Boolean conversions .................................................. 72  

5 Expressions ................................................................. 73  
5.1 Primary expressions .................................................... 74  
5.2 Postfix expressions ...................................................... 76  
5.3 Unary expressions ....................................................... 88  
5.4 Explicit type conversion (cast notation) .......................... 95  
5.5 Pointer-to-member operators ....................................... 96  
5.6 Multiplicative operators ............................................... 97  
5.7 Additive operators ...................................................... 97  
5.8 Shift operators .......................................................... 99  
5.9 Relational operators ................................................... 99  
5.10 Equality operators ..................................................... 100  
5.11 Bitwise AND operator ............................................... 101  
5.12 Bitwise exclusive OR operator .................................... 101  
5.13 Bitwise inclusive OR operator .................................... 101  
5.14 Logical AND operator ............................................... 102  
5.15 Logical OR operator .................................................. 102  
5.16 Conditional operator ................................................ 102  
5.17 Assignment and compound assignment operators .......... 104  
5.18 Comma operator ...................................................... 104  
5.19 Constant expressions ............................................... 105  

6 Statements ................................................................. 107  
6.1 Labeled statement ...................................................... 107  
6.2 Expression statement .................................................. 107  
6.3 Compound statement or block ...................................... 107  
6.4 Selection statements ................................................... 108  
6.5 Iteration statements .................................................... 110  

Draft
12.2 Temporary objects ................................................. 221
12.3 Conversions ..................................................... 223
12.4 Destructors ....................................................... 226
12.5 Free store ........................................................ 229
12.6 Initialization ..................................................... 231
12.7 Construction and destruction ................................. 237
12.8 Copying class objects ......................................... 240

13 Overloading ......................................................... 247
13.1 Overloadable declarations ..................................... 247
13.2 Declaration matching .......................................... 250
13.3 Overload resolution ............................................. 251
13.4 Address of overloaded function ............................. 267
13.5 Overloaded operators ......................................... 269
13.6 Built-in operators .............................................. 272

14 Templates .......................................................... 277
14.1 Template parameters .......................................... 278
14.2 Names of template specializations ......................... 281
14.3 Template arguments .......................................... 283
14.4 Type equivalence .............................................. 288
14.5 Template declarations ........................................ 289
14.6 Name resolution ............................................... 303
14.7 Template instantiation and specialization ............... 317
14.8 Function template specializations ......................... 330

15 Exception handling .............................................. 349
15.1 Throwing an exception ....................................... 350
15.2 Constructors and destructors .............................. 352
15.3 Handling an exception ....................................... 353
15.4 Exception specifications ..................................... 355
15.5 Special functions .............................................. 358
15.6 Exceptions and access ....................................... 359

16 Preprocessing directives ......................................... 361
16.1 Conditional inclusion ......................................... 363
16.2 Source file inclusion .......................................... 364
16.3 Macro replacement ........................................... 365
16.4 Line control .................................................... 371
16.5 Error directive ................................................ 371
16.6 Pragma directive .............................................. 371
16.7 Null directive .................................................. 372
16.8 Predefined macro names .................................... 372
16.9 Pragma operator ............................................... 373

17 Library introduction ............................................. 375
## CONTENTS

17.1 Definitions .......................................................... 375
17.2 Additional definitions ........................................... 378
17.3 Method of description (Informative) ......................... 378
17.4 Library-wide requirements ..................................... 384

18 Language support library .......................................... 393
  18.1 Types ................................................................. 393
  18.2 Implementation properties .................................... 394
  18.3 TR1: Integer types ............................................... 404
  18.4 Start and termination .......................................... 405
  18.5 Dynamic memory management ................................. 406
  18.6 Type identification ............................................ 411
  18.7 Exception handling ............................................ 413
  18.8 Other runtime support ........................................ 417

19 Diagnostics library .................................................. 419
  19.1 Exception classes ............................................... 419
  19.2 Assertions ......................................................... 423
  19.3 Error numbers .................................................... 423

20 General utilities library ............................................ 425
  20.1 Requirements ..................................................... 425
  20.2 Utility components ............................................. 429
  20.3 TR1: Tuples ....................................................... 432
  20.4 TR1: Metaprogramming and type traits ..................... 437
  20.5 Function objects ............................................... 448
  20.6 Memory ............................................................ 469
  20.7 Date and time .................................................... 490

21 Strings library ....................................................... 493
  21.1 Character traits ................................................ 493
  21.2 String classes .................................................. 498
  21.3 Class template `basic_string` ................................. 500
  21.4 Null-terminated sequence utilities ......................... 526

22 Localization library ................................................. 531
  22.1 Locales ........................................................... 531
  22.2 Standard locale categories .................................. 541
  22.3 C Library Locales ............................................... 583

23 Containers library .................................................. 585
  23.1 Container requirements ....................................... 585
  23.2 Sequences ......................................................... 601
  23.3 Associative containers ....................................... 630
  23.4 TR1: Unordered associative containers .................... 653

24 Iterators library ..................................................... 667

Draft
A Grammar summary
A.1 Keywords ................................................. 927
A.2 Lexical conventions ........................................ 927
A.3 Basic concepts ............................................. 931
A.4 Expressions ............................................... 931
A.5 Statements ................................................ 934
A.6 Declarations .............................................. 935
A.7 Declarators ............................................... 938
A.8 Classes .................................................. 939
A.9 Derived classes .......................................... 940
A.10 Special member functions ............................... 940
A.11 Overloading .............................................. 941
A.12 Templates ............................................... 941
A.13 Exception handling ..................................... 942
A.14 Preprocessing directives ................................ 942

B Implementation quantities .................................. 945

C Compatibility ................................................ 947
C.1 C++ and ISO C ............................................ 947
C.2 Standard C library ....................................... 957

D Compatibility features ..................................... 963
D.1 Increment operator with bool operand .................. 963
D.2 static keyword .......................................... 963
D.3 Access declarations ..................................... 963
D.4 Implicit conversion from const strings ................ 963
D.5 Standard C library headers ............................. 963
D.6 Old iostreams members .................................. 964
D.7 char* streams ........................................... 965
D.8 Binders ................................................. 976

E Universal-character-names ................................ 979
# List of Tables

<table>
<thead>
<tr>
<th>Table Number</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>trigraph sequences</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>alternative tokens</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>keywords</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>alternative representations</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>Types of Integer Constants</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>escape sequences</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>relations on <code>const</code> and <code>volatile</code></td>
<td>65</td>
</tr>
<tr>
<td>8</td>
<td><code>simple-type-specifiers</code> and the types they specify</td>
<td>126</td>
</tr>
<tr>
<td>9</td>
<td>relationship between operator and function call notation</td>
<td>256</td>
</tr>
<tr>
<td>10</td>
<td>conversions</td>
<td>263</td>
</tr>
<tr>
<td>11</td>
<td>Library Categories</td>
<td>378</td>
</tr>
<tr>
<td>12</td>
<td>C++ Library Headers</td>
<td>385</td>
</tr>
<tr>
<td>13</td>
<td>C++ Headers for C Library Facilities</td>
<td>385</td>
</tr>
<tr>
<td>14</td>
<td>C++ Headers for Freestanding Implementations</td>
<td>386</td>
</tr>
<tr>
<td>15</td>
<td>Language support library summary</td>
<td>393</td>
</tr>
<tr>
<td>16</td>
<td>Header <code>&lt;cstdlib&gt;</code> synopsis</td>
<td>394</td>
</tr>
<tr>
<td>17</td>
<td>Header <code>&lt;climits&gt;</code> synopsis</td>
<td>403</td>
</tr>
<tr>
<td>18</td>
<td>Header <code>&lt;cfloat&gt;</code> synopsis</td>
<td>403</td>
</tr>
<tr>
<td>19</td>
<td>Header <code>&lt;cstdlib&gt;</code> synopsis</td>
<td>405</td>
</tr>
<tr>
<td>20</td>
<td>Header <code>&lt;cstdlib&gt;</code> synopsis</td>
<td>417</td>
</tr>
<tr>
<td>21</td>
<td>Header <code>&lt;csetjmp&gt;</code> synopsis</td>
<td>417</td>
</tr>
<tr>
<td>22</td>
<td>Header <code>&lt;ctime&gt;</code> synopsis</td>
<td>417</td>
</tr>
<tr>
<td>23</td>
<td>Header <code>&lt;cint&gt;</code> synopsis</td>
<td>418</td>
</tr>
<tr>
<td>24</td>
<td>Header <code>&lt;csetjmp&gt;</code> synopsis</td>
<td>418</td>
</tr>
<tr>
<td>25</td>
<td>Header <code>&lt;cstdlib&gt;</code> synopsis</td>
<td>418</td>
</tr>
<tr>
<td>26</td>
<td>Diagnostics library summary</td>
<td>419</td>
</tr>
<tr>
<td>27</td>
<td>Header <code>&lt;cassert&gt;</code> synopsis</td>
<td>423</td>
</tr>
<tr>
<td>28</td>
<td>Header <code>&lt;cerrno&gt;</code> synopsis</td>
<td>423</td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>29</td>
<td>General utilities library summary</td>
<td>425</td>
</tr>
<tr>
<td>30</td>
<td>EqualityComparable requirements</td>
<td>426</td>
</tr>
<tr>
<td>31</td>
<td>LessThanComparable requirements</td>
<td>426</td>
</tr>
<tr>
<td>32</td>
<td>CopyConstructible requirements</td>
<td>426</td>
</tr>
<tr>
<td>33</td>
<td>Swappable requirements</td>
<td>426</td>
</tr>
<tr>
<td>34</td>
<td>Descriptive variable definitions</td>
<td>427</td>
</tr>
<tr>
<td>35</td>
<td>Allocator requirements</td>
<td>427</td>
</tr>
<tr>
<td>36</td>
<td>Type traits library summary</td>
<td>428</td>
</tr>
<tr>
<td>37</td>
<td>Primary Type Category Predicates</td>
<td>429</td>
</tr>
<tr>
<td>38</td>
<td>Composite Type Category Predicates</td>
<td>429</td>
</tr>
<tr>
<td>39</td>
<td>Type Property Predicates</td>
<td>430</td>
</tr>
<tr>
<td>40</td>
<td>Type Property Queries</td>
<td>430</td>
</tr>
<tr>
<td>41</td>
<td>Type Relationship Predicates</td>
<td>430</td>
</tr>
<tr>
<td>42</td>
<td>Const-volatile modifications</td>
<td>430</td>
</tr>
<tr>
<td>43</td>
<td>Reference modifications</td>
<td>430</td>
</tr>
<tr>
<td>44</td>
<td>Array modifications</td>
<td>430</td>
</tr>
<tr>
<td>45</td>
<td>Pointer modifications</td>
<td>430</td>
</tr>
<tr>
<td>46</td>
<td>Other transformations</td>
<td>430</td>
</tr>
<tr>
<td>47</td>
<td>Header <code>&lt;cstdlib&gt;</code> synopsis</td>
<td>430</td>
</tr>
<tr>
<td>48</td>
<td>Header <code>&lt;cstring&gt;</code> synopsis</td>
<td>430</td>
</tr>
<tr>
<td>49</td>
<td>Header <code>&lt;ctime&gt;</code> synopsis</td>
<td>430</td>
</tr>
<tr>
<td>50</td>
<td>Strings library summary</td>
<td>430</td>
</tr>
<tr>
<td>51</td>
<td>Traits requirements</td>
<td>430</td>
</tr>
<tr>
<td>52</td>
<td><code>basic_string(const Allocator&amp;)</code> effects</td>
<td>506</td>
</tr>
<tr>
<td>53</td>
<td><code>basic_string(basic_string, size_type, size_type, const Allocator&amp;)</code> effects</td>
<td>506</td>
</tr>
<tr>
<td>54</td>
<td><code>basic_string(const charT*, size_type, const Allocator&amp;)</code> effects</td>
<td>506</td>
</tr>
<tr>
<td>55</td>
<td><code>basic_string(const charT*, const Allocator&amp;)</code> effects</td>
<td>507</td>
</tr>
<tr>
<td>56</td>
<td><code>basic_string(size_t, charT, const Allocator&amp;)</code> effects</td>
<td>507</td>
</tr>
<tr>
<td>57</td>
<td><code>operator=(const basic_string&lt;charT, traits, Allocator&gt;&amp;)</code> effects</td>
<td>508</td>
</tr>
<tr>
<td>58</td>
<td><code>compare()</code> results</td>
<td>520</td>
</tr>
<tr>
<td>59</td>
<td>Header <code>&lt;ctype&gt;</code> synopsis</td>
<td>526</td>
</tr>
<tr>
<td>60</td>
<td>Header <code>&lt;cwctype&gt;</code> synopsis</td>
<td>526</td>
</tr>
<tr>
<td>61</td>
<td>Header <code>&lt;cstring&gt;</code> synopsis</td>
<td>527</td>
</tr>
<tr>
<td>62</td>
<td>Header <code>&lt;cwchar&gt;</code> synopsis</td>
<td>527</td>
</tr>
<tr>
<td>63</td>
<td>Header <code>&lt;cwchar&gt;</code> synopsis</td>
<td>527</td>
</tr>
<tr>
<td>64</td>
<td>Localization library summary</td>
<td>527</td>
</tr>
<tr>
<td>65</td>
<td>Locale Category Facets</td>
<td>527</td>
</tr>
<tr>
<td>66</td>
<td>Required Specializations</td>
<td>527</td>
</tr>
<tr>
<td>67</td>
<td><code>do_in/do_out</code> result values</td>
<td>551</td>
</tr>
<tr>
<td>68</td>
<td><code>do_unshift</code> result values</td>
<td>552</td>
</tr>
<tr>
<td>69</td>
<td>Integer Conversions</td>
<td>553</td>
</tr>
<tr>
<td>70</td>
<td>Length Modifier</td>
<td>553</td>
</tr>
<tr>
<td>71</td>
<td>Integer Conversions</td>
<td>553</td>
</tr>
<tr>
<td>72</td>
<td>Floating-point Conversions</td>
<td>553</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table Number</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>73</td>
<td>Length Modifier</td>
<td>560</td>
</tr>
<tr>
<td>74</td>
<td>Numeric conversions</td>
<td>561</td>
</tr>
<tr>
<td>75</td>
<td>Fill padding</td>
<td>561</td>
</tr>
<tr>
<td>76</td>
<td>do_get_date effects</td>
<td>568</td>
</tr>
<tr>
<td>77</td>
<td>Header &lt;locale&gt; synopsis</td>
<td>583</td>
</tr>
<tr>
<td>78</td>
<td>Containers library summary</td>
<td>585</td>
</tr>
<tr>
<td>79</td>
<td>Assignable requirements</td>
<td>586</td>
</tr>
<tr>
<td>80</td>
<td>Container requirements</td>
<td>586</td>
</tr>
<tr>
<td>81</td>
<td>Reversible container requirements</td>
<td>588</td>
</tr>
<tr>
<td>82</td>
<td>Sequence requirements (in addition to container)</td>
<td>589</td>
</tr>
<tr>
<td>83</td>
<td>Optional sequence operations</td>
<td>591</td>
</tr>
<tr>
<td>84</td>
<td>Associative container requirements (in addition to container)</td>
<td>592</td>
</tr>
<tr>
<td>85</td>
<td>Container requirements that are not required for unordered associative containers</td>
<td>595</td>
</tr>
<tr>
<td>86</td>
<td>Unordered associative container requirements (in addition to container)</td>
<td>596</td>
</tr>
<tr>
<td>87</td>
<td>Iterators library summary</td>
<td>667</td>
</tr>
<tr>
<td>88</td>
<td>Relations among iterator categories</td>
<td>667</td>
</tr>
<tr>
<td>89</td>
<td>Input iterator requirements</td>
<td>669</td>
</tr>
<tr>
<td>90</td>
<td>Output iterator requirements</td>
<td>669</td>
</tr>
<tr>
<td>91</td>
<td>Forward iterator requirements</td>
<td>670</td>
</tr>
<tr>
<td>92</td>
<td>Bidirectional iterator requirements (in addition to forward iterator)</td>
<td>671</td>
</tr>
<tr>
<td>93</td>
<td>Random access iterator requirements (in addition to bidirectional iterator)</td>
<td>672</td>
</tr>
<tr>
<td>94</td>
<td>Algorithms library summary</td>
<td>697</td>
</tr>
<tr>
<td>95</td>
<td>Header &lt;stdlib&gt; synopsis</td>
<td>731</td>
</tr>
<tr>
<td>96</td>
<td>Numerics library summary</td>
<td>733</td>
</tr>
<tr>
<td>97</td>
<td>Uniform random number generator requirements</td>
<td>745</td>
</tr>
<tr>
<td>98</td>
<td>Pseudo-random number engine requirements (in addition to uniform random number generator, Copy-Constructible, and Assignable)</td>
<td>746</td>
</tr>
<tr>
<td>99</td>
<td>Random distribution requirements (in addition to CopyConstructible, and Assignable)</td>
<td>748</td>
</tr>
<tr>
<td>100</td>
<td>Header &lt;cmath&gt; synopsis</td>
<td>794</td>
</tr>
<tr>
<td>101</td>
<td>Header &lt;stdlib&gt; synopsis</td>
<td>795</td>
</tr>
<tr>
<td>102</td>
<td>Input/output library summary</td>
<td>799</td>
</tr>
<tr>
<td>103</td>
<td>fmtflags effects</td>
<td>809</td>
</tr>
<tr>
<td>104</td>
<td>fmtflags constants</td>
<td>809</td>
</tr>
<tr>
<td>105</td>
<td>iostate effects</td>
<td>809</td>
</tr>
<tr>
<td>106</td>
<td>openmode effects</td>
<td>810</td>
</tr>
<tr>
<td>107</td>
<td>seekdir effects</td>
<td>810</td>
</tr>
<tr>
<td>108</td>
<td>Position type requirements</td>
<td>815</td>
</tr>
<tr>
<td>109</td>
<td>basic_ios::init() effects</td>
<td>817</td>
</tr>
<tr>
<td>110</td>
<td>seekoff positioning</td>
<td>862</td>
</tr>
<tr>
<td>111</td>
<td>newoff values</td>
<td>862</td>
</tr>
<tr>
<td>112</td>
<td>File open modes</td>
<td>870</td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>seekoff effects</td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>Header <code>&lt;cstdio&gt;</code> synopsis</td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>Header <code>&lt;cinttypes&gt;</code> synopsis</td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>regular expression traits class requirements</td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>syntax_option_type effects</td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>regex_constants::match_flag_type effects when obtaining a match against a character container sequence [first,last].</td>
<td></td>
</tr>
<tr>
<td>119</td>
<td>error_type values in the C locale</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>match_results assignment operator effects</td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>Effects of regex_match algorithm</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>Effects of regex_search algorithm</td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>Standard Macros</td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>Standard Values</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>Standard Types</td>
<td></td>
</tr>
<tr>
<td>126</td>
<td>Standard Structs</td>
<td></td>
</tr>
<tr>
<td>127</td>
<td>Standard Functions</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>C Headers</td>
<td></td>
</tr>
<tr>
<td>129</td>
<td>strstreambuf(streamsize) effects</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>strstreambuf(void* (<em>)(size_t), void (</em>)(void*)) effects</td>
<td></td>
</tr>
<tr>
<td>131</td>
<td>strstreambuf(charT*, streamsize, charT*) effects</td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>seekoff positioning</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>newoff values</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 1  General

1.1 Scope

1 This International Standard specifies requirements for implementations of the C++ programming language. The first such requirement is that they implement the language, and so this International Standard also defines C++. Other requirements and relaxations of the first requirement appear at various places within this International Standard.

2 C++ is a general purpose programming language based on the C programming language as described in ISO/IEC 9899:1990 Programming languages - C (1.2). In addition to the facilities provided by C, C++ provides additional data types, classes, templates, exceptions, namespaces, inline functions, operator overloading, function name overloading, references, free store management operators, and additional library facilities.

1.2 Normative references

1 The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

— ISO/IEC 2382 (all parts), Information technology - Vocabulary
— ISO/IEC 9899:1990, Programming languages - C
— ISO/IEC 9899/Amd.1:1995, Programming languages - C, AMENDMENT 1: C Integrity
TR1: — ISO/IEC 9899:1999, Programming languages - C
— ISO/IEC 10646-1:1993 Information technology - Universal Multiple-Octet Coded Character Set (UCS) - Part 1: Architecture and Basic Multilingual Plane

2 The library described in clause 7 of ISO/IEC 9899:1990 and clause 7 of ISO/IEC 9899/Amd.1:1995 is hereinafter called the Standard C Library.1)

1) With the qualifications noted in clauses 17 through 27, and in C.2, the Standard C library is a subset of the Standard C++ library.
1.3 Definitions [intro.defs]

For the purposes of this International Standard, the definitions given in ISO/IEC 2382 and the following definitions apply. 17.1 defines additional terms that are used only in clauses 17 through 27 and Annex D.

Terms that are used only in a small portion of this International Standard are defined where they are used and italicized where they are defined.

1.3.1 argument [defns.argument]

an expression in the comma-separated list bounded by the parentheses in a function call expression, a sequence of preprocessing tokens in the comma-separated list bounded by the parentheses in a function-like macro invocation, the operand of throw, or an expression, type-id or template-name in the comma-separated list bounded by the angle brackets in a template instantiation. Also known as an actual argument or actual parameter.

1.3.2 conditionally-supported [defns.cond.supp]

a program construct that an implementation is not required to support. [ Note: Each implementation documents all conditionally-supported constructs that it does not support. — end note ]

1.3.3 diagnostic message [defns.diagnostic]

a message belonging to an implementation-defined subset of the implementation’s output messages.

1.3.4 dynamic type [defns.dynamic.type]

the type of the most derived object (1.8) to which the lvalue denoted by an lvalue expression refers. [ Example: if a pointer (8.3.1) \( p \) whose static type is “pointer to class \( B \)” is pointing to an object of class \( D \), derived from \( B \) (clause 10), the dynamic type of the expression \( *p \) is “\( D \)” References (8.3.2) are treated similarly. — end example ] The dynamic type of an rvalue expression is its static type.

1.3.5 ill-formed program [defns.ill.formed]

input to a C++ implementation that is not a well-formed program (1.3.15).

1.3.6 implementation-defined behavior [defns.impl.defined]

behavior, for a well-formed program construct and correct data, that depends on the implementation and that each
implementation documents.

**1.3.7 implementation limits**

restrictions imposed upon programs by the implementation.

**1.3.8 locale-specific behavior**

behavior that depends on local conventions of nationality, culture, and language that each implementation documents.

**1.3.9 multibyte character**

a sequence of one or more bytes representing a member of the extended character set of either the source or the execution environment. The extended character set is a superset of the basic character set (2.2).

**1.3.10 parameter**

an object or reference declared as part of a function declaration or definition, or in the catch clause of an exception handler, that acquires a value on entry to the function or handler; an identifier from the comma-separated list bounded by the parentheses immediately following the macro name in a function-like macro definition; or a template-parameter. Parameters are also known as formal arguments or formal parameters.

**1.3.11 signature**

the information about a function that participates in overload resolution (13.3): its parameter-type-list (8.3.5) and, if the function is a class member, the cv-qualifiers (if any) on the function itself and the class in which the member function is declared. The signature of a function template specialization includes the types of its template arguments (14.5.5.1).

**1.3.12 static type**

the type of an expression (3.9), which type results from analysis of the program without considering execution semantics. The static type of an expression depends only on the form of the program in which the expression appears, and does not change while the program is executing.

**1.3.13 undefined behavior**

behavior, such as might arise upon use of an erroneous program construct or erroneous data, for which this International Standard imposes no requirements. Undefined behavior may also be expected when this International Standard omits the description of any explicit definition of behavior. [Note: permissible undefined behavior ranges from ignoring the situation completely with unpredictable results, to behaving during translation or program execution in a documented manner characteristic of the environment (with or without the issuance of a diagnostic message), to terminating a translation or execution (with the issuance of a diagnostic message). Many erroneous program constructs do not engender undefined behavior; they are required to be diagnosed. — end note]

**1.3.14 unspecified behavior**

behavior, for a well-formed program construct and correct data, that depends on the implementation. The implementation is not required to document which behavior occurs. [Note: usually, the range of possible behaviors is delineated by

---

2) Function signatures do not include return type, because that does not participate in overload resolution.
1.4 Implementation compliance

The set of diagnosable rules consists of all syntactic and semantic rules in this International Standard except for those rules containing an explicit notation that “no diagnostic is required” or which are described as resulting in “undefined behavior.”

Although this International Standard states only requirements on C++ implementations, those requirements are often easier to understand if they are phrased as requirements on programs, parts of programs, or execution of programs. Such requirements have the following meaning:

---

1. If a program contains no violations of the rules in this International Standard, a conforming implementation shall, within its resource limits, accept and correctly execute that program.

2. If a program contains a violation of any diagnosable rule or an occurrence of a construct described in this Standard as “conditionally-supported” when the implementation does not support that construct, a conforming implementation shall issue at least one diagnostic message, except that

3. If a program contains a violation of a rule for which no diagnostic is required, this International Standard places no requirement on implementations with respect to that program.

For classes and class templates, the library clauses specify partial definitions. Private members (clause 11) are not specified, but each implementation shall supply them to complete the definitions according to the description in the library clauses.

For functions, function templates, objects, and values, the library clauses specify declarations. Implementations shall supply definitions consistent with the descriptions in the library clauses.

The names defined in the library have namespace scope (7.3). A C++ translation unit (2.1) obtains access to these names by including the appropriate standard library header (16.2).

The templates, classes, functions, and objects in the library have external linkage (3.5). The implementation provides definitions for standard library entities, as necessary, while combining translation units to form a complete C++ program (2.1).

Two kinds of implementations are defined: hosted and freestanding. For a hosted implementation, this International Standard defines the set of available libraries. A freestanding implementation is one in which execution may take place without the benefit of an operating system, and has an implementation-defined set of libraries that includes certain language-support libraries (17.4.1.3).

A conforming implementation may have extensions (including additional library functions), provided they do not alter the behavior of any well-formed program. Implementations are required to diagnose programs that use such extensions that are ill-formed according to this International Standard. Having done so, however, they can compile and execute such programs.

---

3) “Correct execution” can include undefined behavior, depending on the data being processed; see 1.3 and 1.9.
Each implementation shall include documentation that identifies all conditionally-supported constructs that it does not support and defines all locale-specific characteristics.  

1.5 Structure of this International Standard  

Clauses 2 through 16 describe the C++ programming language. That description includes detailed syntactic specifications in a form described in 1.6. For convenience, Annex A repeats all such syntactic specifications.

Clauses 17 through 27 and Annex D (the library clauses) describe the Standard C++ library, which provides definitions for the following kinds of entities: macros (16.3), values (clause 3), types (8.1, 8.3), templates (clause 14), classes (clause 9), functions (8.3.5), and objects (clause 7).

Annex B recommends lower bounds on the capacity of conforming implementations.

Annex C summarizes the evolution of C++ since its first published description, and explains in detail the differences between C++ and C. Certain features of C++ exist solely for compatibility purposes; Annex D describes those features.

Finally, Annex E says what characters are valid in universal-character names in C++ identifiers (2.10).

Throughout this International Standard, each example is introduced by “[Example:’” and terminated by “—end example]”. Each note is introduced by “[Note:’” and terminated by “—end note]”. Examples and notes may be nested.

1.6 Syntax notation  

In the syntax notation used in this International Standard, syntactic categories are indicated by italic type, and literal words and characters in constant width type. Alternatives are listed on separate lines except in a few cases where a long set of alternatives is presented on one line, marked by the phrase “one of.” An optional terminal or nonterminal symbol is indicated by the subscript “opt”, so

{ expression_{opt} }

indicates an optional expression enclosed in braces.

Names for syntactic categories have generally been chosen according to the following rules:

— X-name is a use of an identifier in a context that determines its meaning (e.g. class-name, typedef-name).

— X-id is an identifier with no context-dependent meaning (e.g. qualified-id).

— X-seq is one or more X’s without intervening delimiters (e.g. declaration-seq is a sequence of declarations).

— X-list is one or more X’s separated by intervening commas (e.g. expression-list is a sequence of expressions separated by commas).

1.7 The C++ memory model  

The fundamental storage unit in the C++ memory model is the byte. A byte is at least large enough to contain any member of the basic execution character set and is composed of a contiguous sequence of bits, the number of which is implementation-defined. The least significant bit is called the low-order bit; the most significant bit is called the high-order bit. The memory available to a C++ program consists of one or more sequences of contiguous bytes. Every byte has a unique address.

---

4) This documentation also defines implementation-defined behavior; see 1.9.
1.8 The C++ object model

The constructs in a C++ program create, destroy, refer to, access, and manipulate objects. An object is a region of storage. [Note: A function is not an object, regardless of whether or not it occupies storage in the way that objects do. — end note] An object is created by a definition (3.1), by a new-expression (5.3.4) or by the implementation (12.2) when needed. The properties of an object are determined when the object is created. An object can have a name (clause 3). An object has a storage duration (3.7) which influences its lifetime (3.8). An object has a type (3.9). The term object type refers to the type with which the object is created. Some objects are polymorphic (10.3); the implementation generates information associated with each such object that makes it possible to determine that object’s type during program execution. For other objects, the interpretation of the values found therein is determined by the type of the expressions (clause 5) used to access them.

2 Objects can contain other objects, called subobjects. A subobject can be a member subobject (9.2), a base class subobject (clause 10), or an array element. An object that is not a subobject of any other object is called a complete object.

3 For every object \( x \), there is some object called the complete object of \( x \), determined as follows:
   - If \( x \) is a complete object, then \( x \) is the complete object of \( x \).
   - Otherwise, the complete object of \( x \) is the complete object of the (unique) object that contains \( x \).

4 If a complete object, a data member (9.2), or an array element is of class type, its type is considered the most derived class, to distinguish it from the class type of any base class subobject; an object of a most derived class type or of a non-class type is called a most derived object.

5 Unless it is a bit-field (9.6), a most derived object shall have a non-zero size and shall occupy one or more bytes of storage. Base class subobjects may have zero size. An object of POD\(^5\) type (3.9) shall occupy contiguous bytes of storage.

6 [Note: C++ provides a variety of built-in types and several ways of composing new types from existing types (3.9). — end note]

1.9 Program execution

The semantic descriptions in this International Standard define a parameterized nondeterministic abstract machine. This International Standard places no requirement on the structure of conforming implementations. In particular, they need not copy or emulate the structure of the abstract machine. Rather, conforming implementations are required to emulate (only) the observable behavior of the abstract machine as explained below.\(^6\)

2 Certain aspects and operations of the abstract machine are described in this International Standard as implementation-defined (for example, \sizeof(int)\). These constitute the parameters of the abstract machine. Each implementation shall include documentation describing its characteristics and behavior in these respects.\(^7\) Such documentation shall

\(^5\) The acronym POD stands for “plain old data.”

\(^6\) This provision is sometimes called the “as-if” rule, because an implementation is free to disregard any requirement of this International Standard as long as the result is as if the requirement had been obeyed, as far as can be determined from the observable behavior of the program. For instance, an actual implementation need not evaluate part of an expression if it can deduce that its value is not used and that no side effects affecting the observable behavior of the program are produced.

\(^7\) This documentation also includes conditionally-supported constructs and locale-specific behavior. See 1.4.
define the instance of the abstract machine that corresponds to that implementation (referred to as the “corresponding instance” below).

3 Certain other aspects and operations of the abstract machine are described in this International Standard as unspecified (for example, order of evaluation of arguments to a function). Where possible, this International Standard defines a set of allowable behaviors. These define the nondeterministic aspects of the abstract machine. An instance of the abstract machine can thus have more than one possible execution sequence for a given program and a given input.

4 Certain other operations are described in this International Standard as undefined (for example, the effect of dereferencing the null pointer). [Note: this International Standard imposes no requirements on the behavior of programs that contain undefined behavior. —end note]

5 A conforming implementation executing a well-formed program shall produce the same observable behavior as one of the possible execution sequences of the corresponding instance of the abstract machine with the same program and the same input. However, if any such execution sequence contains an undefined operation, this International Standard places no requirement on the implementation executing that program with that input (not even with regard to operations preceding the first undefined operation).

6 The observable behavior of the abstract machine is its sequence of reads and writes to volatile data and calls to library I/O functions.8)

7 Accessing an object designated by a volatile lvalue (3.10), modifying an object, calling a library I/O function, or calling a function that does any of those operations are all side effects, which are changes in the state of the execution environment. Evaluation of an expression might produce side effects. At certain specified points in the execution sequence called sequence points, all side effects of previous evaluations shall be complete and no side effects of subsequent evaluations shall have taken place."9"

8 Once the execution of a function begins, no expressions from the calling function are evaluated until execution of the called function has completed.10)

9 When the processing of the abstract machine is interrupted by receipt of a signal, the values of objects with type other than volatile std::sig_atomic_t are unspecified, and the value of any object not of volatile std::sig_atomic_t that is modified by the handler becomes undefined.

10 An instance of each object with automatic storage duration (3.7.2) is associated with each entry into its block. Such an object exists and retains its last-stored value during the execution of the block and while the block is suspended (by a call of a function or receipt of a signal).

11 The least requirements on a conforming implementation are:

- At sequence points, volatile objects are stable in the sense that previous evaluations are complete and subsequent evaluations have not yet occurred.

- At program termination, all data written into files shall be identical to one of the possible results that execution of the program according to the abstract semantics would have produced.

8) An implementation can offer additional library I/O functions as an extension. Implementations that do so should treat calls to those functions as “observable behavior” as well.

9) Note that some aspects of sequencing in the abstract machine are unspecified; the preceding restriction upon side effects applies to that particular execution sequence in which the actual code is generated. Also note that when a call to a library I/O function returns, the side effect is considered complete, even though some external actions implied by the call (such as the I/O itself) may not have completed yet.

10) In other words, function executions do not “interleave” with each other.
1.9 Program execution

— The input and output dynamics of interactive devices shall take place in such a fashion that prompting messages actually appear prior to a program waiting for input. What constitutes an interactive device is implementation-defined.

[Note: more stringent correspondences between abstract and actual semantics may be defined by each implementation. —end note]

A full-expression is an expression that is not a subexpression of another expression. If a language construct is defined to produce an implicit call of a function, a use of the language construct is considered to be an expression for the purposes of this definition. Conversions applied to the result of an expression in order to satisfy the requirements of the language construct in which the expression appears are also considered to be part of the full-expression. [Example:

```c
struct S {
    S(int i): I(i) { }
    int& v() { return I; }
    private:
        int I;
};

S s1(1);            // full-expression is call of S::S(int)
S s2 = 2;           // full-expression is call of S::S(int)

void f() {
    if (S(3).v()) // full-expression includes lvalue-to-rvalue and
        // int to bool conversions, performed before
        // temporary is deleted at end of full-expression

    { }
}

— end example ]

[Note: the evaluation of a full-expression can include the evaluation of subexpressions that are not lexically part of the full-expression. For example, subexpressions involved in evaluating default argument expressions (8.3.6) are considered to be created in the expression that calls the function, not the expression that defines the default argument. —end note]

[Note: operators can be regrouped according to the usual mathematical rules only where the operators really are associative or commutative.11] For example, in the following fragment

```c
int a, b;
/* ... */
a = a + 32760 + b + 5;
```

the expression statement behaves exactly the same as

```c
a = (((a + 32760) + b) + 5);
```

due to the associativity and precedence of these operators. Thus, the result of the sum (a + 32760) is next added to b, and that result is then added to 5 which results in the value assigned to a. On a machine in which overflows produce an exception and in which the range of values representable by an int is [-32768,+32767], the implementation cannot rewrite this expression as

11) Overloaded operators are never assumed to be associative or commutative.
a = ((a + b) + 32765);

since if the values for \(a\) and \(b\) were, respectively, -32754 and -15, the sum \(a + b\) would produce an exception while the original expression would not; nor can the expression be rewritten either as

\[a = ((a + 32765) + b);\]

or

\[a = (a + (b + 32765));\]

since the values for \(a\) and \(b\) might have been, respectively, 4 and -8 or -17 and 12. However on a machine in which overflows do not produce an exception and in which the results of overflows are reversible, the above expression statement can be rewritten by the implementation in any of the above ways because the same result will occur. — end note

There is a sequence point at the completion of evaluation of each full-expression\(^{12}\).

When calling a function (whether or not the function is inline), there is a sequence point after the evaluation of all function arguments (if any) which takes place before execution of any expressions or statements in the function body. There is also a sequence point after the copying of a returned value and before the execution of any expressions outside the function\(^{13}\). Several contexts in C++ cause evaluation of a function call, even though no corresponding function call syntax appears in the translation unit. [Example: evaluation of a new expression invokes one or more allocation and constructor functions; see 5.3.4. For another example, invocation of a conversion function (12.3.2) can arise in contexts in which no function call syntax appears. — end example] The sequence points at function-entry and function-exit (as described above) are features of the function calls as evaluated, whatever the syntax of the expression that calls the function might be.

In the evaluation of each of the expressions

\[a \&\& b\]
\[a || b\]
\[a ? b : c\]
\[a, b\]

using the built-in meaning of the operators in these expressions (5.14, 5.15, 5.16, 5.18), there is a sequence point after the evaluation of the first expression\(^{14}\).

1.10 Acknowledgments

The C++ programming language as described in this International Standard is based on the language as described in Chapter R (Reference Manual) of Stroustrup: The C++ Programming Language (second edition, Addison-Wesley Publishing Company, ISBN 0-201-53992-6, copyright ©1991 AT&T). That, in turn, is based on the C programming lan-

\(^{12}\) As specified in 12.2, after the “end-of-full-expression” sequence point, a sequence of zero or more invocations of destructor functions for temporary objects takes place, usually in reverse order of the construction of each temporary object.

\(^{13}\) The sequence point at the function return is not explicitly specified in ISO C, and can be considered redundant with sequence points at full-expressions, but the extra clarity is important in C++. In C++, there are more ways in which a called function can terminate its execution, such as the throw of an exception.

\(^{14}\) The operators indicated in this paragraph are the built-in operators, as described in clause 5. When one of these operators is overloaded (clause 13) in a valid context, thus designating a user-defined operator function, the expression designates a function invocation, and the operands form an argument list, without an implied sequence point between them.


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Chapter 2  Lexical conventions

The text of the program is kept in units called source files in this International Standard. A source file together with all the headers (17.4.1.2) and source files included (16.2) via the preprocessing directive #include, less any source lines skipped by any of the conditional inclusion (16.1) preprocessing directives, is called a translation unit. [Note: a C++ program need not all be translated at the same time. — end note]

Note: previously translated translation units and instantiation units can be preserved individually or in libraries. The separate translation units of a program communicate (3.5) by (for example) calls to functions whose identifiers have external linkage, manipulation of objects whose identifiers have external linkage, or manipulation of data files. Translation units can be separately translated and then later linked to produce an executable program (3.5). — end note]

2.1 Phases of translation

The precedence among the syntax rules of translation is specified by the following phases.\footnote{Implementations must behave as if these separate phases occur, although in practice different phases might be folded together.}

1. Physical source file characters are mapped, in an implementation-defined manner, to the basic source character set (introducing new-line characters for end-of-line indicators) if necessary. Trigraph sequences (2.3) are replaced by corresponding single-character internal representations. Any source file character not in the basic source character set (2.2) is replaced by the universal-character-name that designates that character. (An implementation may use any internal encoding, so long as an actual extended character encountered in the source file, and the same extended character expressed in the source file as a universal-character-name (i.e. using the \uXXXX notation), are handled equivalently.)

2. Each instance of a backslash character (\) immediately followed by a new-line character is deleted, splicing physical source lines to form logical source lines. Only the last backslash on any physical source line shall be eligible for being part of such a splice. If, as a result, a character sequence that matches the syntax of a universal-character-name is produced, the behavior is undefined. If a source file that is not empty does not end in a new-line character, or ends in a new-line character immediately preceded by a backslash character before any such splicing takes place, the behavior is undefined.

3. The source file is decomposed into preprocessing tokens (2.4) and sequences of white-space characters (including comments). A source file shall not end in a partial preprocessing token or in a partial comment.\footnote{A partial preprocessing token would arise from a source file ending in the first portion of a multi-character token that requires a terminating sequence of characters, such as a header-name that is missing the closing " or ">. A partial comment would arise from a source file ending with an unclosed /* comment.} Each comment is replaced by one space character. New-line characters are retained. Whether each nonempty sequence of white-space characters other than new-line is retained or replaced by one space character is implementation-defined.
The process of dividing a source file’s characters into preprocessing tokens is context-dependent. [Example: see the handling of < within a #include preprocessing directive. — end example]

4. Preprocessing directives are executed, macro invocations are expanded, and _Pragma unary operator expressions are executed. If a character sequence that matches the syntax of a universal-character-name is produced by token concatenation (16.3.3), the behavior is undefined. A #include preprocessing directive causes the named header or source file to be processed from phase 1 through phase 4, recursively. All preprocessing directives are then deleted.

5. Each source character set member, escape sequence, or universal-character-name in character literals and string literals is converted to the corresponding member of the execution character set (2.13.2, 2.13.4); if there is no corresponding member, it is converted to an implementation-defined member other than the null (wide) character. 17

6. Adjacent literal tokens are concatenated.

7. White-space characters separating tokens are no longer significant. Each preprocessing token is converted into a token. (2.6). The resulting tokens are syntactically and semantically analyzed and translated as a translation unit. [Note: The process of analyzing and translating the tokens may occasionally result in one token being replaced by a sequence of other tokens (14.2). — end note] [Note: Source files, translation units and translated translation units need not necessarily be stored as files, nor need there be any one-to-one correspondence between these entities and any external representation. The description is conceptual only, and does not specify any particular implementation. — end note]

8. Translated translation units and instantiation units are combined as follows: [Note: some or all of these may be supplied from a library. — end note] Each translated translation unit is examined to produce a list of required instantiations. [Note: this may include instantiations which have been explicitly requested (14.7.2). — end note] The definitions of the required templates are located. It is implementation-defined whether the source of the translation units containing these definitions is required to be available. [Note: an implementation could encode sufficient information into the translated translation unit so as to ensure the source is not required here. — end note] All the required instantiations are performed to produce instantiation units. [Note: these are similar to translated translation units, but contain no references to uninstantiated templates and no template definitions. — end note] The program is ill-formed if any instantiation fails.

9. All external object and function references are resolved. Library components are linked to satisfy external references to functions and objects not defined in the current translation. All such translator output is collected into a program image which contains information needed for execution in its execution environment.

2.2 Character sets [lex.charset]

The basic source character set consists of 96 characters: the space character, the control characters representing horizontal tab, vertical tab, form feed, and new-line, plus the following 91 graphical characters:18

a b c d e f g h i j k l m n o p q r s t u v w x y z

17) An implementation need not convert all non-corresponding source characters to the same execution character.

18) The glyphs for the members of the basic source character set are intended to identify characters from the subset of ISO/IEC 10646 which corresponds to the ASCII character set. However, because the mapping from source file characters to the source character set (described in translation phase 1) is specified as implementation-defined, an implementation is required to document how the basic source characters are represented in source files.
The **universal-character-name** construct provides a way to name other characters.

```
hex-quad:
  hexadecimal-digit hexadecimal-digit hexadecimal-digit hexadecimal-digit
universal-character-name:
  \u hex-quad
  \U hex-quad hex-quad
```

The character designated by the universal-character-name \U{NNNNNNNN} is that character whose character short name in ISO/IEC 10646 is NNNNNNNN; the character designated by the universal-character-name \u{NNNN} is that character whose character short name in ISO/IEC 10646 is 0000NNNN. If the hexadecimal value for a universal character name is less than 0x20 or in the range 0x7F-0x9F (inclusive), or if the universal character name designates a character in the basic source character set, then the program is ill-formed.

The **basic execution character set** and the **basic execution wide-character set** shall each contain all the members of the basic source character set, plus control characters representing alert, backspace, and carriage return, plus a *null character* (respectively, *null wide character*), whose representation has all zero bits. For each basic execution character set, the values of the members shall be non-negative and distinct from one another. In both the source and execution basic character sets, the value of each character after 0 in the above list of decimal digits shall be one greater than the value of the previous. The **execution character set** and the **execution wide-character set** are supersets of the basic execution character set and the basic execution wide-character set, respectively. The values of the members of the execution character sets are implementation-defined, and any additional members are locale-specific.

### 2.3 Trigraph sequences

Before any other processing takes place, each occurrence of one of the following sequences of three characters ("trigraph sequences") is replaced by the single character indicated in Table 1.

<table>
<thead>
<tr>
<th>trigraph</th>
<th>replacement</th>
<th>trigraph</th>
<th>replacement</th>
<th>trigraph</th>
<th>replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>??=</td>
<td>#</td>
<td>??(</td>
<td>[</td>
<td>??&lt;</td>
<td>{</td>
</tr>
<tr>
<td>??/</td>
<td>\</td>
<td>??)</td>
<td>]</td>
<td>??&gt;</td>
<td>}</td>
</tr>
<tr>
<td>??'</td>
<td>~</td>
<td>??!</td>
<td></td>
<td></td>
<td>??~</td>
</tr>
</tbody>
</table>

**Example:**

```
??=define arraycheck(a,b) a??(b??) ??!??! b??(a??)
```

becomes

```
#define arraycheck(a,b) a[b] || b[a]
```
2.4 Preprocessing tokens

--- end example ---

No other trigraph sequence exists. Each ? that does not begin one of the trigraphs listed above is not changed.

A preprocessing token is the minimal lexical element of the language in translation phases 3 through 6. The categories of preprocessing token are: header names, identifiers, preprocessing numbers, character literals, string literals, preprocessing-op-or-punc, and single non-white-space characters that do not lexically match the other preprocessing token categories. If a ' or a " character matches the last category, the behavior is undefined. Preprocessing tokens can be separated by white space; this consists of comments (2.7), or white-space characters (space, horizontal tab, new-line, vertical tab, and form-feed), or both. As described in clause 16, in certain circumstances during translation phase 4, white space (or the absence thereof) serves as more than preprocessing token separation. White space can appear within a preprocessing token only as part of a header name or between the quotation characters in a character literal or string literal.

If the input stream has been parsed into preprocessing tokens up to a given character, the next preprocessing token is the longest sequence of characters that could constitute a preprocessing token, even if that would cause further lexical analysis to fail.

[ Example: The program fragment 1Ex is parsed as a preprocessing number token (one that is not a valid floating or integer literal token), even though a parse as the pair of preprocessing tokens 1 and Ex might produce a valid expression (for example, if Ex were a macro defined as +1). Similarly, the program fragment 1E1 is parsed as a preprocessing number (one that is a valid floating literal token), whether or not E is a macro name. --- end example ---]

[ Example: The program fragment x+++++y is parsed as x ++ ++ ++ y, which, if x and y are of built-in types, violates a constraint on increment operators, even though the parse x ++ + ++ y might yield a correct expression. --- end example ---]

2.5 Alternative tokens

Alternative token representations are provided for some operators and punctuators.¹⁹)

In all respects of the language, each alternative token behaves the same, respectively, as its primary token, except for its
The set of alternative tokens is defined in Table 2.

2.6 Tokens

There are five kinds of tokens: identifiers, keywords, literals, operators, and other separators. Blanks, horizontal and vertical tabs, newlines, formfeeds, and comments (collectively, “white space”), as described below, are ignored except as they serve to separate tokens. [Note: Some white space is required to separate otherwise adjacent identifiers, keywords, numeric literals, and alternative tokens containing alphabetic characters. —end note]

2.7 Comments

The characters /* start a comment, which terminates with the characters */. These comments do not nest. The characters // start a comment, which terminates with the next new-line character. If there is a form-feed or a vertical-tab character in such a comment, only white-space characters shall appear between it and the new-line that terminates the comment; no diagnostic is required. [Note: The comment characters //, /*, and */ have no special meaning within a // comment and are treated just like other characters. Similarly, the comment characters // and */ have no special meaning within a /* comment. —end note]

2.8 Header names

These include “digraphs” and additional reserved words. The term “digraph” (token consisting of two characters) is not perfectly descriptive, since one of the alternative preprocessing-tokens is %:%: and of course several primary tokens contain two characters. Nonetheless, those alternative tokens that aren’t lexical keywords are colloquially known as “digraphs”.

Thus the “stringized” values (16.3.2) of [ and <: will be different, maintaining the source spelling, but the tokens can otherwise be freely interchanged.

21) Literals include strings and character and numeric literals.

Table 2: alternative tokens

<table>
<thead>
<tr>
<th>alternative primary</th>
<th>alternative primary</th>
<th>alternative primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;%;</td>
<td>and</td>
<td>&amp;&amp; and_eq &amp;=</td>
</tr>
<tr>
<td>%&gt;</td>
<td>bitor</td>
<td></td>
</tr>
<tr>
<td>&lt;: ]</td>
<td>or</td>
<td></td>
</tr>
<tr>
<td>:&gt; }</td>
<td>xor</td>
<td>^ not !</td>
</tr>
<tr>
<td>%: #</td>
<td>compl</td>
<td>~ not_eq !=</td>
</tr>
<tr>
<td>%:%: ##</td>
<td>bitand</td>
<td>&amp;</td>
</tr>
</tbody>
</table>

Draft
2.9 Preprocessing numbers

\[ h-char: \]
any member of the source character set except new-line and >

\[ q-char-sequence: \]
\[ q-char \]
\[ q-char-sequence q-char \]

\[ q-char: \]
any member of the source character set except new-line and "

1 Header name preprocessing tokens shall only appear within a \#include preprocessing directive (16.2). The sequences in both forms of header-names are mapped in an implementation-defined manner to headers or to external source file names as specified in 16.2.

2 If either of the characters ’ or \, or either of the character sequences /* or // appears in a q-char-sequence or a h-char-sequence, or the character " appears in a h-char-sequence, the behavior is undefined.\(^{22}\)

2.9 Preprocessing numbers

\[ pp-number: \]
\[ digit \]
\[ . digit \]
\[ pp-number digit \]
\[ pp-number nondigit \]
\[ pp-number E sign \]
\[ pp-number . \]

1 Preprocessing number tokens lexically include all integral literal tokens (2.13.1) and all floating literal tokens (2.13.3).

2 A preprocessing number does not have a type or a value; it acquires both after a successful conversion (as part of translation phase 7, 2.1) to an integral literal token or a floating literal token.

2.10 Identifiers

\[ identifier: \]
\[ identifier-nondigit \]
\[ identifier identifier-nondigit \]
\[ identifier digit \]

\[ identifier-nondigit: \]
\[ nondigit \]
\[ universal-character-name \]
\[ other implementation-defined characters \]

\[ nondigit: \] one of
\[ a b c d e f g h i j k l m \]
\[ n o p q r s t u v w x y z \]
\[ A B C D E F G H I J K L M \]
\[ N O P Q R S T U V W X Y Z \]

\[ digit: \] one of
\[ 0 1 2 3 4 5 6 7 8 9 \]

\(^{22}\) Thus, sequences of characters that resemble escape sequences cause undefined behavior.
An identifier is an arbitrarily long sequence of letters and digits. Each universal-character-name in an identifier shall designate a character whose encoding in ISO 10646 falls into one of the ranges specified in Annex E. Upper- and lower-case letters are different. All characters are significant.

In addition, some identifiers are reserved for use by C++ implementations and standard libraries (17.4.3.1.2) and shall not be used otherwise; no diagnostic is required.

### Keywords

The identifiers shown in Table 3 are reserved for use as keywords (that is, they are unconditionally treated as keywords in phase 7):

<table>
<thead>
<tr>
<th>asm</th>
<th>do</th>
<th>if</th>
<th>return</th>
<th>try</th>
</tr>
</thead>
<tbody>
<tr>
<td>auto</td>
<td>double</td>
<td>inline</td>
<td>short</td>
<td>typedef</td>
</tr>
<tr>
<td>bool</td>
<td>dynamic_cast</td>
<td>int</td>
<td>signed</td>
<td>typeid</td>
</tr>
<tr>
<td>break</td>
<td>else</td>
<td>long</td>
<td>sizeof</td>
<td>typename</td>
</tr>
<tr>
<td>case</td>
<td>enum</td>
<td>mutable</td>
<td>static</td>
<td>union</td>
</tr>
<tr>
<td>catch</td>
<td>explicit</td>
<td>namespace</td>
<td>static_assert</td>
<td>unsigned</td>
</tr>
<tr>
<td>char</td>
<td>export</td>
<td>new</td>
<td>static_cast</td>
<td>using</td>
</tr>
<tr>
<td>class</td>
<td>extern</td>
<td>operator</td>
<td>struct</td>
<td>virtual</td>
</tr>
<tr>
<td>const</td>
<td>false</td>
<td>private</td>
<td>switch</td>
<td>void</td>
</tr>
<tr>
<td>const_cast</td>
<td>float</td>
<td>protected</td>
<td>template</td>
<td>volatile</td>
</tr>
<tr>
<td>continue</td>
<td>for</td>
<td>public</td>
<td>this</td>
<td>wchar_t</td>
</tr>
<tr>
<td>default</td>
<td>friend</td>
<td>register</td>
<td>throw</td>
<td>while</td>
</tr>
<tr>
<td>delete</td>
<td>goto</td>
<td>reinterpret_cast</td>
<td>true</td>
<td></td>
</tr>
</tbody>
</table>

Furthermore, the alternative representations shown in Table 4 for certain operators and punctuators (2.5) are reserved and shall not be used otherwise:

<table>
<thead>
<tr>
<th>and</th>
<th>and_eq</th>
<th>bitand</th>
<th>bitor</th>
<th>compl</th>
<th>not</th>
</tr>
</thead>
<tbody>
<tr>
<td>not_eq</td>
<td>or</td>
<td>or_eq</td>
<td>xor</td>
<td>xor_eq</td>
<td></td>
</tr>
</tbody>
</table>

### Operators and Punctuators

The lexical representation of C++ programs includes a number of preprocessing tokens which are used in the syntax of the preprocessor or are converted into tokens for operators and punctuators:

---

23) On systems in which linkers cannot accept extended characters, an encoding of the universal-character-name may be used in forming valid external identifiers. For example, some otherwise unused character or sequence of characters may be used to encode the ‘\u’ in a universal-character-name. Extended characters may produce a long external identifier, but C++ does not place a translation limit on significant characters for external identifiers. In C++, upper- and lower-case letters are considered different for all identifiers, including external identifiers.

Draft
2.13 Literals

preprocessing-op-or-punc: one of
{ } [ ] # ## ( )
<: :> <% %> %: %:%: ; : ... 
new delete ? :: . .*
+ - * / % ~ & |
!= -= %= /= %= ^= &= |= && || ++ -- , , ->*
and and_eq bitand bitor compl not not_eq
or or_eq xor xor_eq

Each preprocessing-op-or-punc is converted to a single token in translation phase 7 (2.1).

2.13 Literals

There are several kinds of literals.24)

literal:
integer-literal
character-literal
floating-literal
string-literal
boolean-literal

2.13.1 Integer literals

integer-literal:
decimal-literal integer-suffixopt
octal-literal integer-suffixopt
hexadecimal-literal integer-suffixopt
decimal-literal:
nonzero-digit
decimal-literal digit
octal-literal:
0
octal-literal octal-digit
hexadecimal-literal:
0x hexadecimal-digit
0X hexadecimal-digit
hexadecimal-literal hexadecimal-digit
nonzero-digit: one of
1 2 3 4 5 6 7 8 9
octal-digit: one of
0 1 2 3 4 5 6 7
hexadecimal-digit: one of
0 1 2 3 4 5 6 7 8 9
a b c d e f
A B C D E F

24) The term “literal” generally designates, in this International Standard, those tokens that are called “constants” in ISO C.
integer-suffix:
  unsigned-suffix long-suffix opt
  unsigned-suffix long-long-suffix opt
  long-suffix unsigned-suffix opt
  long-long-suffix unsigned-suffix opt

unsigned-suffix: one of
  u U
long-suffix: one of
  l L
long-long-suffix: one of
  ll LL

1 An integer literal is a sequence of digits that has no period or exponent part. An integer literal may have a prefix that specifies its base and a suffix that specifies its type. The lexically first digit of the sequence of digits is the most significant. A decimal integer literal (base ten) begins with a digit other than 0 and consists of a sequence of decimal digits. An octal integer literal (base eight) begins with the digit 0 and consists of a sequence of octal digits. A hexadecimal integer literal (base sixteen) begins with 0x or 0X and consists of a sequence of hexadecimal digits, which include the decimal digits and the letters a through f and A through F with decimal values ten through fifteen. [Example: the number twelve can be written 12, 014, or 0xc. — end example]

2 The type of an integer constant is the first of the corresponding list in Table 5 in which its value can be represented.

Table 5: Types of Integer Constants

<table>
<thead>
<tr>
<th>Suffix</th>
<th>Decimal Constant</th>
<th>Octal or Hexadecimal Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>int</td>
<td>int</td>
</tr>
<tr>
<td></td>
<td>long int</td>
<td>unsigned int</td>
</tr>
<tr>
<td></td>
<td>long long int</td>
<td>long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unsigned long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>long long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unsigned long long int</td>
</tr>
<tr>
<td>u or U</td>
<td>unsigned int</td>
<td>unsigned int</td>
</tr>
<tr>
<td></td>
<td>unsigned long int</td>
<td>unsigned long int</td>
</tr>
<tr>
<td></td>
<td>unsigned long long int</td>
<td>unsigned long long int</td>
</tr>
<tr>
<td>l or L</td>
<td>long int</td>
<td>long int</td>
</tr>
<tr>
<td></td>
<td>long long int</td>
<td>long long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unsigned long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>long long int</td>
</tr>
<tr>
<td>Both u or U and l or L</td>
<td>unsigned long int</td>
<td>unsigned long int</td>
</tr>
<tr>
<td>ll or LL</td>
<td>long long int</td>
<td>long long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unsigned long int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unsigned long int</td>
</tr>
</tbody>
</table>

3 A program is ill-formed if one of its translation units contains an integer literal that cannot be represented by any of the

25) The digits 8 and 9 are not octal digits.
2.13 Literals

2.13.2 Character literals

character-literal:
  ' c-char-sequence '  \L ' c-char-sequence '  

c-char-sequence:
  c-char
  c-char-sequence c-char

c-char:
  any member of the source character set except
  the single-quote ', backslash \, or new-line character
  escape-sequence
  universal-character-name

escape-sequence:
  simple-escape-sequence
  octal-escape-sequence
  hexadecimal-escape-sequence

simple-escape-sequence: one of
  \a \b \f \n \r \t \v

octal-escape-sequence:
  \octal-digit
  \octal-digit octal-digit
  \octal-digit octal-digit octal-digit

hexadecimal-escape-sequence:
  \x hexadecimal-digit
  hexadecimal-escape-sequence hexadecimal-digit

1. A character literal is one or more characters enclosed in single quotes, as in 'x', optionally preceded by the letter L, as in L'x'. A character literal that does not begin with L is an ordinary character literal, also referred to as a narrow-character literal. An ordinary character literal that contains a single c-char has type char, with value equal to the numerical value of the encoding of the c-char in the execution character set. An ordinary character literal that contains more than one c-char is a multicharacter literal. A multicharacter literal has type int and implementation-defined value.

2. A character literal that begins with the letter L, such as L'x', is a wide-character literal. A wide-character literal has type wchar_t. The value of a wide-character literal containing a single c-char has value equal to the numerical value of the encoding of the c-char in the execution wide-character set. The value of a wide-character literal containing multiple c-chars is implementation-defined.

3. Certain nongraphic characters, the single quote ', the double quote \, the question mark ?, and the backslash \, can be represented according to Table 6. The double quote " and the question mark ?, can be represented as themselves or by the escape sequences \" and \? respectively, but the single quote ' and the backslash \ shall be represented by the escape sequences \' and \\ respectively. If the character following a backslash is not one of those specified, the
behavior is undefined. An escape sequence specifies a single character.

The escape \`ooo\ consists of the backslash followed by one, two, or three octal digits that are taken to specify the value of the desired character. The escape `\xhhh\ consists of the backslash followed by x followed by one or more hexadecimal digits that are taken to specify the value of the desired character. There is no limit to the number of digits in a hexadecimal sequence. A sequence of octal or hexadecimal digits is terminated by the first character that is not an octal digit or a hexadecimal digit, respectively. The value of a character literal is implementation-defined if it falls outside of the implementation-defined range defined for char (for ordinary literals) or wchar_t (for wide literals).

A universal-character-name is translated to the encoding, in the execution character set, of the character named. If there is no such encoding, the universal-character-name is translated to an implementation-defined encoding. [ Note: in translation phase 1, a universal-character-name is introduced whenever an actual extended character is encountered in the source text. Therefore, all extended characters are described in terms of universal-character-names. However, the actual compiler implementation may use its own native character set, so long as the same results are obtained. — end note ]

2.13.3 Floating literals

```
floating-literal:
  fractional-constant exponent-part_opt floating-suffix_opt
  digit-sequence exponent-part floating-suffix_opt

fractional-constant:
  digit-sequence_opt . digit-sequence
  digit-sequence

exponent-part:
  e sign_opt digit-sequence
  E sign_opt digit-sequence

sign: one of
  + –
```

26) They are intended for character sets where a character does not fit into a single byte.
2.13 Literals

**Lexical conventions**

---

A floating literal consists of an integer part, a decimal point, a fraction part, an e or E, an optionally signed integer exponent, and an optional type suffix. The integer and fraction parts both consist of a sequence of decimal (base ten) digits. Either the integer part or the fraction part (not both) can be omitted; either the decimal point or the letter e (or E) and the exponent (not both) can be omitted. The integer part, the optional decimal point and the optional fraction part form the significant part of the floating literal. The exponent, if present, indicates the power of 10 by which the significant part is to be scaled. If the scaled value is in the range of representable values for its type, the result is the scaled value if representable, else the larger or smaller representable value nearest the scaled value, chosen in an implementation-defined manner. The type of a floating literal is double unless explicitly specified by a suffix. The suffixes f and F specify float, the suffixes l and L specify long double. If the scaled value is not in the range of representable values for its type, the program is ill-formed.

### 2.13.4 String literals

---

A string literal is a sequence of characters (as defined in 2.13.2) surrounded by double quotes, optionally beginning with the letter L, as in "..." or L"...". A string literal that does not begin with L is an ordinary string literal, also referred to as a narrow string literal. An ordinary string literal has type "array of n const char" and static storage duration (3.7), where \( n \) is the size of the string as defined below, and is initialized with the given characters. A string literal that begins with L, such as L"asdf", is a wide string literal. A wide string literal has type "array of n const wchar_t" and has static storage duration, where \( n \) is the size of the string as defined below, and is initialized with the given characters.

**Example:**

```
"\xA" "B"
```

contains the two characters ’\xA’ and ’B’ after concatenation (and not the single hexadecimal character ’\xAB’).

---

Whether all string literals are distinct (that is, are stored in nonoverlapping objects) is implementation-defined. The effect of attempting to modify a string literal is undefined.

---

In translation phase 6 (2.1), adjacent string literals are concatenated. If a narrow string literal token is adjacent to a wide string literal token, the result is a wide string literal. Characters in concatenated strings are kept distinct. [Example:

```
"\xA" "B"
```

contains the two characters ’\xA’ and ’B’ after concatenation (and not the single hexadecimal character ’\xAB’).]

---

After any necessary concatenation, in translation phase 7 (2.1), ’\0’ is appended to every string literal so that programs that scan a string can find its end.
Escape sequences and universal-character-names in string literals have the same meaning as in character literals (2.13.2), except that the single quote ' is representable either by itself or by the escape sequence \', and the double quote " shall be preceded by a \. In a narrow string literal, a universal-character-name may map to more than one char element due to multibyte encoding. The size of a wide string literal is the total number of escape sequences, universal-character-names, and other characters, plus one for the terminating L'\0'. The size of a narrow string literal is the total number of escape sequences and other characters, plus at least one for the multibyte encoding of each universal-character-name, plus one for the terminating '\0'.

2.13.5 Boolean literals

boolean-literal:

    false
    true

The Boolean literals are the keywords false and true. Such literals have type bool. They are not lvalues.
Draft
Chapter 3  Basic concepts

[Note: this clause presents the basic concepts of the C++ language. It explains the difference between an object and a name and how they relate to the notion of an lvalue. It introduces the concepts of a declaration and a definition and presents C++’s notion of type, scope, linkage, and storage duration. The mechanisms for starting and terminating a program are discussed. Finally, this clause presents the fundamental types of the language and lists the ways of constructing compound types from these.]

This clause does not cover concepts that affect only a single part of the language. Such concepts are discussed in the relevant clauses. — end note ]

An entity is a value, object, subobject, base class subobject, array element, variable, function, instance of a function, enumerator, type, class member, template, or namespace.

A name is a use of an identifier (2.10) that denotes an entity or label (6.6.4, 6.1). A variable is introduced by the declaration of an object. The variable’s name denotes the object.

Every name that denotes an entity is introduced by a declaration. Every name that denotes a label is introduced either by a goto statement (6.6.4) or a labeled-statement (6.1).

Some names denote types, classes, enumerations, or templates. In general, it is necessary to determine whether or not a name denotes one of these entities before parsing the program that contains it. The process that determines this is called name lookup (3.4).

Two names are the same if

— they are identifiers composed of the same character sequence; or
— they are the names of overloaded operator functions formed with the same operator; or
— they are the names of user-defined conversion functions formed with the same type.

An identifier used in more than one translation unit can potentially refer to the same entity in these translation units depending on the linkage (3.5) of the identifier specified in each translation unit.

3.1 Declarations and definitions

A declaration (clause 7) introduces names into a translation unit or redeclares names introduced by previous declarations. A declaration specifies the interpretation and attributes of these names.

A declaration is a definition unless it declares a function without specifying the function’s body (8.4), it contains the
extern specifier (7.1.1) or a linkage-specification \(^{27}\) (7.5) and neither an initializer nor a function-body, it declares a static data member in a class definition (9.4), it is a class name declaration (9.1), or it is a typedef declaration (7.1.3), a using-declaration (7.3.3), or a using-directive(7.3.4).

[ Example: all but one of the following are definitions:

```c
int a;                           // defines a
extern const int c = 1;          // defines c
int f(int x) { return x+a; }    // defines f and defines x
struct S { int a; int b; };      // defines S, S::a, and S::b
struct X {
  int x;                         // defines non-static data member x
  static int y;                  // declares static data member y
  X(): x(0) { }          // defines a constructor of X
};
int X::y = 1;                    // defines X::y
enum { up, down };              // defines up and down
namespace N { int d; }           // defines N and N::d
namespace N1 = N;               // defines N1
X anX;                           // defines anX
```

whereas these are just declarations:

```c
extern int a;                    // declares a
extern const int c;             // declares c
int f(int);                     // declares f
struct S;                       // declares S
typedef int Int;                // declares Int
extern X anotherX;              // declares anotherX
using N::d;                      // declares N::d
```

— end example ]

[ Note: in some circumstances, C++ implementations implicitly define the default constructor (12.1), copy constructor (12.8), assignment operator (12.8), or destructor (12.4) member functions. [ Example: given

```c
#include <string>

struct C {
  std::string s;                     // std::string is the standard library class (clause 21)
};

int main()
{
  C a;
  C b = a;
  b = a;
}
```

the implementation will implicitly define functions to make the definition of C equivalent to

\(^{27}\) Appearing inside the braced-enclosed declaration-seq in a linkage-specification does not affect whether a declaration is a definition.
struct C {
    std::string s;
    C(): s() { }
    C(const C& x): s(x.s) { }
    C& operator=(const C& x) { s = x.s; return *this; }
    ~C() { }
};

— end example ] — end note ]

4 [ Note: a class name can also be implicitly declared by an elaborated-type-specifier (3.3.1). — end note ]

5 A program is ill-formed if the definition of any object gives the object an incomplete type (3.9).

3.2 One definition rule [basic.def.odr]

1 No translation unit shall contain more than one definition of any variable, function, class type, enumeration type or template.

2 An expression is potentially evaluated unless it appears where an integral constant expression is required (see 5.19), is the operand of the sizeof operator (5.3.3), or is the operand of the typeid operator and the expression does not designate an lvalue of polymorphic class type (5.2.8). An object or non-overloaded function is used if its name appears in a potentially-evaluated expression. A virtual member function is used if it is not pure. An overloaded function is used if it is selected by overload resolution when referred to from a potentially-evaluated expression. [ Note: this covers calls to named functions (5.2.2), operator overloading (clause 13), user-defined conversions (12.3.2), allocation function for placement new (5.3.4), as well as non-default initialization (8.5). A copy constructor is used even if the call is actually elided by the implementation. — end note ] An allocation or deallocation function for a class is used by a new expression appearing in a potentially-evaluated expression as specified in 5.3.4 and 12.5. A deallocation function for a class is used by a delete expression appearing in a potentially-evaluated expression as specified in 5.3.5 and 12.5. A non-placement allocation or deallocation function for a class is used by the definition of a constructor of that class. A non-placement deallocation function for a class is used by the definition of the destructor of that class, or by being selected by the lookup at the point of definition of a virtual destructor (12.4).28 A copy-assignment function for a class is used by an implicitly-defined copy-assignment function for another class as specified in 12.8. A default constructor for a class is used by default initialization or value initialization as specified in 8.5. A constructor for a class is used as specified in 8.5. A destructor for a class is used as specified in 12.4.

3 Every program shall contain exactly one definition of every non-inline function or object that is used in that program; no diagnostic required. The definition can appear explicitly in the program, it can be found in the standard or a user-defined library, or (when appropriate) it is implicitly defined (see 12.1, 12.4 and 12.8). An inline function shall be defined in every translation unit in which it is used.

4 Exactly one definition of a class is required in a translation unit if the class is used in a way that requires the class type to be complete. [ Example: the following complete translation unit is well-formed, even though it never defines X :

```cpp
struct X;
struct X* x1;   // declare X as a struct type
X* x2;          // use X in pointer formation
```

28) An implementation is not required to call allocation and deallocation functions from constructors or destructors; however, this is a permissible implementation technique.
— *end example* ]  [ *Note:* the rules for declarations and expressions describe in which contexts complete class types are required. A class type $T$ must be complete if:

— an object of type $T$ is defined (3.1), or

— a non-static class data member of type $T$ is declared (9.2), or

— $T$ is used as the object type or array element type in a *new-expression* (5.3.4), or

— an lvalue-to-rvalue conversion is applied to an lvalue referring to an object of type $T$ (4.1), or

— an expression is converted (either implicitly or explicitly) to type $T$ (clause 4, 5.2.3, 5.2.7, 5.2.9, 5.4), or

— an expression that is not a null pointer constant, and has type other than `void *`, is converted to the type pointer to $T$ or reference to $T$ using an implicit conversion (clause 4), a `dynamic_cast` (5.2.7) or a `static_cast` (5.2.9), or

— a class member access operator is applied to an expression of type $T$ (5.2.5), or

— the `typeid` operator (5.2.8) or the `sizeof` operator (5.3.3) is applied to an operand of type $T$, or

— a function with a return type or argument type of type $T$ is defined (3.1) or called (5.2.2), or

— a class with a base class of type $T$ is defined (10), or

— an lvalue of type $T$ is assigned to (5.17). — *end note* ]

There can be more than one definition of a class type (clause 9), enumeration type (7.2), inline function with external linkage (7.1.2), class template (clause 14), non-static function template (14.5.5), static data member of a class template (14.5.1.3), member function of a class template (14.5.1.1), or template specialization for which some template parameters are not specified (14.7, 14.5.4) in a program provided that each definition appears in a different translation unit, and provided the definitions satisfy the following requirements. Given such an entity named $D$ defined in more than one translation unit, then

— each definition of $D$ shall consist of the same sequence of tokens; and

— in each definition of $D$, corresponding names, looked up according to 3.4, shall refer to an entity defined within the definition of $D$, or shall refer to the same entity, after overload resolution (13.3) and after matching of partial template specialization (14.8.3), except that a name can refer to a `const` object with internal or no linkage if the object has the same integral or enumeration type in all definitions of $D$, and the object is initialized with a constant expression (5.19), and the value (but not the address) of the object is used, and the object has the same value in all definitions of $D$; and

— in each definition of $D$, the overloaded operators referred to, the implicit calls to conversion functions, constructors, operator new functions and operator delete functions, shall refer to the same function, or to a function defined within the definition of $D$; and

— in each definition of $D$, a default argument used by an (implicit or explicit) function call is treated as if its token sequence were present in the definition of $D$; that is, the default argument is subject to the three requirements described above (and, if the default argument has sub-expressions with default arguments, this requirement applies recursively).29

29) 8.3.6 describes how default argument names are looked up.
— if D is a class with an implicitly-declared constructor (12.1), it is as if the constructor was implicitly defined in every translation unit where it is used, and the implicit definition in every translation unit shall call the same constructor for a base class or a class member of D. [Example:

```c
// translation unit 1:
struct X {
    X(int);
    X(int, int);
};
X::X(int = 0) { }
class D: public X { }; //X(int) called by D()
D d2;

// translation unit 2:
struct X {
    X(int);
    X(int, int);
};
X::X(int = 0, int = 0) { } //X(int, int) called by D(): //D()'s implicit definition //violates the ODR
class D: public X { }; //X(int called by D())
```

— end example] If D is a template, and is defined in more than one translation unit, then the last four requirements from the list above shall apply to names from the template’s enclosing scope used in the template definition (14.6.3), and also to dependent names at the point of instantiation (14.6.2). If the definitions of D satisfy all these requirements, then the program shall behave as if there were a single definition of D. If the definitions of D do not satisfy these requirements, then the behavior is undefined.

### 3.3 Declarative regions and scopes

[basic.scope]

1 Every name is introduced in some portion of program text called a declarative region, which is the largest part of the program in which that name is valid, that is, in which that name may be used as an unqualified name to refer to the same entity. In general, each particular name is valid only within some possibly contiguous portion of program text called its scope. To determine the scope of a declaration, it is sometimes convenient to refer to the potential scope of a declaration. The scope of a declaration is the same as its potential scope unless the potential scope contains another declaration of the same name. In that case, the potential scope of the declaration in the inner (contained) declarative region is excluded from the scope of the declaration in the outer (containing) declarative region.

2 [Example: in

```c
int j = 24;
int main()
{
    int i = j, j;
    j = 42;
}
```

the identifier j is declared twice as a name (and used twice). The declarative region of the first j includes the entire example. The potential scope of the first j begins immediately after that j and extends to the end of the program, but
3.3 Declarative regions and scopes

The names declared by a declaration are introduced into the scope in which the declaration occurs, except that the presence of a friend specifier (11.4), certain uses of the elaborated-type-specifier (3.3.1), and using-directives (7.3.4) alter this general behavior.

Given a set of declarations in a single declarative region, each of which specifies the same unqualified name,

- they shall all refer to the same entity, or all refer to functions and function templates; or
- exactly one declaration shall declare a class name or enumeration name that is not a typedef name and the other declarations shall all refer to the same object or enumerator, or all refer to functions and function templates; in this case the class name or enumeration name is hidden (3.3.7). [Note: a namespace name or a class template name must be unique in its declarative region (7.3.2, clause 14). —end note]

[Note: these restrictions apply to the declarative region into which a name is introduced, which is not necessarily the same as the region in which the declaration occurs. In particular, elaborated-type-specifiers (3.3.1) and friend declarations (11.4) may introduce a (possibly not visible) name into an enclosing namespace; these restrictions apply to that region. Local extern declarations (3.5) may introduce a name into the declarative region where the declaration appears and also introduce a (possibly not visible) name into an enclosing namespace; these restrictions apply to both regions. —end note]

3.3.1 Point of declaration

1 The point of declaration for a name is immediately after its complete declarator (clause 8) and before its initializer (if any), except as noted below. [Example:

```c
int x = 12;
{ int x = x; }
```

Here the second `x` is initialized with its own (indeterminate) value. —end example]

2 A nonlocal name remains visible up to the point of declaration of the local name that hides it. [Example:

```c
const int i = 2;
{ int [i]; }
```

declares a local array of two integers. —end example] —end note]

3 The point of declaration for a class first declared by a class-specifier is immediately after the identifier or template-id (if any) in its class-head (Clause 9). The point of declaration for an enumeration is immediately after the identifier (if any) in its enum-specifier (7.2).

4 The point of declaration for an enumerator is immediately after its enumerator-definition. [Example:

```c
const int x = 12;
{ enum { x = x }; }
```
3.3 Declarative regions and scopes

Here, the enumerator \( x \) is initialized with the value of the constant \( x \), namely 12. — end example

After the point of declaration of a class member, the member name can be looked up in the scope of its class. [Note: this is true even if the class is an incomplete class. For example,

```cpp
struct X {
    enum E { z = 16 };
    int b[X::z];  // OK
};
— end note]

The point of declaration of a class first declared in an elaborated-type-specifier is as follows:

— for a declaration of the form `class-key identifier ;`
  the `identifier` is declared to be a class-name in the scope that contains the declaration, otherwise

— for an elaborated-type-specifier of the form `class-key identifier`
  if the elaborated-type-specifier is used in the decl-specifier-seq or parameter-declaration-clause of a function defined in namespace scope, the `identifier` is declared as a class-name in the namespace that contains the declaration; otherwise, except as a friend declaration, the `identifier` is declared in the smallest non-class, non-function-prototype scope that contains the declaration. [Note: These rules also apply within templates. — end note]
  [Note: Other forms of elaborated-type-specifier do not declare a new name, and therefore must refer to an existing type-name. See 3.4.4 and 7.1.5.3. — end note]

The point of declaration for an injected-class-name (9) is immediately following the opening brace of the class definition.

[Note: friend declarations refer to functions or classes that are members of the nearest enclosing namespace, but they do not introduce new names into that namespace (7.3.1.2). Function declarations at block scope and object declarations with the extern specifier at block scope refer to declarations that are members of an enclosing namespace, but they do not introduce new names into that scope. — end note]

[Note: For point of instantiation of a template, see 14.6.4.1. — end note]

3.3.2 Local scope

A name declared in a block (6.3) is local to that block. Its potential scope begins at its point of declaration (3.3.1) and ends at the end of its declarative region.

The potential scope of a function parameter name in a function definition (8.4) begins at its point of declaration. If the function has a function-try-block the potential scope of a parameter ends at the end of the last associated handler, else it ends at the end of the outermost block of the function definition. A parameter name shall not be redeclared in the outermost block of the function definition nor in the outermost block of any handler associated with a function-try-block.

The name in a catch exception-declaration is local to the handler and shall not be redeclared in the outermost block of the handler.

Names declared in the for-init-statement, and in the condition of if, while, for, and switch statements are local to the if, while, for, or switch statement (including the controlled statement), and shall not be redeclared in a subsequent
3.3 Declarative regions and scopes

condition of that statement nor in the outermost block (or, for the if statement, any of the outermost blocks) of the controlled statement; see 6.4.

3.3.3 Function prototype scope

In a function declaration, or in any function declarator except the declarator of a function definition (8.4), names of parameters (if supplied) have function prototype scope, which terminates at the end of the nearest enclosing function declarator.

3.3.4 Function scope

Labels (6.1) have function scope and may be used anywhere in the function in which they are declared. Only labels have function scope.

3.3.5 Namespace scope

The declarative region of a namespace-definition is its namespace-body. The potential scope denoted by an original-namespace-name is the concatenation of the declarative regions established by each of the namespace-definitions in the same declarative region with that original-namespace-name. Entities declared in a namespace-body are said to be members of the namespace, and names introduced by these declarations into the declarative region of the namespace are said to be member names of the namespace. A namespace member name has namespace scope. Its potential scope includes its namespace from the name’s point of declaration (3.3.1) onwards; and for each using-directive (7.3.4) that nominates the member’s namespace, the member’s potential scope includes that portion of the potential scope of the using-directive that follows the member’s point of declaration. [Example:

```c
namespace N {
  int i;
  int g(int a) { return a; }
  int j();
  void q();
}
namespace { int l=1; }
// the potential scope of l is from its point of declaration
// to the end of the translation unit
namespace N {
  int g(char a) // overloads N::g(int)
  {
    return l+a; // l is from unnamed namespace
  }
  int i; // error: duplicate definition
  int j(); // OK: duplicate function declaration
  int j() // OK: definition of N::j()
  {
    return g(i); // calls N::g(int)
  }
  int q(); // error: different return type
}
```

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A namespace member can also be referred to after the `::` scope resolution operator (5.1) applied to the name of its namespace or the name of a namespace which nominates the member’s namespace in a using-directive; see 3.4.3.2.

The outermost declarative region of a translation unit is also a namespace, called the global namespace. A name declared in the global namespace has global namespace scope (also called global scope). The potential scope of such a name begins at its point of declaration (3.3.1) and ends at the end of the translation unit that is its declarative region. Names with global namespace scope are said to be global.

### 3.3.6 Class scope

1) The potential scope of a name declared in a class consists not only of the declarative region following the name’s point of declaration, but also of all function bodies, default arguments, and constructor ctor-initializers in that class (including such things in nested classes).

2) A name \( N \) used in a class \( S \) shall refer to the same declaration in its context and when re-evaluated in the completed scope of \( S \). No diagnostic is required for a violation of this rule.

3) If reordering member declarations in a class yields an alternate valid program under (1) and (2), the program is ill-formed, no diagnostic is required.

4) A name declared within a member function hides a declaration of the same name whose scope extends to or past the end of the member function’s class.

5) The potential scope of a declaration that extends to or past the end of a class definition also extends to the regions defined by its member definitions, even if the members are defined lexically outside the class (this includes static data member definitions, nested class definitions, member function definitions (including the member function body and, for constructor functions (12.1), the ctor-initializer (12.6.2)) and any portion of the declarator part of such definitions which follows the identifier, including a parameter-declaration-clause and any default arguments (8.3.6). [Example:

```c
typedef int c;
enum { i = 1 };

class X {
    char v[i]; // error: i refers to ::i
    // but when reevaluated is X::i
    int f() { return sizeof(c); } // OK: X::c
    char c;
    enum { i = 2 };}
};

typedef char* T;
struct Y {
    T a; // error: T refers to ::T
    // but when reevaluated is Y::T
    typedef long T;
    T b;
};
```

Draft
3.4 Name lookup

```cpp
typedef int I;
class D {
    typedef I I; // error, even though no reordering involved
};
```

— end example ]

2 The name of a class member shall only be used as follows:

— in the scope of its class (as described above) or a class derived (clause 10) from its class,
— after the . operator applied to an expression of the type of its class (5.2.5) or a class derived from its class,
— after the -> operator applied to a pointer to an object of its class (5.2.5) or a class derived from its class,
— after the :: scope resolution operator (5.1) applied to the name of its class or a class derived from its class.

3.3.7 Name hiding [basic.scope.hiding]

1 A name can be hidden by an explicit declaration of that same name in a nested declarative region or derived class (10.2).

2 A class name (9.1) or enumeration name (7.2) can be hidden by the name of an object, function, or enumerator declared in the same scope. If a class or enumeration name and an object, function, or enumerator are declared in the same scope (in any order) with the same name, the class or enumeration name is hidden wherever the object, function, or enumerator name is visible.

3 In a member function definition, the declaration of a local name hides the declaration of a member of the class with the same name; see 3.3.6. The declaration of a member in a derived class (clause 10) hides the declaration of a member of a base class of the same name; see 10.2.

4 During the lookup of a name qualified by a namespace name, declarations that would otherwise be made visible by a using-directive can be hidden by declarations with the same name in the namespace containing the using-directive; see (3.4.3.2).

5 If a name is in scope and is not hidden it is said to be visible.

3.4 Name lookup [basic.lookup]

1 The name lookup rules apply uniformly to all names (including typedef-names (7.1.3), namespace-names (7.3) and class-names (9.1)) wherever the grammar allows such names in the context discussed by a particular rule. Name lookup associates the use of a name with a declaration (3.1) of that name. Name lookup shall find an unambiguous declaration for the name (see 10.2). Name lookup may associate more than one declaration with a name if it finds the name to be a function name; the declarations are said to form a set of overloaded functions (13.1). Overload resolution (13.3) takes place after name lookup has succeeded. The access rules (clause 11) are considered only once name lookup and function overload resolution (if applicable) have succeeded. Only after name lookup, function overload resolution (if applicable) and access checking have succeeded are the attributes introduced by the name’s declaration used further in expression processing (clause 5).

2 A name “looked up in the context of an expression” is looked up as an unqualified name in the scope where the expression is found.
3.4 Name lookup

The injected-class-name of a class (clause 9) is also considered to be a member of that class for the purposes of name hiding and lookup.

[Note: 3.5 discusses linkage issues. The notions of scope, point of declaration and name hiding are discussed in 3.3. — end note]

3.4.1 Unqualified name lookup

In all the cases listed in 3.4.1, the scopes are searched for a declaration in the order listed in each of the respective categories; name lookup ends as soon as a declaration is found for the name. If no declaration is found, the program is ill-formed.

The declarations from the namespace nominated by a using-directive become visible in a namespace enclosing the using-directive; see 7.3.4. For the purpose of the unqualified name lookup rules described in 3.4.1, the declarations from the namespace nominated by the using-directive are considered members of that enclosing namespace.

The lookup for an unqualified name used as the postfix-expression of a function call is described in 3.4.2. [Note: for purposes of determining (during parsing) whether an expression is a postfix-expression for a function call, the usual name lookup rules apply. The rules in 3.4.2 have no effect on the syntactic interpretation of an expression. For example,

typedef int f;
namespace N {
    struct A {
        friend void f(A &);
        operator int();
        void g(A a) {
            int i = f(a);
            // i is the typedef, not the friend
            // function: equivalent to int(a)
        }
    };
};

Because the expression is not a function call, the argument-dependent name lookup (3.4.2) does not apply and the friend function f is not found. — end note]

4 A name used in global scope, outside of any function, class or user-declared namespace, shall be declared before its use in global scope.

5 A name used in a user-declared namespace outside of the definition of any function or class shall be declared before its use in that namespace or before its use in a namespace enclosing its namespace.

6 A name used in the definition of a function following the function’s declarator-id30) that is a member of namespace N (where, only for the purpose of exposition, N could represent the global scope) shall be declared before its use in the block in which it is used or in one of its enclosing blocks (6.3) or, shall be declared before its use in namespace N or, if N is a nested namespace, shall be declared before its use in one of N’s enclosing namespaces.

[Example:

30) This refers to unqualified names that occur, for instance, in a type or default argument expression in the parameter-declaration-clause or used in the function body.]
3.4 Name lookup

namespace A {
    namespace N {
        void f();
    }
}

void A::N::f() {
    i = 5;
    // The following scopes are searched for a declaration of i:
    // 1) outermost block scope of A::N::f, before the use of i
    // 2) scope of namespace N
    // 3) scope of namespace A
    // 4) global scope, before the definition of A::N::f
}

— end example ]

7 A name used in the definition of a class X outside of a member function body or nested class definition\(^ {31}\) shall be declared in one of the following ways:

— before its use in class X or be a member of a base class of X (10.2), or

— if X is a nested class of class Y (9.7), before the definition of X in Y, or shall be a member of a base class of Y (this lookup applies in turn to Y’s enclosing classes, starting with the innermost enclosing class),\(^ {32}\)

— if X is a local class (9.8) or is a nested class of a local class, before the definition of class X in a block enclosing the definition of class X, or

— if X is a member of namespace N, or is a nested class of a class that is a member of N, or is a local class or a nested class within a local class of a function that is a member of N, before the definition of class X in namespace N or in one of N’s enclosing namespaces.

[ Example:

namespace M {
    class B { };
}

namespace N {
    class Y : public M::B {
        class X {
            int a[i];
        };
    };
}

// The following scopes are searched for a declaration of i:
// 1) scope of class N::Y::X, before the use of i
// 2) scope of class N::Y, before the definition of N::Y::X

\(^ {31}\) This refers to unqualified names following the class name; such a name may be used in the base-clause or may be used in the class definition.

\(^ {32}\) This lookup applies whether the definition of X is nested within Y’s definition or whether X’s definition appears in a namespace scope enclosing Y’s definition (9.7).
3.4 Name lookup

// 3) scope of N::Y’s base class M::B
// 4) scope of namespace N, before the definition of N::Y
// 5) global scope, before the definition of N

— end example ] [ Note: when looking for a prior declaration of a class or function introduced by a friend declaration, scopes outside of the innermost enclosing namespace scope are not considered; see 7.3.1.2. — end note ] [ Note: 3.3.6 further describes the restrictions on the use of names in a class definition. 9.7 further describes the restrictions on the use of names in nested class definitions. 9.8 further describes the restrictions on the use of names in local class definitions. — end note ]

8 A name used in the definition of a member function (9.3) of class X following the function’s declarator-id 33) shall be declared in one of the following ways:

— before its use in the block in which it is used or in an enclosing block (6.3), or
— shall be a member of class X or be a member of a base class of X (10.2), or
— if X is a nested class of class Y (9.7), shall be a member of Y, or shall be a member of a base class of Y (this lookup applies in turn to Y ’s enclosing classes, starting with the innermost enclosing class),34) or
— if X is a local class (9.8) or is a nested class of a local class, before the definition of class X in a block enclosing the definition of class X, or
— if X is a member of namespace N, or is a nested class of a class that is a member of N, or is a local class or a nested class within a local class of a function that is a member of N, before the member function definition, in namespace N or in one of N ’s enclosing namespaces.

[ Example:

class B { }
namespace M {
    namespace N {
        class X : public B {
            void f();
        };
    }
}
void M::N::X::f() {
    i = 16;
}

// The following scopes are searched for a declaration of i:
// 1) outermost block scope of M::N::X::f, before the use of i
// 2) scope of class M::N::X
// 3) scope of M::N::X’s base class B
// 4) scope of namespace M::N
// 5) scope of namespace M
// 6) global scope, before the definition of M::N::X::f

33) That is, an unqualified name that occurs, for instance, in a type or default argument expression in the parameter-declaration-clause, in the function body, or in an expression of a mem-initializer in a constructor definition.

34) This lookup applies whether the member function is defined within the definition of class X or whether the member function is defined in a namespace scope enclosing X ’s definition.
3.4 Name lookup

— end example ]  [ Note: 9.3 and 9.4 further describe the restrictions on the use of names in member function definitions. 9.7 further describes the restrictions on the use of names in the scope of nested classes. 9.8 further describes the restrictions on the use of names in local class definitions. — end note ]

Name lookup for a name used in the definition of a friend function (11.4) defined inline in the class granting friendship shall proceed as described for lookup in member function definitions. If the friend function is not defined in the class granting friendship, name lookup in the friend function definition shall proceed as described for lookup in namespace member function definitions.

In a friend declaration naming a member function, a name used in the function declarator and not part of a template-argument in a template-id is first looked up in the scope of the member function’s class. If it is not found, or if the name is part of a template-argument in a template-id, the look up is as described for unqualified names in the definition of the class granting friendship. [ Example:

```
struct A {
    typedef int AT;
    void f1(AT);
    void f2(float);
};
struct B {
    typedef float BT;
    friend void A::f1(AT);  // parameter type is A::AT
    friend void A::f2(BT);  // parameter type is B::BT
};
```

— end example ]

During the lookup for a name used as a default argument (8.3.6) in a function parameter-declaration-clause or used in the expression of a mem-initializer for a constructor (12.6.2), the function parameter names are visible and hide the names of entities declared in the block, class or namespace scopes containing the function declaration. [ Note: 8.3.6 further describes the restrictions on the use of names in default arguments. 12.6.2 further describes the restrictions on the use of names in a ctor-initializer. — end note ]

A name used in the definition of a static data member of class X (9.4.2) (after the qualified-id of the static member) is looked up as if the name was used in a member function of X. [ Note: 9.4.2 further describes the restrictions on the use of names in the definition of a static data member. — end note ]

A name used in the handler for a function-try-block (clause 15) is looked up as if the name was used in the outermost block of the function definition. In particular, the function parameter names shall not be redeclared in the exception-declaration nor in the outermost block of a handler for the function-try-block. Names declared in the outermost block of the function definition are not found when looked up in the scope of a handler for the function-try-block. [ Note: but function parameter names are found. — end note ]

[ Note: the rules for name lookup in template definitions are described in 14.6. — end note ]

3.4.2 Argument-dependent name lookup  [basic.lookup.argdep]

When an unqualified name is used as the postfix-expression in a function call (5.2.2), other namespaces not considered during the usual unqualified lookup (3.4.1) may be searched, and in those namespaces, namespace-scope friend function
declarations (11.4) not otherwise visible may be found. These modifications to the search depend on the types of the arguments (and for template template arguments, the namespace of the template argument).

For each argument type \( T \) in the function call, there is a set of zero or more associated namespaces and a set of zero or more associated classes to be considered. The sets of namespaces and classes is determined entirely by the types of the function arguments (and the namespace of any template template argument). Typedef names and using-declarations used to specify the types do not contribute to this set. The sets of namespaces and classes are determined in the following way:

- If \( T \) is a fundamental type, its associated sets of namespaces and classes are both empty.
- If \( T \) is a class type (including unions), its associated classes are: the class itself; the class of which it is a member, if any; and its direct and indirect base classes. Its associated namespaces are the namespaces in which its associated classes are defined.
- If \( T \) is an enumeration type, its associated namespace is the namespace in which it is defined. If it is class member, its associated class is the member’s class; else it has no associated class.
- If \( T \) is a pointer to \( U \) or an array of \( U \), its associated namespaces and classes are those associated with \( U \).
- If \( T \) is a function type, its associated namespaces and classes are those associated with the function parameter types and those associated with the return type.
- If \( T \) is a pointer to a member function of a class \( X \), its associated namespaces and classes are those associated with the function parameter types and return type, together with those associated with \( X \).
- If \( T \) is a pointer to a data member of class \( X \), its associated namespaces and classes are those associated with the member type together with those associated with \( X \).
- If \( T \) is a class template specialization its associated namespaces and classes are the namespace in which the template is defined; for member templates, the member template’s class; the namespaces and classes associated with the types of the template arguments provided for template type parameters (excluding template template parameters); the namespaces in which any template template arguments are defined; and the classes in which any member templates used as template template arguments are defined. [Note: non-type template arguments do not contribute to the set of associated namespaces. — end note ]

In addition, if the argument is the name or address of a set of overloaded functions and/or function templates, its associated classes and namespaces are the union of those associated with each of the members of the set: the namespace in which the function or function template is defined and the classes and namespaces associated with its (non-dependent) parameter types and return type.

If the ordinary unqualified lookup of the name finds the declaration of a class member function, or a block-scope function declaration that is not a using-declaration, the associated namespaces are not considered. Otherwise the set of declarations found by the lookup of the function name is the union of the set of declarations found using ordinary unqualified lookup and the set of declarations found in the namespaces associated with the argument types. [Note: the namespaces and classes associated with the argument types can include namespaces and classes already considered by the ordinary unqualified lookup. — end note ]

```
namespace NS {
    class T { };
    void f(T);
    void g(T, int);
}
```
3.4 Name lookup

When considering an associated namespace, the lookup is the same as the lookup performed when the associated namespace is used as a qualifier (3.4.3.2) except that:

— Any using-directive s in the associated namespace are ignored.
— Any namespace-scope friend functions declared in associated classes are visible within their respective namespaces even if they are not visible during an ordinary lookup (11.4).

3.4.3 Qualified name lookup

The name of a class or namespace member can be referred to after the :: scope resolution operator (5.1) applied to a nested-name-specifier that nominates its class or namespace. During the lookup for a name preceding the :: scope resolution operator, object, function, and enumerator names are ignored. If the name found is not a class-name (clause 9) or namespace-name (7.3.1), the program is ill-formed. [Example:

```cpp
class A {
  public:
    static int n;
  };
  int main()
  {
    int A;
    A::n = 42;           // OK
    A b;                 // ill-formed: k does not name a type
  }

  — end example]
```

[Note: Multiply qualified names, such as \texttt{N1::N2::N3::n}, can be used to refer to members of nested classes (9.7) or members of nested namespaces. — end note]

In a declaration in which the declarator-id is a qualified-id, names used before the qualified-id being declared are looked up in the defining namespace scope; names following the qualified-id are looked up in the scope of the member’s class or namespace. [Example:

```cpp
class X { }
class C {
  class X { }
  static const int number = 50;
  static X arr[number];

  — end example]
```

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A name prefixed by the unary scope operator `::` (5.1) is looked up in global scope, in the translation unit where it is used. The name shall be declared in global namespace scope or shall be a name whose declaration is visible in global scope because of a using-directive (3.4.3.2). The use of `::` allows a global name to be referred to even if its identifier has been hidden (3.3.7).

If a pseudo-destructor-name (5.2.4) contains a nested-name-specifier, the type-names are looked up as types in the scope designated by the nested-name-specifier. Similarly, in a qualified-id of the form:

```
::opt nested-name-specifier opt class-name :: ∼ class-name
```

the second `class-name` is looked up in the same scope as the first. [Example:

```c
struct C {
    typedef int I;
};
typedef int I1, I2;
extern int* p;
extern int* q;
p->C::I::~I(); // I is looked up in the scope of C
q->I1:~I2(); // I2 is looked up in the scope of // the postfix-expression
```

```c
struct A {
    ~A();
};
typedef A AB;
int main()
{
    AB *p;
p->AB::~AB(); // explicitly calls the destructor for A
}
```

— end example ] [Note: 3.4.5 describes how name lookup proceeds after the . and -> operators. — end note ]

### 3.4.3.1 Class members

[3.4.3.1] If the nested-name-specifier of a qualified-id nominates a class, the name specified after the nested-name-specifier is looked up in the scope of the class (10.2), except for the cases listed below. The name shall represent one or more members of that class or of one of its base classes (clause 10). [Note: a class member can be referred to using a qualified-id at any point in its potential scope (3.3.6). — end note ] The exceptions to the name lookup rule above are the following:

- a destructor name is looked up as specified in 3.4.3;
— a conversion-type-id of an operator-function-id is looked up both in the scope of the class and in the context in which the entire postfix-expression occurs and shall refer to the same type in both contexts;

— the template-arguments of a template-id are looked up in the context in which the entire postfix-expression occurs.

— the lookup for a name specified in a using-declaration (7.3.3) also finds class or enumeration names hidden within the same scope (3.3.7).

In a lookup in which the constructor is an acceptable lookup result, if the nested-name-specifier nominates a class C, and the name specified after the nested-name-specifier, when looked up in C, is the injected-class-name of C (clause 9), the name is instead considered to name the constructor of class C. [Note: For example, the constructor is not an acceptable lookup result in an elaborated-type-specifier so the constructor would not be used in place of the injected-class-name. —end note] Such a constructor name shall be used only in the declarator-id of a declaration that names a constructor. [Example:

```c
struct A { A(); }; 
struct B: public A { B(); }; 
A::A(); // error, A::A is not a type name
A::A a;  // object of type A
A::A a2; // object of type A
```

—end example]

A class member name hidden by a name in a nested declarative region or by the name of a derived class member can still be found if qualified by the name of its class followed by the :: operator.

3.4.3.2 Namespace members [namespace.qual]

1 If the nested-name-specifier of a qualified-id nominates a namespace, the name specified after the nested-name-specifier is looked up in the scope of the namespace, except that the template-arguments of a template-id are looked up in the context in which the entire postfix-expression occurs.

2 Given X::m (where X is a user-declared namespace), or given ::m (where X is the global namespace), let S be the set of all declarations of m in X and in the transitive closure of all namespaces nominated by using-directives in X and its used namespaces, except that using-directives are ignored in any namespace, including X, directly containing one or more declarations of m. No namespace is searched more than once in the lookup of a name. If S is the empty set, the program is ill-formed. Otherwise, if S has exactly one member, or if the context of the reference is a using-declaration (7.3.3), S is the required set of declarations of m. Otherwise if the use of m is not one that allows a unique declaration to be chosen from S, the program is ill-formed. [Example:

```c
int x;
namespace Y {
    void f(float);
    void h(int);
}
```

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namespace Z {
    void h(double);
}

namespace A {
    using namespace Y;
    void f(int);
    void g(int);
    int i;
}

namespace B {
    using namespace Z;
    void f(char);
    int i;
}

namespace AB {
    using namespace A;
    using namespace B;
    void g();
}

void h()
{
    AB::g();  // g is declared directly in AB,
               // therefore S is { AB::g() } and AB::g() is chosen
    AB::f(1);  // f is not declared directly in AB so the rules are
               // applied recursively to A and B;
               // namespace Y is not searched and Y::f(float)  
               // is not considered;
               // S is { A::f(int), B::f(char) } and overload
               // resolution chooses A::f(int)
    AB::f('c');  // as above but resolution chooses B::f(char)
    AB::x++;     // x is not declared directly in AB, and
                 // is not declared in A or B, so the rules are
                 // applied recursively to A and B;
                 // S is { } so the program is ill-formed
    AB::i++;     // i is not declared directly in AB so the rules are
                 // applied recursively to A and B;
                 // S is { A::i, B::i } so the use is ambiguous
                 // and the program is ill-formed
    AB::h(16.8);  // h is not declared directly in AB and
                 // not declared directly in A or B so the rules are
                 // applied recursively to A and B;
                 // S is { Y::h(int), Z::h(double) } and overload
                 // resolution chooses Z::h(double)}
3 The same declaration found more than once is not an ambiguity (because it is still a unique declaration). For example:

```cpp
namespace A {
    int a;
}

namespace B {
    using namespace A;
}

namespace C {
    using namespace A;
}

namespace BC {
    using namespace B;
    using namespace C;
}

void f()
{
    BC::a++; // OK: S is { A::a, A::a }
}

namespace D {
    using A::a;
}

namespace BD {
    using namespace B;
    using namespace D;
}

void g()
{
    BD::a++; // OK: S is { A::a, A::a }
}
```

4 Because each referenced namespace is searched at most once, the following is well-defined:

```cpp
namespace B {
    int b;
}

namespace A {
    using namespace B;
    int a;
}

namespace B {
    using namespace A;
}
void f()
{
    A::a++;  // OK: a declared directly in A, S is {A::a}
    B::a++;  // OK: both A and B searched (once), S is {A::a}
    A::b++;  // OK: both A and B searched (once), S is {B::b}
    B::b++;  // OK: b declared directly in B, S is {B::b}
}

— end example ]

5 During the lookup of a qualified namespace member name, if the lookup finds more than one declaration of the member, and if one declaration introduces a class name or enumeration name and the other declarations either introduce the same object, the same enumerator or a set of functions, the non-type name hides the class or enumeration name if and only if the declarations are from the same namespace; otherwise (the declarations are from different namespaces), the program is ill-formed. [ Example:

```cpp
namespace A {
    struct x { }
    int x;
    int y;
}
namespace B {
    struct y { }
}
namespace C {
    using namespace A;
    using namespace B;
    int i = C::x;       // OK, A::x (of type int)
    int j = C::y;       // ambiguous, A::y or B::y
}
```

— end example ]

6 In a declaration for a namespace member in which the declarator-id is a qualified-id, given that the qualified-id for the namespace member has the form nested-name-specifier unqualified-id the unqualified-id shall name a member of the namespace designated by the nested-name-specifier. [ Example:

```cpp
namespace A {
    namespace B {
    }
    using namespace B;
}
void A::f1(int);  // ill-formed, f1 is not a member of A
```

— end example ] However, in such namespace member declarations, the nested-name-specifier may rely on using-directives to implicitly provide the initial part of the nested-name-specifier. [ Example:
namespace A {
    namespace B {
        void f1(int);
    }
}

namespace C {
    namespace D {
        void f1(int);
    }
}

using namespace A;
using namespace C::D;
void B::f1(int) {}  // OK, defines A::B::f1(int)

— end example ]

3.4.4 Elaborated type specifiers [basic.lookup.elab]

1 An elaborated-type-specifier (7.1.5.3) may be used to refer to a previously declared class-name or enum-name even though the name has been hidden by a non-type declaration (3.3.7).

2 If the elaborated-type-specifier has no nested-name-specifier, and unless the elaborated-type-specifier appears in a declaration with the following form:

   class-key identifier;

the identifier is looked up according to 3.4.1 but ignoring any non-type names that have been declared. If the elaborated-type-specifier is introduced by the enum keyword and this lookup does not find a previously declared type-name, the elaborated-type-specifier is ill-formed. If the elaborated-type-specifier is introduced by the class-key and this lookup does not find a previously declared type-name, or if the elaborated-type-specifier appears in a declaration with the form:

   class-key identifier;

the elaborated-type-specifier is a declaration that introduces the class-name as described in 3.3.1.

3 If the elaborated-type-specifier has a nested-name-specifier, qualified name lookup is performed, as described in 3.4.3, but ignoring any non-type names that have been declared. If the name lookup does not find a previously declared type-name, the elaborated-type-specifier is ill-formed. [ Example:

```c
struct Node {
    struct Node* Next;  // OK: Refers to Node at global scope
    struct Data* Data;  // OK: Declares type Data
        // at global scope and member Data
};

struct Data {
    struct Node* Node;    // OK: Refers to Node at global scope
    friend struct ::Glob; // error: Glob is not declared
        // cannot introduce a qualified type (7.1.5.3)
    friend struct Glob;   // OK: Refers to (as yet) undeclared Glob
};
```

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3.4.5 Class member access

In a class member access expression (5.2.5), if the . or -> token is immediately followed by an identifier followed by a <, the identifier must be looked up to determine whether the < is the beginning of a template argument list (14.2) or a less-than operator. The identifier is first looked up in the class of the object expression. If the identifier is not found, it is then looked up in the context of the entire postfix-expression and shall name a class or function template. If the lookup in the class of the object expression finds a template, the name is also looked up in the context of the entire postfix-expression and

— if the name is not found, the name found in the class of the object expression is used, otherwise

— if the name is found in the context of the entire postfix-expression and does not name a class template, the name found in the class of the object expression is used, otherwise

— if the name found is a class template, it must refer to the same entity as the one found in the class of the object expression, otherwise the program is ill-formed.

2 If the id-expression in a class member access (5.2.5) is an unqualified-id, and the type of the object expression is of a class type C (or of pointer to a class type C), the unqualified-id is looked up in the scope of class C. If the type of the object expression is of pointer to scalar type, the unqualified-id is looked up in the context of the complete postfix-expression.

3 If the unqualified-id is type-name, and the type of the object expression is of a class type C (or of pointer to a class type C), the type-name is looked up in the context of the entire postfix-expression and in the scope of class C. The type-name shall refer to a class-name. If type-name is found in both contexts, the name shall refer to the same class type. If the type of the object expression is of scalar type, the type-name is looked up in the scope of the complete postfix-expression.

4 If the id-expression in a class member access is a qualified-id of the form

    class-name-or-namespace-name::...
the class-name-or-namespace-name following the . or -> operator is looked up both in the context of the entire postfix-expression and in the scope of the class of the object expression. If the name is found only in the scope of the class of the object expression, the name shall refer to a class-name. If the name is found only in the context of the entire postfix-expression, the name shall refer to a class-name or namespace-name. If the name is found in both contexts, the class-name-or-namespace-name shall refer to the same entity.

5 If the qualified-id has the form

::class-name-or-namespace-name::...

the class-name-or-namespace-name is looked up in global scope as a class-name or namespace-name.

6 If the nested-name-specifier contains a class template-id (14.2), its template-arguments are evaluated in the context in which the entire postfix-expression occurs.

7 If the id-expression is a conversion-function-id, its conversion-type-id shall denote the same type in both the context in which the entire postfix-expression occurs and in the context of the class of the object expression (or the class pointed to by the pointer expression).

3.4.6 Using-directives and namespace aliases

[basic.lookup.udir]

1 When looking up a namespace-name in a using-directive or namespace-alias-definition, only namespace names are considered.

3.5 Program and linkage

[basic.link]

1 A program consists of one or more translation units (clause 2) linked together. A translation unit consists of a sequence of declarations.

   translation-unit:
   declaration-seq opt

2 A name is said to have linkage when it might denote the same object, reference, function, type, template, namespace or value as a name introduced by a declaration in another scope:

   — When a name has external linkage, the entity it denotes can be referred to by names from scopes of other translation units or from other scopes of the same translation unit.

   — When a name has internal linkage, the entity it denotes can be referred to by names from other scopes in the same translation unit.

   — When a name has no linkage, the entity it denotes cannot be referred to by names from other scopes.

3 A name having namespace scope (3.3.5) has internal linkage if it is the name of

   — an object, reference, function or function template that is explicitly declared static or,

   — an object or reference that is explicitly declared const and neither explicitly declared extern nor previously declared to have external linkage; or

   — a data member of an anonymous union.

4 A name having namespace scope has external linkage if it is the name of

   — an object or reference, unless it has internal linkage; or

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— a function, unless it has internal linkage; or
— a named class (clause 9), or an unnamed class defined in a typedef declaration in which the class has the typedef name for linkage purposes (7.1.3); or
— a named enumeration (7.2), or an unnamed enumeration defined in a typedef declaration in which the enumeration has the typedef name for linkage purposes (7.1.3); or
— an enumerator belonging to an enumeration with external linkage; or
— a template, unless it is a function template that has internal linkage (clause 14); or
— a namespace (7.3), unless it is declared within an unnamed namespace.

In addition, a member function, static data member, a named class or enumeration of class scope, or an unnamed class or enumeration defined in a class-scope typedef declaration such that the class or enumeration has the typedef name for linkage purposes (7.1.3), has external linkage if the name of the class has external linkage.

The name of a function declared in block scope, and the name of an object declared by a block scope extern declaration, have linkage. If there is a visible declaration of an entity with linkage having the same name and type, ignoring entities declared outside the innermost enclosing namespace scope, the block scope declaration declares that same entity and receives the linkage of the previous declaration. If there is more than one such matching entity, the program is ill-formed. Otherwise, if no matching entity is found, the block scope entity receives external linkage.

[Example:
static void f();
static int i = 0; // 1
void g() {
    extern void f(); // internal linkage
    int i; // 2: i has no linkage
    {
        extern void f(); // internal linkage
        extern int i; // 3: external linkage
    }
}

There are three objects named \( i \) in this program. The object with internal linkage introduced by the declaration in global scope (line //1 ), the object with automatic storage duration and no linkage introduced by the declaration on line //2, and the object with static storage duration and external linkage introduced by the declaration on line //3. — end example]

When a block scope declaration of an entity with linkage is not found to refer to some other declaration, then that entity is a member of the innermost enclosing namespace. However such a declaration does not introduce the member name in its namespace scope. [Example:

namespace X {
    void p() {
        q(); // error: q not yet declared
        extern void q(); // q is a member of namespace X
    }
}
3.5 Program and linkage

```c
void middle()
{
    q(); // error: q not yet declared
}

void q() { /* ... */ } // definition of X::q

void q() { /* ... */ } // some other, unrelated q
```

— end example ]

8 Names not covered by these rules have no linkage. Moreover, except as noted, a name declared in a local scope (3.3.2) has no linkage. A type is said to have linkage if and only if:

— it is a class or enumeration type that is named (or has a name for linkage purposes (7.1.3) and the name has linkage; or
— it is a specialization of a class template (14)\(^{35}\); or
— it is a fundamental type (3.9.1); or
— it is a compound type (3.9.2) other than a class or enumeration, compounded exclusively from types that have linkage; or
— it is a cv-qualified (3.9.3) version of a type that has linkage.

A type without linkage shall not be used as the type of a variable or function with linkage, unless the variable or function has extern "C" linkage (7.5). [Note: in other words, a type without linkage contains a class or enumeration that cannot be named outside its translation unit. An entity with external linkage declared using such a type could not correspond to any other entity in another translation unit of the program and thus is not permitted. Also note that classes with linkage may contain members whose types do not have linkage, and that typedef names are ignored in the determination of whether a type has linkage. — end note ] [ Example:

```c
void f()
{
    struct A { int x; }; // no linkage
    extern A a; // ill-formed
typedef A B; // ill-formed
    extern B b; // ill-formed
}
```

— end example ]

This implies that names with no linkage cannot be used as template arguments (14.3).

9 Two names that are the same (clause 3) and that are declared in different scopes shall denote the same object, reference, function, type, enumerator, template or namespace if

— both names have external linkage or else both names have internal linkage and are declared in the same translation unit; and

\(^{35}\) a class template always has external linkage, and the requirements of 14.3.1 and 14.3.2 ensure that the template arguments will also have appropriate linkage.

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After all adjustments of types (during which typedefs (7.1.3) are replaced by their definitions), the types specified by all declarations referring to a given object or function shall be identical, except that declarations for an array object can specify array types that differ by the presence or absence of a major array bound (8.3.4). A violation of this rule on type identity does not require a diagnostic.

[Note: linkage to non-C++ declarations can be achieved using a linkage-specification (7.5). — end note]

3.6 Start and termination

3.6.1 Main function

A program shall contain a global function called `main`, which is the designated start of the program. It is implementation-defined whether a program in a freestanding environment is required to define a `main` function. [Note: in a freestanding environment, start-up and termination is implementation-defined; start-up contains the execution of constructors for objects of namespace scope with static storage duration; termination contains the execution of destructors for objects with static storage duration. — end note]

An implementation shall not predefine the `main` function. This function shall not be overloaded. It shall have a return type of type `int`, but otherwise its type is implementation-defined. All implementations shall allow both of the following definitions of `main`:

```c
int main() { /* ... */ }
```

and

```c
int main(int argc, char* argv[]) { /* ... */ }
```

In the latter form `argc` shall be the number of arguments passed to the program from the environment in which the program is run. If `argc` is nonzero these arguments shall be supplied in `argv[0]` through `argv[argc-1]` as pointers to the initial characters of null-terminated multibyte strings (NTMBSs) (17.3.2.1.3.2) and `argv[0]` shall be the pointer to the initial character of a NTMBS that represents the name used to invoke the program or `""`. The value of `argc` shall be nonnegative. The value of `argv[argc]` shall be 0. [Note: it is recommended that any further (optional) parameters be added after `argv`. — end note]

The function `main` shall not be used (3.2) within a program. The linkage (3.5) of `main` is implementation-defined. A program that declares `main` to be `inline` or `static` is ill-formed. The name `main` is not otherwise reserved. [Example: member functions, classes, and enumerations can be called `main`, as can entities in other namespaces. — end example]

Calling the function `std::exit(int)` declared in `<cstdlib>` (18.4) terminates the program without leaving the current block and hence without destroying any objects with automatic storage duration (12.4). If `std::exit` is called to end a program during the destruction of an object with static storage duration, the program has undefined behavior.

A return statement in `main` has the effect of leaving the main function (destroying any objects with automatic storage duration) and calling `std::exit` with the return value as the argument. If control reaches the end of `main` without encountering a `return` statement, the effect is that of executing

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return 0;

3.6.2 Initialization of non-local objects

Objects with static storage duration (3.7.1) shall be zero-initialized (8.5) before any other initialization takes place. A reference with static storage duration and an object of POD type with static storage duration can be initialized with a constant expression (5.19); this is called constant initialization. Together, zero-initialization and constant initialization are called static initialization; all other initialization is dynamic initialization. Static initialization shall be performed before any dynamic initialization takes place. Dynamic initialization of an object is either ordered or unordered. Definitions of explicitly specialized class template static data members have ordered initialization. Other class template static data members (i.e., implicitly or explicitly instantiated specializations) have unordered initialization. Other objects defined in namespace scope have ordered initialization. Objects defined within a single translation unit and with ordered initialization shall be initialized in the order of their definitions in the translation unit. The order of initialization is unspecified for objects with unordered initialization and for objects defined in different translation units. [Note: 8.5.1 describes the order in which aggregate members are initialized. The initialization of local static objects is described in 6.7. — end note]

An implementation is permitted to perform the initialization of an object of namespace scope with static storage duration as a static initialization even if such initialization is not required to be done statically, provided that

— the dynamic version of the initialization does not change the value of any other object of namespace scope with static storage duration prior to its initialization, and
— the static version of the initialization produces the same value in the initialized object as would be produced by the dynamic initialization if all objects not required to be initialized statically were initialized dynamically.

[Note: as a consequence, if the initialization of an object obj1 refers to an object obj2 of namespace scope with static storage duration potentially requiring dynamic initialization and defined later in the same translation unit, it is unspecified whether the value of obj2 used will be the value of the fully initialized obj2 (because obj2 was statically initialized) or will be the value of obj2 merely zero-initialized. For example,

```cpp
inline double fd() { return 1.0; }
extern double d1;
double d2 = d1;  // unspecified:
// may be statically initialized to 0.0 or
// dynamically initialized to 1.0

double d1 = fd();  // may be initialized statically to 1.0
```

— end note]

It is implementation-defined whether or not the dynamic initialization (8.5, 9.4, 12.1, 12.6.1) of an object of namespace scope is done before the first statement of main. If the initialization is deferred to some point in time after the first statement of main, it shall occur before the first use of any function or object defined in the same translation unit as the object to be initialized. [Example:

```cpp
// - File 1 -
#include "a.h"
#include "b.h"
B b;
```

36) An object defined in namespace scope having initialization with side-effects must be initialized even if it is not used (3.7.1).
A::A()
{
    b.Use();
}

// File 2 -
#include "a.h"
A a;

// File 3 -
#include "a.h"
#include "b.h"
extern A a;
extern B b;

int main()
{
    a.Use();
    b.Use();
}

It is implementation-defined whether either a or b is initialized before main is entered or whether the initializations are delayed until a is first used in main. In particular, if a is initialized before main is entered, it is not guaranteed that b will be initialized before it is used by the initialization of a, that is, before A::A is called. If, however, a is initialized at some point after the first statement of main, b will be initialized prior to its use in A::A. — end example }

4 If construction or destruction of a non-local static object ends in throwing an uncaught exception, the result is to call std::terminate (18.7.3.3).

3.6.3 Termination [basic.start.term]

1 Destructors (12.4) for initialized objects of static storage duration (declared at block scope or at namespace scope) are called as a result of returning from main and as a result of calling std::exit (18.4). These objects are destroyed in the reverse order of the completion of their constructor or of the completion of their dynamic initialization. If an object is initialized statically, the object is destroyed in the same order as if the object was dynamically initialized. For an object of array or class type, all subobjects of that object are destroyed before any local object with static storage duration initialized during the construction of the subobjects is destroyed.

2 If a function contains a local object of static storage duration that has been destroyed and the function is called during the destruction of an object with static storage duration, the program has undefined behavior if the flow of control passes through the definition of the previously destroyed local object.

3 If a function is registered with std::atexit (see <cstdlib>, 18.4) then following the call to std::exit, any objects with static storage duration initialized prior to the registration of that function shall not be destroyed until the registered function is called from the termination process and has completed. For an object with static storage duration constructed after a function is registered with std::atexit, then following the call to std::exit, the registered function is not called until the execution of the object’s destructor has completed. If std::atexit is called during the construction of an object, the complete object to which it belongs shall be destroyed before the registered function is called.

4 Calling the function std::abort() declared in <cstdlib> terminates the program without executing destructors for
3.7 Storage duration

Storage duration is the property of an object that defines the minimum potential lifetime of the storage containing the object. The storage duration is determined by the construct used to create the object and is one of the following:

- static storage duration
- automatic storage duration
- dynamic storage duration

Static and automatic storage durations are associated with objects introduced by declarations (3.1) and implicitly created by the implementation (12.2). The dynamic storage duration is associated with objects created with `operator new` (5.3.4).

The storage class specifiers `static` and `auto` are related to storage duration as described below.

The storage duration categories apply to references as well. The lifetime of a reference is its storage duration.

3.7.1 Static storage duration

All objects which neither have dynamic storage duration nor are local have *static storage duration*. The storage for these objects shall last for the duration of the program (3.6.2, 3.6.3).

If an object of static storage duration has initialization or a destructor with side effects, it shall not be eliminated even if it appears to be unused, except that a class object or its copy may be eliminated as specified in 12.8.

The keyword `static` can be used to declare a local variable with static storage duration. *Note: 6.7 describes the initialization of local static variables; 3.6.3 describes the destruction of local static variables. — end note*

The keyword `static` applied to a class data member in a class definition gives the data member static storage duration.

3.7.2 Automatic storage duration

Local objects explicitly declared `auto` or `register` or not explicitly declared `static` or `extern` have *automatic storage duration*. The storage for these objects lasts until the block in which they are created exits.

*Note: these objects are initialized and destroyed as described in 6.7. — end note*

If a named automatic object has initialization or a destructor with side effects, it shall not be destroyed before the end of its block, nor shall it be eliminated as an optimization even if it appears to be unused, except that a class object or its copy may be eliminated as specified in 12.8.

3.7.3 Dynamic storage duration

Objects can be created dynamically during program execution (1.9), using `new-expressions` (5.3.4), and destroyed using `delete-expressions` (5.3.5). A C++ implementation provides access to, and management of, dynamic storage via the global allocation functions `operator new` and `operator new[]` and the global deallocation functions `operator delete` and `operator delete[]`.

The library provides default definitions for the global allocation and deallocation functions. Some global allocation and deallocation functions are replaceable (18.5.1). A C++ program shall provide at most one definition of a replaceable
allocation or deallocation function. Any such function definition replaces the default version provided in the library (17.4.3.4). The following allocation and deallocation functions (18.5) are implicitly declared in global scope in each translation unit of a program:

```c
void* operator new(std::size_t) throw(std::bad_alloc);
void* operator new[](std::size_t) throw(std::bad_alloc);
void operator delete(void*) throw();
void operator delete[](void*) throw();
```

These implicit declarations introduce only the function names `operator new`, `operator new[]`, `operator delete`, `operator delete[]`. [Note: the implicit declarations do not introduce the names `std`, `std::bad_alloc`, and `std::size_t`, or any other names that the library uses to declare these names. Thus, a `new-expression`, `delete-expression` or function call that refers to one of these functions without including the header `<new>` is ill-formed. However, referring to `std`, `std::bad_alloc`, and `std::size_t` is ill-formed unless the name has been declared by including the appropriate header. —end note] Allocation and/or deallocation functions can also be declared and defined for any class (12.5).

Any allocation and/or deallocation functions defined in a C++ program, including the default versions in the library, shall conform to the semantics specified in 3.7.3.1 and 3.7.3.2.

### 3.7.3.1 Allocation functions

An allocation function shall be a class member function or a global function; a program is ill-formed if an allocation function is declared in a namespace scope other than global scope or declared static in global scope. The return type shall be `void*`. The first parameter shall have type `std::size_t` (18.1). The first parameter shall not have an associated default argument (8.3.6). The value of the first parameter shall be interpreted as the requested size of the allocation.

An allocation function can be a function template. Such a template shall declare its return type and first parameter as specified above (that is, template parameter types shall not be used in the return type and first parameter type). Template allocation functions shall have two or more parameters.

The allocation function attempts to allocate the requested amount of storage. If it is successful, it shall return the address of the start of a block of storage whose length in bytes shall be at least as large as the requested size. There are no constraints on the contents of the allocated storage on return from the allocation function. The order, contiguity, and initial value of storage allocated by successive calls to an allocation function is unspecified. The pointer returned shall be suitably aligned so that it can be converted to a pointer of any complete object type and then used to access the object or array in the storage allocated (until the storage is explicitly deallocated by a call to a corresponding deallocation function). Even if the size of the space requested is zero, the request can fail. If the request succeeds, the value returned shall be a non-null pointer value (4.10) p0 different from any previously returned value p1, unless that value p1 was subsequently passed to an `operator delete`. The effect of dereferencing a pointer returned as a request for zero size is undefined.

An allocation function that fails to allocate storage can invoke the currently installed new-handler function (18.5.2.2), if any. [Note: A program-supplied allocation function can obtain the address of the currently installed new_handler using the `std::set_new_handler` function (18.5.2.3). —end note] If an allocation function declared with an empty `exception-specification` (15.4), `throw()`, fails to allocate storage, it shall return a null pointer. Any other allocation function that fails to allocate storage shall only indicate failure by throwing an exception of class `std::bad_alloc` (18.5.2.1) or a class derived from `std::bad_alloc`.

---

37) The intent is to have `operator new()` implementable by calling `std::malloc()` or `std::calloc()`, so the rules are substantially the same. C++ differs from C in requiring a zero request to return a non-null pointer.
3.8 Object Lifetime

1 The **lifetime** of an object is a runtime property of the object. The lifetime of an object of type T begins when:

   — storage with the proper alignment and size for type T is obtained, and

---

38) On some implementations, it causes a system-generated runtime fault.
if T is a class type and the constructor invoked to create the object is non-trivial (12.1), the principal constructor call 12.6.2 has completed. [Note: the initialization can be performed by a constructor call or, in the case of an aggregate with an implicitly-declared non-trivial default constructor, an aggregate initialization 8.5.1. — end note]

The lifetime of an object of type T ends when:

— if T is a class type with a non-trivial destructor (12.4), the destructor call starts, or

— the storage which the object occupies is reused or released.

[Note: the lifetime of an array object or of an object of POD type (3.9) starts as soon as storage with proper size and alignment is obtained, and its lifetime ends when the storage which the array or object occupies is reused or released. 12.6.2 describes the lifetime of base and member subobjects. — end note]

The properties ascribed to objects throughout this International Standard apply for a given object only during its lifetime. [Note: in particular, before the lifetime of an object starts and after its lifetime ends there are significant restrictions on the use of the object, as described below, in 12.6.2 and in 12.7. Also, the behavior of an object under construction and destruction might not be the same as the behavior of an object whose lifetime has started and not ended. 12.6.2 and 12.7 describe the behavior of objects during the construction and destruction phases. — end note]

A program may end the lifetime of any object by reusing the storage which the object occupies or by explicitly calling the destructor for an object of a class type with a non-trivial destructor. For an object of a class type with a non-trivial destructor, the program is not required to call the destructor explicitly before the storage which the object occupies is reused or released; however, if there is no explicit call to the destructor or if a delete-expression (5.3.5) is not used to release the storage, the destructor shall not be implicitly called and any program that depends on the side effects produced by the destructor has undefined behavior.

Before the lifetime of an object has started but after the storage which the object will occupy has been allocated\(^\text{39}\) or, after the lifetime of an object has ended and before the storage which the object occupied is reused or released, any pointer that refers to the storage location where the object will be or was located may be used but only in limited ways. Such a pointer refers to allocated storage (3.7.3.2), and using the pointer as if the pointer were of type void*, is well-defined. Such a pointer may be dereferenced but the resulting lvalue may only be used in limited ways, as described below. If the object will be or was of a class type with a non-trivial destructor, and the pointer is used as the operand of a delete-expression, the program has undefined behavior. If the object will be or was of a non-POD class type, the program has undefined behavior if:

— the pointer is used to access a non-static data member or call a non-static member function of the object, or

— the pointer is implicitly converted (4.10) to a pointer to a base class type, or

— the pointer is used as the operand of a static_cast (5.2.9) (except when the conversion is to void*, or to void* and subsequently to char*, or unsigned char*).

— the pointer is used as the operand of a dynamic_cast (5.2.7). [Example:

```
#include <cstdlib>

struct B {
    virtual void f();
```\(^\text{39}\)

For example, before the construction of a global object of non-POD class type (12.7).
3.8 Object Lifetime

```cpp
void mutate();
virtual ~B();
};

struct D1 : B { void f(); };
struct D2 : B { void f(); };

void B::mutate() {
    new (this) D2; // reuses storage — ends the lifetime of *this
    f(); // undefined behavior
    ... = this; // OK, this points to valid memory
}

void g() {
    void* p = std::malloc(sizeof(D1) + sizeof(D2));
    B* pb = new (p) D1;
    pb->mutate();
    &pb; // OK: pb points to valid memory
    void* q = pb; // OK: pb points to valid memory
    pb->f(); // undefined behavior, lifetime of *pb has ended
}
```

— end example —

6 Similarly, before the lifetime of an object has started but after the storage which the object will occupy has been allocated or, after the lifetime of an object has ended and before the storage which the object occupied is reused or released, any lvalue which refers to the original object may be used but only in limited ways. Such an lvalue refers to allocated storage (3.7.3.2), and using the properties of the lvalue which do not depend on its value is well-defined. If an lvalue-to-rvalue conversion (4.1) is applied to such an lvalue, the program has undefined behavior; if the original object will be or was of a non-POD class type, the program has undefined behavior if:

- the lvalue is used to access a non-static data member or call a non-static member function of the object, or
- the lvalue is implicitly converted (4.10) to a reference to a base class type, or
- the lvalue is used as the operand of a static_cast (5.2.9) except when the conversion is ultimately to cv char\& or cv unsigned char\&), or
- the lvalue is used as the operand of a dynamic_cast (5.2.7) or as the operand of typeid.

7 If, after the lifetime of an object has ended and before the storage which the object occupied is reused or released, a new object is created at the storage location which the original object occupied, a pointer that pointed to the original object, a reference that referred to the original object, or the name of the original object will automatically refer to the new object and, once the lifetime of the new object has started, can be used to manipulate the new object, if:

- the storage for the new object exactly overlays the storage location which the original object occupied, and
- the new object is of the same type as the original object (ignoring the top-level cv-qualifiers), and
- the type of the original object is not const-qualified, and, if a class type, does not contain any non-static data member whose type is const-qualified or a reference type, and
3.8 Object Lifetime

— the original object was a most derived object (1.8) of type \( T \) and the new object is a most derived object of type \( T \) (that is, they are not base class subobjects). [Example:

```c
struct C {
    int i;
    void f();
    const C& operator=( const C& );
};

const C& C::operator=( const C& other)
{
    if ( this != &other ) {
        this->~C(); // lifetime of *this ends
        new (this) C(other); // new object of type C created
        f(); // well-defined
    }
    return *this;
}
```

```c
C c1;
C c2;
c1 = c2; // well-defined
```

— end example]

8 If a program ends the lifetime of an object of type \( T \) with static (3.7.1) or automatic (3.7.2) storage duration and if \( T \) has a non-trivial destructor,\(^{40}\) the program must ensure that an object of the original type occupies that same storage location when the implicit destructor call takes place; otherwise the behavior of the program is undefined. This is true even if the block is exited with an exception. [Example:

```c
class T { }
struct B {
    ~B();
};

void h() {
    B b;
    new (&b) T;
} // undefined behavior at block exit
```

— end example]

9 Creating a new object at the storage location that a \texttt{const} object with static or automatic storage duration occupies or, at the storage location that such a \texttt{const} object used to occupy before its lifetime ended results in undefined behavior. [Example:

```c
struct B {
    B();
```

\[^{40}\text{that is, an object for which a destructor will be called implicitly–either upon exit from the block for an object with automatic storage duration or upon exit from the program for an object with static storage duration.}\]
3.9 Types

3.9 Types

[Note: 3.9 and the subclauses thereof impose requirements on implementations regarding the representation of types. There are two kinds of types: fundamental types and compound types. Types describe objects (1.8), references (8.3.2), or functions (8.3.5). —end note]

2 For any object (other than a base-class subobject) of POD type \( T \), whether or not the object holds a valid value of type \( T \), the underlying bytes (1.7) making up the object can be copied into an array of char or unsigned char.\(^{41}\) If the content of the array of char or unsigned char is copied back into the object, the object shall subsequently hold its original value. [Example:

```
#define N sizeof(T)
char buf[N];
T obj; // obj initialized to its original value
std::memcpy(buf, &obj, N); // between these two calls to std::memcpy, // obj might be modified
std::memcpy(&obj, buf, N); // at this point, each subobject of obj of scalar type // holds its original value
```
—end example]

3 For any POD type \( T \), if two pointers to \( T \) point to distinct \( T \) objects \( \text{obj1} \) and \( \text{obj2} \), where neither \( \text{obj1} \) nor \( \text{obj2} \) is a base-class subobject, if the value of \( \text{obj1} \) is copied into \( \text{obj2} \), using the \( \text{std::memcpy} \) library function, \( \text{obj2} \) shall subsequently hold the same value as \( \text{obj1} \). [Example:

```
T* t1p;
T* t2p; // provided that t2p points to an initialized object...
std::memcpy(t1p, t2p, sizeof(T)); // at this point, every subobject of POD type in *t1p contains // the same value as the corresponding subobject in *t2p
```
—end example]

4 The object representation of an object of type \( T \) is the sequence of \( N \) unsigned char objects taken up by the object of type \( T \), where \( N \) equals \( \text{sizeof(T)} \). The value representation of an object is the set of bits that hold the value of type \( T \).\(^{41}\) By using, for example, the library functions (17.4.1.2) \( \text{std::memcpy} \) or \( \text{std::memmove} \).
For POD types, the value representation is a set of bits in the object representation that determines a \textit{value}, which is one discrete element of an implementation-defined set of values.\footnote{The intent is that the memory model of C++ is compatible with that of ISO/IEC 9899 Programming Language C.}

Object types have \textit{alignment requirements} (3.9.1, 3.9.2). The \textit{alignment} of a complete object type is an implementation-defined integer value representing a number of bytes; an object is allocated at an address that meets the alignment requirements of its object type.

A class that has been declared but not defined, or an array of unknown size or of incomplete element type, is an incompletely-defined object type.\footnote{The size and layout of an instance of an incompletely-defined object type is unknown.} Incompletely-defined object types and the void types are incomplete types (3.9.1). Objects shall not be defined to have an incomplete type.

A class type (such as “\texttt{class X}”) might be incomplete at one point in a translation unit and complete later on; the type “\texttt{class X}” is the same type at both points. The declared type of an array object might be an array of incomplete class type and therefore incomplete; if the class type is completed later on in the translation unit, the array type becomes complete; the array type at those two points is the same type. The declared type of an array object might be an array of unknown size and therefore be incomplete at one point in a translation unit and complete later on; the array types at those two points (“array of unknown bound of $T$” and “array of N $T$”) are different types. The type of a pointer to array of unknown size, or of a type defined by a \texttt{typedef} declaration to be an array of unknown size, cannot be completed.

\begin{example}
\begin{verbatim}
class X; // X is an incomplete type extern X* xp; // xp is a pointer to an incomplete type extern int arr[]; // the type of arr is incomplete typedef int UNKA[]; // UNKA is an incomplete type UNKA* arrp; // arrp is a pointer to an incomplete type UNKA** arrpp;

void foo()
{
  xp++; // ill-formed: X is incomplete
  arrp++; // ill-formed: incomplete type
  arrpp++; // OK: sizeof UNKA* is known
}

struct X { int i; }; // now X is a complete type int arr[10]; // now the type of arr is complete
\end{verbatim}
\end{example}

\begin{verbatim}
X x;
void bar()
{
  xp = &x; // OK: type is "pointer to X"
  arrp = &arr; // ill-formed: different types
  xp++; // OK: X is complete
  arrp++; // ill-formed: UNKA can't be completed
}
\end{verbatim}

--- end example \]
An object type is a (possibly cv-qualified) type that is not a function type, not a reference type, and not a void type.

Arithmetic types (3.9.1), enumeration types, pointer types, and pointer to member types (3.9.2), and cv-qualified versions of these types (3.9.3) are collectively called scalar types. Scalar types, POD-struct types, POD-union types (clause 9), arrays of such types and cv-qualified versions of these types (3.9.3) are collectively called POD types.

If two types T1 and T2 are the same type, then T1 and T2 are layout-compatible types. [Note: Layout-compatible enumerations are described in 7.2. Layout-compatible POD-structs and POD-unions are described in 9.2. —end note]

3.9.1 Fundamental types

Objects declared as characters (char) shall be large enough to store any member of the implementation’s basic character set. If a character from this set is stored in a character object, the integral value of that character object is equal to the value of the single character literal form of that character. It is implementation-defined whether a char object can hold negative values. Characters can be explicitly declared unsigned or signed. Plain char, signed char, and unsigned char are three distinct types. A char, a signed char, and an unsigned char occupy the same amount of storage and have the same alignment requirements (3.9); that is, they have the same object representation. For character types, all bits of the object representation participate in the value representation. For unsigned character types, all possible bit patterns of the value representation represent numbers. These requirements do not hold for other types. In any particular implementation, a plain char object can take on either the same values as a signed char or an unsigned char; which one is implementation-defined.

There are five signed integer types: “signed char”, “short int”, “int”, “long int”, and “long long int”. In this list, each type provides at least as much storage as those preceding it in the list. Plain int s have the natural size suggested by the architecture of the execution environment\(^{44}\); the other signed integer types are provided to meet special needs.

For each of the signed integer types, there exists a corresponding (but different) unsigned integer type: “unsigned char”, “unsigned short int”, “unsigned int”, “unsigned long int”, and “unsigned long long int”, each of which occupies the same amount of storage and has the same alignment requirements (3.9) as the corresponding signed integer type\(^{45}\); that is, each signed integer type has the same object representation as its corresponding unsigned integer type. The range of nonnegative values of a signed integer type is a subrange of the corresponding unsigned integer type, and the value representation of each corresponding signed/unsigned type shall be the same.

Unsigned integers, declared unsigned, shall obey the laws of arithmetic modulo \(2^n\) where \(n\) is the number of bits in the value representation of that particular size of integer.\(^{46}\)

Type wchar_t is a distinct type whose values can represent distinct codes for all members of the largest extended character set specified among the supported locales (22.1.1). Type wchar_t shall have the same size, signedness, and alignment requirements (3.9) as one of the other integral types, called its underlying type.

Values of type bool are either true or false.\(^{47}\) [Note: there are no signed, unsigned, short, or long bool types

\(^{44}\) that is, large enough to contain any value in the range of INT_MIN and INT_MAX, as defined in the header <climits>.

\(^{45}\) See 7.1.5.2 regarding the correspondence between types and the sequences of type-specifiers that designate them.

\(^{46}\) This implies that unsigned arithmetic does not overflow because a result that cannot be represented by the resulting unsigned integer type is reduced modulo the number that is one greater than the largest value that can be represented by the resulting unsigned integer type.

\(^{47}\) Using a bool value in ways described by this International Standard as “undefined,” such as by examining the value of an uninitialized automatic variable, might cause it to behave as if it is neither true nor false.
or values. — end note] As described below, bool values behave as integral types. Values of type bool participate in integral promotions (4.5).

Types bool, char, wchar_t, and the signed and unsigned integer types are collectively called integral types.48) A synonym for integral type is integer type. The representations of integral types shall define values by use of a pure binary numeration system.49) [Example: this International Standard permits 2’s complement, 1’s complement and signed magnitude representations for integral types. — end example]

There are three floating point types: float, double, and long double. The type double provides at least as much precision as float, and the type long double provides at least as much precision as double. The set of values of the type float is a subset of the set of values of the type double; the set of values of the type double is a subset of the set of values of the type long double. The value representation of floating-point types is implementation-defined. Integral and floating types are collectively called arithmetic types. Specializations of the standard template std::numeric_limits (18.2) shall specify the maximum and minimum values of each arithmetic type for an implementation.

The void type has an empty set of values. The void type is an incomplete type that cannot be completed. It is used as the return type for functions that do not return a value. Any expression can be explicitly converted to type cv void (5.4). An expression of type void shall be used only as an expression statement (6.2), as an operand of a comma expression (5.18), as a second or third operand of ?: (5.16), as the operand of typeid, or as the expression in a return statement (6.6.3) for a function with the return type void.

[Note: even if the implementation defines two or more basic types to have the same value representation, they are nevertheless different types. — end note]

3.9.2 Compound types [basic.compound]

Compound types can be constructed in the following ways:

— arrays of objects of a given type, 8.3.4;
— functions, which have parameters of given types and return void or references or objects of a given type, 8.3.5;
— pointers to void or objects or functions (including static members of classes) of a given type, 8.3.1;
— references to objects or functions of a given type, 8.3.2;
— classes containing a sequence of objects of various types (clause 9), a set of types, enumerations and functions for manipulating these objects (9.3), and a set of restrictions on the access to these entities (clause 11);
— unions, which are classes capable of containing objects of different types at different times, 9.5;
— enumerations, which comprise a set of named constant values. Each distinct enumeration constitutes a different enumerated type, 7.2;
— pointers to non-static 50) class members, which identify members of a given type within objects of a given class, 8.3.3.

48) Therefore, enumerations (7.2) are not integral; however, enumerations can be promoted to integral types as specified in 4.5.
49) A positional representation for integers that uses the binary digits 0 and 1, in which the values represented by successive bits are additive, begin with 1, and are multiplied by successive integral power of 2, except perhaps for the bit with the highest position. (Adapted from the American National Dictionary for Information Processing Systems.)
50) Static class members are objects or functions, and pointers to them are ordinary pointers to objects or functions.
These methods of constructing types can be applied recursively; restrictions are mentioned in 8.3.1, 8.3.4, 8.3.5, and 8.3.2.

A pointer to objects of type T is referred to as a “pointer to T.” [Example: a pointer to an object of type int is referred to as “pointer to int.”] Except for pointers to static members, text referring to “pointers” does not apply to pointers to members. Pointers to incomplete types are allowed although there are restrictions on what can be done with them (3.9). A valid value of an object pointer represents either the address of a byte in memory (1.7) or a null pointer (4.10). If an object of type T is located at an address A, a pointer of type cv T* whose value is the address A is said to point to that object, regardless of how the value was obtained. [Note: for instance, the address one past the end of an array (5.7) would be considered to point to an unrelated object of the array’s element type that might be located at that address. — end note] The value representation of pointer types is implementation-defined. Pointers to cv-qualified and cv-unqualified versions (3.9.3) of layout-compatible types shall have the same value representation and alignment requirements (3.9).

Objects of cv-qualified (3.9.3) or cv-unqualified type void* (pointer to void), can be used to point to objects of unknown type. A void* shall be able to hold any object pointer. A cv-qualified or cv-unqualified (3.9.3) void* shall have the same representation and alignment requirements as a cv-qualified or cv-unqualified char*.

3.9.3 CV-qualifiers

A type mentioned in 3.9.1 and 3.9.2 is a cv-unqualified type. Each type which is a cv-unqualified complete or incomplete object type or is void (3.9) has three corresponding cv-qualified versions of its type: a const-qualified version, a volatile-qualified version, and a const-volatile-qualified version. The term object type (1.8) includes the cv-qualifiers specified when the object is created. The presence of a const specifier in a decl-specifier-seq declares an object of const-qualified object type; such object is called a const object. The presence of a volatile specifier in a decl-specifier-seq declares an object of volatile-qualified object type; such object is called a volatile object. The presence of both cv-qualifiers in a decl-specifier-seq declares an object of const-volatile-qualified object type; such object is called a const volatile object. The cv-qualified or cv-unqualified versions of a type are distinct types; however, they shall have the same representation and alignment requirements (3.9).

There is a (partial) ordering on cv-qualifiers, so that a type can be said to be more cv-qualified than another. Table 7 shows the relations that constitute this ordering.

In this International Standard, the notation cv (or cv1, cv2, etc.), used in the description of types, represents an arbitrary set of cv-qualifiers, i.e., one of {const}, {volatile}, {const, volatile}, or the empty set. Cv-qualifiers applied to an array type attach to the underlying element type, so the notation “cv T,” where T is an array type, refers to an array whose elements are so-qualified. Such array types can be said to be more (or less) cv-qualified than other types based

51) The same representation and alignment requirements are meant to imply interchangeability as arguments to functions, return values from functions, and members of unions.
### 3.10 Lvalues and rvalues

<table>
<thead>
<tr>
<th>no cv-qualifier</th>
<th>&lt;</th>
<th>const</th>
</tr>
</thead>
<tbody>
<tr>
<td>no cv-qualifier</td>
<td>&lt;</td>
<td>volatile</td>
</tr>
<tr>
<td>no cv-qualifier</td>
<td>&lt;</td>
<td>const volatile</td>
</tr>
<tr>
<td>const</td>
<td>&lt;</td>
<td>const volatile</td>
</tr>
<tr>
<td>volatile</td>
<td>&lt;</td>
<td>const volatile</td>
</tr>
</tbody>
</table>

Table 7: relations on `const` and `volatile`

on the cv-qualification of the underlying element types.

3.10 Lvalues and rvalues

1. Every expression is either an *lvalue* or an *rvalue*.

2. An lvalue refers to an object or function. Some rvalue expressions—those of (possibly cv-qualified) class or array type—also refer to objects.\(^{52}\)

3. [Note: some built-in operators and function calls yield lvalues. [Example: if \(E\) is an expression of pointer type, then \(*E\) is an lvalue expression referring to the object or function to which \(E\) points. As another example, the function `int& f();` yields an lvalue, so the call `f()` is an lvalue expression. — end example ] — end note ]

4. [Note: some built-in operators expect lvalue operands. [Example: built-in assignment operators all expect their left-hand operands to be lvalues. — end example ] Other built-in operators yield rvalues, and some expect them. [Example: the unary and binary + operators expect rvalue arguments and yield rvalue results. — end example ] The discussion of each built-in operator in clause 5 indicates whether it expects lvalue operands and whether it yields an lvalue. — end note ]

5. The result of calling a function that does not return a reference is an rvalue. User defined operators are functions, and whether such operators expect or yield lvalues is determined by their parameter and return types.

6. An expression which holds a temporary object resulting from a cast to a nonreference type is an rvalue (this includes the explicit creation of an object using functional notation (5.2.3)).

7. Whenever an lvalue appears in a context where an rvalue is expected, the lvalue is converted to an rvalue; see 4.1, 4.2, and 4.3.

8. The discussion of reference initialization in 8.5.3 and of temporaries in 12.2 indicates the behavior of lvalues and rvalues in other significant contexts.

9. Class rvalues can have cv-qualified types; non-class rvalues always have cv-unqualified types. Rvalues shall always have complete types or the `void` type; in addition to these types, lvalues can also have incomplete types.

10. An lvalue for an object is necessary in order to modify the object except that an rvalue of class type can also be used to modify its referent under certain circumstances. [Example: a member function called for an object (9.3) can modify the object. — end example ]

11. Functions cannot be modified, but pointers to functions can be modifiable.

\(^{52}\) Expressions such as invocations of constructors and of functions that return a class type refer to objects, and the implementation can invoke a member function upon such objects, but the expressions are not lvalues.
A pointer to an incomplete type can be modifiable. At some point in the program when the pointed to type is complete, the object at which the pointer points can also be modified.

The referent of a `const`-qualified expression shall not be modified (through that expression), except that if it is of class type and has a `mutable` component, that component can be modified (7.1.5.1).

If an expression can be used to modify the object to which it refers, the expression is called `modifiable`. A program that attempts to modify an object through a nonmodifiable lvalue or rvalue expression is ill-formed.

If a program attempts to access the stored value of an object through an lvalue of other than one of the following types the behavior is undefined\(^\text{53}\)

- the dynamic type of the object,
- a cv-qualified version of the dynamic type of the object,
- a type similar (as defined in 4.4) to the dynamic type of the object,
- a type that is the signed or unsigned type corresponding to the dynamic type of the object,
- a type that is the signed or unsigned type corresponding to a cv-qualified version of the dynamic type of the object,
- an aggregate or union type that includes one of the aforementioned types among its members (including, recursively, a member of a subaggregate or contained union),
- a type that is a (possibly cv-qualified) base class type of the dynamic type of the object,
- a `char` or `unsigned char` type.

---

\(^{53}\) The intent of this list is to specify those circumstances in which an object may or may not be aliased.
Chapter 4  Standard conversions

Standard conversions are implicit conversions defined for built-in types. Clause 4 enumerates the full set of such conversions. A standard conversion sequence is a sequence of standard conversions in the following order:

- Zero or one conversion from the following set: lvalue-to-rvalue conversion, array-to-pointer conversion, and function-to-pointer conversion.
- Zero or one conversion from the following set: integral promotions, floating point promotion, integral conversions, floating point conversions, floating-integral conversions, pointer conversions, pointer to member conversions, and boolean conversions.
- Zero or one qualification conversion.

[Note: a standard conversion sequence can be empty, i.e., it can consist of no conversions. — end note] A standard conversion sequence will be applied to an expression if necessary to convert it to a required destination type.

Expressions with a given type will be implicitly converted to other types in several contexts:

- When used as operands of operators. The operator’s requirements for its operands dictate the destination type (clause 5).
- When used in the condition of an if statement or iteration statement (6.4, 6.5). The destination type is bool.
- When used in the expression of a switch statement. The destination type is integral (6.4).
- When used as the source expression for an initialization (which includes use as an argument in a function call and use as the expression in a return statement). The type of the entity being initialized is (generally) the destination type. See 8.5, 8.5.3.

[Note: For user-defined types, user-defined conversions are considered as well; see 12.3. In general, an implicit conversion sequence (13.3.3.1) consists of a standard conversion sequence followed by a user-defined conversion followed by another standard conversion sequence.

There are some contexts where certain conversions are suppressed. For example, the lvalue-to-rvalue conversion is not done on the operand of the unary & operator. Specific exceptions are given in the descriptions of those operators and
4.1 Lvalue-to-rvalue conversion

An lvalue (3.10) of a non-function, non-array type \( T \) can be converted to an rvalue. If \( T \) is an incomplete type, a program that necessitates this conversion is ill-formed. If the object to which the lvalue refers is not an object of type \( T \) and is not an object of a type derived from \( T \), or if the object is uninitialized, a program that necessitates this conversion has undefined behavior. If \( T \) is a non-class type, the type of the rvalue is the cv-unqualified version of \( T \). Otherwise, the type of the rvalue is \( T \).

When an lvalue-to-rvalue conversion occurs within the operand of \( \text{sizeof} \) (5.3.3) the value contained in the referenced object is not accessed, since that operator does not evaluate its operand. Otherwise, if the lvalue has a class type, the conversion copy-initializes a temporary of type \( T \) from the lvalue and the result of the conversion is an rvalue for the temporary. Otherwise, the value contained in the object indicated by the lvalue is the rvalue result.

[ Note: See also 3.10. — end note ]

4.2 Array-to-pointer conversion

An lvalue or rvalue of type “array of \( N \ T \)” or “array of unknown bound of \( T \)” can be converted to an rvalue of type “pointer to \( T \).” The result is a pointer to the first element of the array.

A string literal (2.13.4) that is not a wide string literal can be converted to an rvalue of type “pointer to \( \text{char} \)”; a wide string literal can be converted to an rvalue of type “pointer to \( \text{wchar}_\text{t} \).” In either case, the result is a pointer to the first element of the array. This conversion is considered only when there is an explicit appropriate pointer target type, and not when there is a general need to convert from an lvalue to an rvalue. [ Note: this conversion is deprecated. See Annex D. — end note ] For the purpose of ranking in overload resolution (13.3.3.1.1), this conversion is considered an array-to-pointer conversion followed by a qualification conversion (4.4). [ Example: "abc" is converted to “pointer to \( \text{const char} \)” as an array-to-pointer conversion, and then to “pointer to \( \text{char} \)” as a qualification conversion. — end example ]

4.3 Function-to-pointer conversion

An lvalue of function type \( T \) can be converted to an rvalue of type “pointer to \( T \).” The result is a pointer to the function.

[ Note: See 13.4 for additional rules for the case where the function is overloaded. — end note ]

4.4 Qualification conversions

An rvalue of type “pointer to \( cv1 T \)” can be converted to an rvalue of type “pointer to \( cv2 T \)” if “\( cv2 T \)” is more cv-qualified than “\( cv1 T \)”.

An rvalue of type “pointer to member of \( X \) of type \( cv1 T \)” can be converted to an rvalue of type “pointer to member of \( X \) of type \( cv2 T \)” if “\( cv2 T \)” is more cv-qualified than “\( cv1 T \)”.

[ Note: Function types (including those used in pointer to member function types) are never cv-qualified (8.3.5). — end note ]

---

54) In C++ class rvalues can have cv-qualified types (because they are objects). This differs from ISO C, in which non-lvalues never have cv-qualified types.

55) This conversion never applies to non-static member functions because an lvalue that refers to a non-static member function cannot be obtained.
A conversion can add cv-qualifiers at levels other than the first in multi-level pointers, subject to the following rules:56)

Two pointer types T1 and T2 are similar if there exists a type T and integer n > 0 such that:

- T1 is cv1,0 pointer to cv1,1 pointer to · · · cv1,n−1 pointer to cv1,n T

and

- T2 is cv2,0 pointer to cv2,1 pointer to · · · cv2,n−1 pointer to cv2,n T

where each cvi,j is const, volatile, const volatile, or nothing. The n-tuple of cv-qualifiers after the first in a pointer type, e.g., cv1,1, cv1,2, · · · , cv1,n in the pointer type T1, is called the cv-qualification signature of the pointer type. An expression of type T1 can be converted to type T2 if and only if the following conditions are satisfied:

- the pointer types are similar.
- for every j > 0, if const is in cv1,j then const is in cv2,j, and similarly for volatile.
- if the cv1,j and cv2,j are different, then const is in every cv2,k for 0 < k < j.

[Note: if a program could assign a pointer of type T** to a pointer of type const T** (that is, if line //1 below was allowed), a program could inadvertently modify a const object (as it is done on line //2). For example,

int main() {
    const char c = 'c';
    char* pc;
    const char** pcc = &pc; //1: not allowed
    *pcc = &c;
    *pc = 'C'; // 2: modifies a const object
}

— end note ]

A multi-level pointer to member type, or a multi-level mixed pointer and pointer to member type has the form:

cv0P0 to cv1P1 to · · · cvn−1Pn−1 to cvn T

where Pi is either a pointer or pointer to member and where T is not a pointer type or pointer to member type.

Two multi-level pointer to member types or two multi-level mixed pointer and pointer to member types T1 and T2 are similar if there exists a type T and integer n > 0 such that:

- T1 is cv1,0P0 to cv1,1P1 to · · · cv1,n−1Pn−1 to cv1,n T

and

- T2 is cv2,0P0 to cv2,1P1 to · · · cv2,n−1Pn−1 to cv2,n T

For similar multi-level pointer to member types and similar multi-level mixed pointer and pointer to member types, the rules for adding cv-qualifiers are the same as those used for similar pointer types.

56) These rules ensure that const-safety is preserved by the conversion.
4.5 Integral promotions

An rvalue of type `char`, `signed char`, `unsigned char`, `short int`, or `unsigned short int` can be converted to an rvalue of type `int` if `int` rvalue can be converted to an rvalue of type `int` if `int` can represent all the values of the source type; otherwise, the source rvalue can be converted to an rvalue of type `unsigned int`.

An rvalue of type `wchar_t` (3.9.1) can be converted to an rvalue of the first of the following types that can represent all the values of its underlying type: `int`, `unsigned int`, `long int`, `unsigned long int`, or `unsigned long long int`. An rvalue of an enumeration type (7.2) can be converted to an rvalue of the first of the following types that can represent all the values of the enumeration (i.e. the values in the range $b_{\min}$ to $b_{\max}$ as described in 7.2: `int`, `unsigned int`, `long int`, `unsigned long int`, `long long int`, or `unsigned long long int`.

An rvalue for an integral bit-field (9.6) can be converted to an rvalue of type `int` if `int` can represent all the values of the bit-field; otherwise, it can be converted to `unsigned int` if `unsigned int` can represent all the values of the bit-field. If the bit-field is larger yet, no integral promotion applies to it. If the bit-field has an enumerated type, it is treated as any other value of that type for promotion purposes.

An rvalue of type `bool` can be converted to an rvalue of type `int`, with `false` becoming zero and `true` becoming one.

These conversions are called integral promotions.

4.6 Floating point promotion

An rvalue of type `float` can be converted to an rvalue of type `double`. The value is unchanged.

This conversion is called floating point promotion.

4.7 Integral conversions

An rvalue of an integer type can be converted to an rvalue of another integer type. An rvalue of an enumeration type can be converted to an rvalue of an integer type.

If the destination type is unsigned, the resulting value is the least unsigned integer congruent to the source integer (modulo $2^n$ where $n$ is the number of bits used to represent the unsigned type). [Note: In a two’s complement representation, this conversion is conceptual and there is no change in the bit pattern (if there is no truncation). — end note ]

If the destination type is signed, the value is unchanged if it can be represented in the destination type (and bit-field width); otherwise, the value is implementation-defined.

If the destination type is `bool`, see 4.12. If the source type is `bool`, the value `false` is converted to zero and the value `true` is converted to one.

The conversions allowed as integral promotions are excluded from the set of integral conversions.

4.8 Floating point conversions

An rvalue of floating point type can be converted to an rvalue of another floating point type. If the source value can be exactly represented in the destination type, the result of the conversion is that exact representation. If the source value is between two adjacent destination values, the result of the conversion is an implementation-defined choice of either of those values. Otherwise, the behavior is undefined.
The conversions allowed as floating point promotions are excluded from the set of floating point conversions.

### 4.9 Floating-integral conversions

1. An rvalue of a floating point type can be converted to an rvalue of an integer type. The conversion truncates; that is, the fractional part is discarded. The behavior is undefined if the truncated value cannot be represented in the destination type. [Note: If the destination type is `bool`, see 4.12. — end note]

2. An rvalue of an integer type or of an enumeration type can be converted to an rvalue of a floating point type. The result is exact if possible. Otherwise, it is an implementation-defined choice of either the next lower or higher representable value. [Note: loss of precision occurs if the integral value cannot be represented exactly as a value of the floating type. — end note] If the source type is `bool`, the value `false` is converted to zero and the value `true` is converted to one.

### 4.10 Pointer conversions

1. A null pointer constant is an integral constant expression (5.19) rvalue of integer type that evaluates to zero. A null pointer constant can be converted to a pointer type; the result is the null pointer value of that type and is distinguishable from every other value of pointer to object or pointer to function type. Two null pointer values of the same type shall compare equal. The conversion of a null pointer constant to a pointer to cv-qualified type is a single conversion, and not the sequence of a pointer conversion followed by a qualification conversion (4.4).

2. An rvalue of type “pointer to cv T,” where T is an object type, can be converted to an rvalue of type “pointer to cv void”. The result of converting a “pointer to cv T” to a “pointer to cv void” points to the start of the storage location where the object of type T resides, as if the object is a most derived object (1.8) of type T (that is, not a base class subobject). The null pointer value is converted to the null pointer value of the destination type.

3. An rvalue of type “pointer to cv D”, where D is a class type, can be converted to an rvalue of type “pointer to cv B”, where B is a base class (clause 10) of D. If B is an inaccessible (clause 11) or ambiguous (10.2) base class of D, a program that necessitates this conversion is ill-formed. The result of the conversion is a pointer to the base class subobject of the derived class object. The null pointer value is converted to the null pointer value of the destination type.

### 4.11 Pointer to member conversions

1. A null pointer constant (4.10) can be converted to a pointer to member type; the result is the null member pointer value of that type and is distinguishable from any pointer to member not created from a null pointer constant. Two null member pointer values of the same type shall compare equal. The conversion of a null pointer constant to a pointer to member of cv-qualified type is a single conversion, and not the sequence of a pointer to member conversion followed by a qualification conversion (4.4).

2. An rvalue of type “pointer to member of B of type cv T”, where B is a class type, can be converted to an rvalue of type “pointer to member of D of type cv T”, where D is a derived class (clause 10) of B. If B is an inaccessible (clause 11), ambiguous (10.2) or virtual (10.1) base class of D, a program that necessitates this conversion is ill-formed. The result of the conversion refers to the same member as the pointer to member before the conversion took place, but it refers to the base class member as if it were a member of the derived class. The result refers to the member in D’s instance of B. Since the result has type “pointer to member of D of type cv T”, it can be dereferenced with a D object. The result is the same as if the pointer to member of B were dereferenced with the B subobject of D. The null member pointer value is
4.12 Boolean conversions

An rvalue of arithmetic, enumeration, pointer, or pointer to member type can be converted to an rvalue of type `bool`. A zero value, null pointer value, or null member pointer value is converted to `false` any other value is converted to `true`.

\[\text{[conv.bool]}\]

---

57) The rule for conversion of pointers to members (from pointer to member of base to pointer to member of derived) appears inverted compared to the rule for pointers to objects (from pointer to derived to pointer to base) (4.10, clause 10). This inversion is necessary to ensure type safety. Note that a pointer to member is not a pointer to object or a pointer to function and the rules for conversions of such pointers do not apply to pointers to members. In particular, a pointer to member cannot be converted to a `void*`.  

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Chapter 5  Expressions

[ Note: Clause 5 defines the syntax, order of evaluation, and meaning of expressions. An expression is a sequence of operators and operands that specifies a computation. An expression can result in a value and can cause side effects.]

1 Operators can be overloaded, that is, given meaning when applied to expressions of class type (clause 9) or enumeration type (7.2). Uses of overloaded operators are transformed into function calls as described in 13.5. Overloaded operators obey the rules for syntax specified in clause 5, but the requirements of operand type, lvalue, and evaluation order are replaced by the rules for function call. Relations between operators, such as ++a meaning a+=1, are not guaranteed for overloaded operators (13.5), and are not guaranteed for operands of type bool. — end note

2 Clause 5 defines the effects of operators when applied to types for which they have not been overloaded. Operator overloading shall not modify the rules for the built-in operators, that is, for operators applied to types for which they are defined by this Standard. However, these built-in operators participate in overload resolution, and as part of that process user-defined conversions will be considered where necessary to convert the operands to types appropriate for the built-in operator. If a built-in operator is selected, such conversions will be applied to the operands before the operation is considered further according to the rules in clause 5; see 13.3.1.2, 13.6.

3 Except where noted, the order of evaluation of operands of individual operators and subexpressions of individual expressions, and the order in which side effects take place, is unspecified. Between the previous and next sequence point a scalar object shall have its stored value modified at most once by the evaluation of an expression. Furthermore, the prior value shall be accessed only to determine the value to be stored. The requirements of this paragraph shall be met for each allowable ordering of the subexpressions of a full expression; otherwise the behavior is undefined. [Example:

```c
i = v[i++];  // the behavior is undefined
i = 7, i++, i++;  // i becomes 9
i = ++i + 1;  // the behavior is undefined
i = i + 1;  // the value of i is incremented
```

— end example ]

4 If during the evaluation of an expression, the result is not mathematically defined or not in the range of representable values for its type, the behavior is undefined, unless such an expression appears where an integral constant expression is required (5.19), in which case the program is ill-formed. [ Note: most existing implementations of C++ ignore integer overflows. Treatment of division by zero, forming a remainder using a zero divisor, and all floating point exceptions vary among machines, and is usually adjustable by a library function. — end note ]

5 If an expression initially has the type “reference to T (8.3.2, 8.5.3), the type is adjusted to T prior to any further analysis, the expression designates the object or function denoted by the reference, and the expression is an lvalue.

58) The precedence of operators is not directly specified, but it can be derived from the syntax.
5.1 Primary expressions

An expression designating an object is called an *object-expression*.

Whenever an lvalue expression appears as an operand of an operator that expects an rvalue for that operand, the lvalue-to-rvalue (4.1), array-to-pointer (4.2), or function-to-pointer (4.3) standard conversions are applied to convert the expression to an rvalue. [Note: because cv-qualifiers are removed from the type of an expression of non-class type when the expression is converted to an rvalue, an lvalue expression of type const int can, for example, be used where an rvalue expression of type int is required. — end note ]

Many binary operators that expect operands of arithmetic or enumeration type cause conversions and yield result types in a similar way. The purpose is to yield a common type, which is also the type of the result. This pattern is called the *usual arithmetic conversions*, which are defined as follows:

- If either operand is of type long double, the other shall be converted to long double.
- Otherwise, if either operand is double, the other shall be converted to double.
- Otherwise, if either operand is float, the other shall be converted to float.
- Otherwise, the integral promotions (4.5) shall be performed on both operands.
- Then if either operand is unsigned long long int, the other shall be converted to unsigned long long int.
- Otherwise, if one operand is long long int and the other unsigned long int or unsigned int, then if a long long int can represent all the values of the unsigned operand type, the unsigned operand shall be converted to long long int; otherwise both operands shall be converted to unsigned long long int.
- Otherwise, if either operand is long long int, the other shall be converted to long long int.
- Otherwise, if either operand is unsigned long the other shall be converted to unsigned long.
- Otherwise, if one operand is a long int and the other unsigned int, then if a long int can represent all the values of an unsigned int, the unsigned int shall be converted to a long int otherwise both operands shall be converted to unsigned long int.
- Otherwise, if either operand is long, the other shall be converted to long.
- Otherwise, if either operand is unsigned, the other shall be converted to unsigned.

[Note: otherwise, the only remaining case is that both operands are int — end note ]

The values of the floating operands and the results of floating expressions may be represented in greater precision and range than that required by the type; the types are not changed thereby.

5.1 Primary expressions

Primary expressions are literals, names, and names qualified by the scope resolution operator ::.

---

59) As a consequence, operands of type bool, wchar_t, or an enumerated type are converted to some integral type.
60) The cast and assignment operators must still perform their specific conversions as described in 5.4, 5.2.9 and 5.17.
primary-expression:
literal
this
   ( expression )
id-expression

id-expression:
unqualified-id
qualified-id

unqualified-id:
   identifier
   operator-function-id
   conversion-function-id
   ∼ class-name
   template-id

2 A literal is a primary expression. Its type depends on its form (2.13). A string literal is an lvalue; all other literals are rvalues.

3 The keyword this names a pointer to the object for which a non-static member function (9.3.2) is invoked. The keyword this shall be used only inside a non-static class member function body (9.3) or in a constructor mem-initializer (12.6.2). The type of the expression is a pointer to the function’s class (9.3.2), possibly with cv-qualifiers on the class type. The expression is an rvalue.

4 The operator :: followed by an identifier, a qualified-id, or an operator-function-id is a primary-expression. Its type is specified by the declaration of the identifier, qualified-id, or operator-function-id. The result is the entity denoted by the identifier, qualified-id, or operator-function-id. The result is an lvalue if the entity is a function or variable. The identifier, qualified-id, or operator-function-id shall have global namespace scope or be visible in global scope because of a using-directive (7.3.4). [Note: the use of :: allows a type, an object, a function, an enumerator, or a namespace declared in the global namespace to be referred to even if its identifier has been hidden (3.4.3). — end note]

5 A parenthesized expression is a primary expression whose type and value are identical to those of the enclosed expression. The presence of parentheses does not affect whether the expression is an lvalue. The parenthesized expression can be used in exactly the same contexts as those where the enclosed expression can be used, and with the same meaning, except as otherwise indicated.

6 An id-expression is a restricted form of a primary-expression. [Note: an id-expression can appear after . and -> operators (5.2.5). — end note]

7 An identifier is an id-expression provided it has been suitably declared (clause 7). [Note: for operator-function-ids, see 13.5; for conversion-function-ids, see 12.3.2; for template-ids, see 14.2. A class-name prefixed by ~ denotes a destructor; see 12.4. Within the definition of a non-static member function, an identifier that names a non-static member is transformed to a class member access expression (9.3.1). — end note] The type of the expression is the type of the identifier. The result is the entity denoted by the identifier. The result is an lvalue if the entity is a function, variable, or data member.
5.2 Postfix expressions

A nested-name-specifier that names a class, optionally followed by the keyword `template` (14.2), and then followed by the name of a member of either that class (9.2) or one of its base classes (clause 10), is a qualified-id; 3.4.3.1 describes name lookup for class members that appear in qualified-ids. The result is the member. The type of the result is the type of the member. The result is an lvalue if the member is a static member function or a data member. [Note: a class member can be referred to using a qualified-id at any point in its potential scope (3.3.6). — end note] Where `class-name :: class-name` is used, and the two `class-names` refer to the same class, this notation names the constructor (12.1). Where `class-name :: ~ class-name` is used, the two `class-names` shall refer to the same class; this notation names the destructor (12.4). [Note: a typedef-name that names a class is a `class-name` (9.1). — end note]

A nested-name-specifier that names a namespace (7.3), followed by the name of a member of that namespace (or the name of a member of a namespace made visible by a using-directive) is a qualified-id; 3.4.3.2 describes name lookup for namespace members that appear in qualified-ids. The result is the member. The type of the result is the type of the member. The result is an lvalue if the member is a function or a variable.

In a qualified-id, if the id-expression is a conversion-function-id, its conversion-type-id shall denote the same type in both the context in which the entire qualified-id occurs and in the context of the class denoted by the nested-name-specifier.

An id-expression that denotes a non-static data member or non-static member function of a class can only be used:
- as part of a class member access (5.2.5) in which the object-expression refers to the member’s class or a class derived from that class, or
- to form a pointer to member (5.3.1), or
- in the body of a non-static member function of that class or of a class derived from that class (9.3.1), or
- in a mem-initializer for a constructor for that class or for a class derived from that class (12.6.2).

5.2 Postfix expressions

Postfix expressions group left-to-right.
5.2 Postfix expressions

postfix-expression:
  primary-expression
  postfix-expression [ expression ]
  postfix-expression ( expression-list_opt )
  simple-type-specifier ( expression-list_opt )
  typename-specifier ( expression-list_opt )
  postfix-expression . template_opt id-expression
  postfix-expression -> template_opt id-expression
  postfix-expression . pseudo-destructor-name
  postfix-expression -> pseudo-destructor-name
  postfix-expression ++
  postfix-expression --
  dynamic_cast < type-id > ( expression )
  static_cast < type-id > ( expression )
  reinterpret_cast < type-id > ( expression )
  const_cast < type-id > ( expression )
  typeid ( expression )
  typeid ( type-id )

expression-list:
  assignment-expression
  expression-list , assignment-expression

pseudo-destructor-name:
  ::opt nested-name-specifier_opt type-name :: ~ type-name
  ::opt nested-name-specifier template template-id :: ~ type-name
  ::opt nested-name-specifier type-name ~ type-name

[Note: The > token following the type-id in a dynamic_cast, static_cast, reinterpret_cast, or const_cast may be the product of replacing a >> token by two consecutive > tokens (14.2).]

5.2.1 Subscripting [expr.sub]

A postfix expression followed by an expression in square brackets is a postfix expression. One of the expressions shall have the type “pointer to T” and the other shall have enumeration or integral type. The result is an lvalue of type “T.” The type “T” shall be a completely-defined object type. The expression E1[E2] is identical (by definition) to *((E1)+(E2)) [Note: see 5.3 and 5.7 for details of * and + and 8.3.4 for details of arrays. — end note]

5.2.2 Function call [expr.call]

There are two kinds of function call: ordinary function call and member function (9.3) call. A function call is a postfix expression followed by parentheses containing a possibly empty, comma-separated list of expressions which constitute the arguments to the function. For an ordinary function call, the postfix expression shall be either an lvalue that refers to a function (in which case the function-to-pointer standard conversion (4.3) is suppressed on the postfix expression), or it shall have pointer to function type. Calling a function through an expression whose function type has a language linkage that is different from the language linkage of the function type of the called function’s definition is undefined (7.5). For a member function call, the postfix expression shall be an implicit (9.3.1, 9.4) or explicit class member access (5.2.5) whose id-expression is a function member name, or a pointer-to-member expression (5.5) selecting a function member. The first expression in the postfix expression is then called the object expression, and the call is as a member of the object

---

61) This is true even if the subscript operator is used in the following common idiom: &x[0].
62) A static member function (9.4) is an ordinary function.
pointed to or referred to. In the case of an implicit class member access, the implied object is the one pointed to by this

[Note: a member function call of the form \texttt{f()} is interpreted as \texttt{(*this).f()} (see 9.3.1). — end note] If a function or
member function name is used, the name can be overloaded (clause 13), in which case the appropriate function shall be
selected according to the rules in 13.3. The function called in a member function call is normally selected according to
the static type of the object expression (clause 10), but if that function is virtual and is not specified using a qualified-

id then the function actually called will be the final overrider (10.3) of the selected function in the dynamic type of the
object expression [Note: the dynamic type is the type of the object pointed or referred to by the current value of the
object expression. 12.7 describes the behavior of virtual function calls when the object-expression refers to an object
under construction or destruction. — end note]

2 [Note: if a function or member function name is used, and name lookup (3.4) does not find a declaration of that name,
the program is ill-formed. No function is implicitly declared by such a call. — end note]

3 The type of the function call expression is the return type of the statically chosen function (i.e., ignoring the virtual
keyword), even if the type of the function actually called is different. This type shall be a complete object type, a
reference type or the type void.

4 When a function is called, each parameter (8.3.5) shall be initialized (8.5, 12.8, 12.1) with its corresponding argument. If the
function is a non-static member function, the this parameter of the function (9.3.2) shall be initialized with a pointer
to the object of the call, converted as if by an explicit type conversion (5.4). [Note: There is no access or ambiguity
checking on this conversion; the access checking and disambiguation are done as part of the (possibly implicit) class
member access operator. See 10.2, 11.2, and 5.2.5. — end note] When a function is called, the parameters that have
object type shall have completely-defined object type. [Note: this still allows a parameter to be a pointer or reference
to an incomplete class type. However, it prevents a passed-by-value parameter to have an incomplete class type. — end
note] During the initialization of a parameter, an implementation may avoid the construction of extra temporaries by
combining the conversions on the associated argument and/or the construction of temporaries with the initialization
of the parameter (see 12.2). The lifetime of a parameter ends when the function in which it is defined returns. The
initialization and destruction of each parameter occurs within the context of the calling function. [Example: the access of
the constructor, conversion functions or destructor is checked at the point of call in the calling function. If a constructor
or destructor for a function parameter throws an exception, the search for a handler starts in the scope of the calling
function; in particular, if the function called has a function-try-block (clause 15) with a handler that could handle the
exception, this handler is not considered. — end example] The value of a function call is the value returned by the
called function except in a virtual function call if the return type of the final overrider is different from the return type of
the statically chosen function, the value returned from the final overrider is converted to the return type of the statically
chosen function.

5 [Note: a function can change the values of its non-const parameters, but these changes cannot affect the values of the
arguments except where a parameter is of a reference type (8.3.2); if the reference is to a const-qualified type, const-
cast is required to be used to cast away the constness in order to modify the argument’s value. Where a parameter is
of const reference type a temporary object is introduced if needed (7.1.5, 2.13, 2.13.4, 8.3.4, 12.2). In addition, it is
possible to modify the values of nonconstant objects through pointer parameters. — end note]

6 A function can be declared to accept fewer arguments (by declaring default arguments (8.3.6)) or more arguments (by
using the ellipsis, \ldots 8.3.5) than the number of parameters in the function definition (8.4). [Note: this implies that,
ecth except where the ellipsis (\ldots) is used, a parameter is available for each argument. — end note]

7 When there is no parameter for a given argument, the argument is passed in such a way that the receiving function
can obtain the value of the argument by invoking va_arg (18.8). The lvalue-to-rvalue (4.1), array-to-pointer (4.2), and
function-to-pointer (4.3) standard conversions are performed on the argument expression. After these conversions, if the
argument does not have arithmetic, enumeration, pointer, pointer to member, or class type, the program is ill-formed. If the argument has a non-POD class type (clause 9), the behavior is undefined. If the argument has integral or enumeration type that is subject to the integral promotions (4.5), or a floating point type that is subject to the floating point promotion (4.6), the value of the argument is converted to the promoted type before the call. These promotions are referred to as the default argument promotions.

The order of evaluation of arguments is unspecified. All side effects of argument expression evaluations take effect before the function is entered. The order of evaluation of the postfix expression and the argument expression list is unspecified.

Recursive calls are permitted, except to the function named main (3.6.1).

A function call is an lvalue if and only if the result type is a reference.

### 5.2.3 Explicit type conversion (functional notation) [expr.type.conv]

A simple-type-specifier (7.1.5) followed by a parenthesized expression-list constructs a value of the specified type given the expression list. If the expression list is a single expression, the type conversion expression is equivalent (in definedness, and if defined in meaning) to the corresponding cast expression (5.4). If the simple-type-specifier specifies a class type, the class type shall be complete. If the expression list specifies more than a single value, the type shall be a class with a suitably declared constructor (8.5, 12.1), and the expression T(x1, x2, ...) is equivalent in effect to the declaration T t(x1, x2, ...); for some invented temporary variable t, with the result being the value of t as an rvalue.

The expression T(), where T is a simple-type-specifier (7.1.5.2) for a non-array complete object type or the (possibly cv-qualified) void type, creates an rvalue of the specified type, which is value-initialized (8.5; no initialization is done for the void() case). [Note: if T is a non-class type that is cv-qualified, the cv-qualifiers are ignored when determining the type of the resulting rvalue (3.10). —end note]

### 5.2.4 Pseudo destructor call [expr.pseudo]

The use of a pseudo-destructor-name after a dot . or arrow -> operator represents the destructor for the non-class type named by type-name. The result shall only be used as the operand for the function call operator (), and the result of such a call has type void. The only effect is the evaluation of the postfix-expression before the dot or arrow.

The left-hand side of the dot operator shall be of scalar type. The left-hand side of the arrow operator shall be of pointer to scalar type. This scalar type is the object type. The type designated by the pseudo-destructor-name shall be the same as the object type. The cv-unqualified versions of the object type and of the type designated by the pseudo-destructor-name shall be the same type. Furthermore, the two type-names in a pseudo-destructor-name of the form

\[ :_{opt} \text{nested-name-specifier}_{opt} \text{type-name} ::_{opt} \sim \text{type-name} \]

shall designate the same scalar type. The cv-unqualified versions of the object type and of the type designated by the pseudo-destructor-name shall be the same type.

### 5.2.5 Class member access [expr.ref]

A postfix expression followed by a dot . or an arrow ->, optionally followed by the keyword template (14.8.1), and then followed by an id-expression, is a postfix expression. The postfix expression before the dot or arrow is evaluated;\(^{63}\)

\[^{63}\text{This evaluation happens even if the result is unnecessary to determine the value of the entire postfix expression, for example if the id-expression denotes a static member.}\]
5.2 Postfix expressions

Expressions

the result of that evaluation, together with the id-expression, determine the result of the entire postfix expression.

2 For the first option (dot) the type of the first expression (the object expression) shall be “class object” (of a complete type). For the second option (arrow) the type of the first expression (the pointer expression) shall be “pointer to class object” (of a complete type). In these cases, the id-expression shall name a member of the class or of one of its base classes. [Note: because the name of a class is inserted in its class scope (clause 9), the name of a class is also considered a nested member of that class. — end note] [Note: 3.4.5 describes how names are looked up after the . and -> operators. — end note]

3 If \( E_1 \) has the type “pointer to class \( X \),” then the expression \( E_1 \rightarrow E_2 \) is converted to the equivalent form \( *(E_1) . E_2 \); the remainder of 5.2.5 will address only the first option (dot). Abbreviating object-expression.id-expression as \( E_1.E_2 \), then the type and lvalue properties of this expression are determined as follows. In the remainder of 5.2.5, \( cq \) represents an arbitrary set of cv-qualifiers, as defined in 3.9.3.

4 If \( E_2 \) is declared to have type “reference to \( T \),” then \( E_1.E_2 \) is an lvalue; the type of \( E_1.E_2 \) is \( T \). Otherwise, one of the following rules applies.

— If \( E_2 \) is a static data member, and the type of \( E_2 \) is \( T \), then \( E_1.E_2 \) is an lvalue; the expression designates the named member of the class. The type of \( E_1.E_2 \) is \( T \).

— If \( E_2 \) is a non-static data member, and the type of \( E_1 \) is “\( cq1 \ vq1 \ X \)”, and the type of \( E_2 \) is “\( cq2 \ vq2 \ T \)”, the expression designates the named member of the object designated by the first expression. If \( E_1 \) is an lvalue, then \( E_1.E_2 \) is an lvalue; otherwise, it is an rvalue. Let the notation \( vq12 \) stand for the “union” of \( vq1 \) and \( vq2 \); that is, if \( vq1 \) or \( vq2 \) is volatile, then \( vq12 \) is volatile. Similarly, let the notation \( cq12 \) stand for the “union” of \( cq1 \) and \( cq2 \); that is, if \( cq1 \) or \( cq2 \) is const, then \( cq12 \) is const. If \( E_2 \) is declared to be a mutable member, then the type of \( E_1.E_2 \) is “\( vq12 T \)”. If \( E_2 \) is not declared to be a mutable member, then the type of \( E_1.E_2 \) is “\( cq12 vq12 T \)”.

— If \( E_2 \) is a (possibly overloaded) member function, function overload resolution (13.3) is used to determine whether \( E_1.E_2 \) refers to a static or a non-static member function.

— If it refers to a static member function, and the type of \( E_2 \) is “function of parameter-type-list returning \( T \)”, then \( E_1.E_2 \) is an lvalue; the expression designates the static member function. The type of \( E_1.E_2 \) is the same type as that of \( E_2 \), namely “function of parameter-type-list returning \( T \)”.

— Otherwise, if \( E_1.E_2 \) refers to a non-static member function, and the type of \( E_2 \) is “function of parameter-type-list \( cv \) returning \( T \)”, then \( E_1.E_2 \) is not an lvalue. The expression designates a non-static member function. The expression can be used only as the left-hand operand of a member function call (9.3). [Note: any redundant set of parentheses surrounding the expression is ignored (5.1). — end note] The type of \( E_1.E_2 \) is “function of parameter-type-list \( cv \) returning \( T \)”.

— If \( E_2 \) is a nested type, the expression \( E_1.E_2 \) is ill-formed.

— If \( E_2 \) is a member enumerator, and the type of \( E_2 \) is \( T \), the expression \( E_1.E_2 \) is not an lvalue. The type of \( E_1.E_2 \) is \( T \).

[Note: “class objects” can be structures (9.2) and unions (9.5). Classes are discussed in clause 9. — end note]

64) Note that if \( E_1 \) has the type “pointer to class \( X \),” then \( *(E_1) \) is an lvalue.
If E2 is a non-static data member or a non-static member function, the program is ill-formed if the class of which E2 is directly a member is an ambiguous base (10.2) of the naming class (11.2) of E2.

5.2.6 Increment and decrement

The value obtained by applying a postfix ++ is the value that the operand had before applying the operator. [Note: the value obtained is a copy of the original value — end note] The operand shall be a modifiable lvalue. The type of the operand shall be an arithmetic type or a pointer to a complete object type. After the result is noted, the value of the object is modified by adding 1 to it, unless the object is of type `bool`, in which case it is set to `true`. [Note: this use is deprecated, see Annex D. — end note] The result is an rvalue. The type of the result is the cv-unqualified version of the type of the operand. See also 5.7 and 5.17.

The operand of postfix -- is decremented analogously to the postfix ++ operator, except that the operand shall not be of type `bool`. [Note: For prefix increment and decrement, see 5.3.2. — end note]

5.2.7 Dynamic cast

The result of the expression `dynamic_cast<T>(v)` is the result of converting the expression v to type T. T shall be a pointer or reference to a complete class type, or “pointer to cv void.” Types shall not be defined in a `dynamic_cast`. The `dynamic_cast` operator shall not cast away constness (5.2.11).

2 If T is a pointer type, v shall be an rvalue of a pointer to complete class type, and the result is an rvalue of type T. If T is a reference type, v shall be an lvalue of a complete class type, and the result is an lvalue of the type referred to by T.

3 If the type of v is the same as the required result type (which, for convenience, will be called R in this description), or it is the same as R except that the class object type in R is more cv-qualified than the class object type in v, the result is v (converted if necessary).

4 If the value of v is a null pointer value in the pointer case, the result is the null pointer value of type R.

5 If T is “pointer to cv1 B” and v has type “pointer to cv2 D” such that B is a base class of D, the result is a pointer to the unique B subobject of the D object pointed to by v. Similarly, if T is “reference to cv1 B” and v has type cv2 D such that B is a base class of D, the result is an lvalue for the unique B subobject of the D object referred to by v. 65) In both the pointer and reference cases, cv1 shall be the same cv-qualification as, or greater cv-qualification than, cv2, and B shall be an accessible unambiguous base class of D. [Example:

```
struct B {}
struct D : B {}
void foo(D* dp)
{
    B* bp = dynamic_cast<B*>(dp);  // equivalent to B* bp = dp;
}
```

— end example ]

6 Otherwise, v shall be a pointer to or an lvalue of a polymorphic type (10.3).

7 If T is “pointer to cv void,” then the result is a pointer to the most derived object pointed to by v. Otherwise, a run-time check is applied to see if the object pointed or referred to by v can be converted to the type pointed or referred to by T.

65) The most derived object (1.8) pointed or referred to by v can contain other B objects as base classes, but these are ignored.
The run-time check logically executes as follows:

— If, in the most derived object pointed (referred) to by \(v\), \(v\) points (refers) to a public base class subobject of a \(T\) object, and if only one object of type \(T\) is derived from the subobject pointed (referred) to by \(v\) the result is a pointer (an lvalue referring) to that \(T\) object.

— Otherwise, if \(v\) points (refers) to a public base class subobject of the most derived object, and the type of the most derived object has a base class, of type \(T\), that is unambiguous and public, the result is a pointer (an lvalue referring) to the \(T\) subobject of the most derived object.

— Otherwise, the run-time check fails.

The value of a failed cast to pointer type is the null pointer value of the required result type. A failed cast to reference type throws \std::bad_cast\ (18.6.2).

[Example:

```cpp
class A { virtual void f(); };  // A is public
class B { virtual void g(); };  // B is public
class D : public A, private B {};  // D is derived from both A and B
void g()
{
    D d;
    B* bp = (B*)&d;  // cast needed to break protection
    A* ap = &d;  // public derivation, no cast needed
    D& dr = dynamic_cast<D&>/*(bp);  // fails
    ap = dynamic_cast<A*>(bp);  // fails
    bp = dynamic_cast<B*>(ap);  // fails
    ap = dynamic_cast<A*>(&d);  // succeeds
    bp = dynamic_cast<B*>(&d);  // fails
}

class E : public D, public B {};  // E is derived from D and B
class F : public E, public D {};  // F is derived from E and D
void h()
{
    F f;
    A* ap = &f;  // succeeds: finds unique A
    D* dp = dynamic_cast<D*>(ap);  // fails: yields 0
    // d has two D subobjects
    E* ep = (E*)ap;  // ill-formed:
    // cast from virtual base
    E* ep1 = dynamic_cast<E*>(ap);  // succeeds
}

— end example]

[Note: 12.7 describes the behavior of a dynamic_cast applied to an object under construction or destruction. —end note]
std::type_info or const name where name is an implementation-defined class derived from std::type_info which preserves the behavior described in 18.6.1. The lifetime of the object referred to by the lvalue extends to the end of the program. Whether or not the destructor is called for the std::type_info object at the end of the program is unspecified.

2 When typeid is applied to an lvalue expression whose type is a polymorphic class type (10.3), the result refers to a std::type_info object representing the type of the most derived object (1.8) (that is, the dynamic type) to which the lvalue refers. If the lvalue expression is obtained by applying the unary * operator to a pointer and the pointer is a null pointer value (4.10), the typeid expression throws the std::bad_typeid exception (18.6.3).

3 When typeid is applied to an expression other than an lvalue of a polymorphic class type, the result refers to a std::type_info object representing the static type of the expression. Lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) conversions are not applied to the expression. If the type of the expression is a class type, the class shall be completely-defined. The expression is not evaluated.

4 When typeid is applied to a type-id, the result refers to a std::type_info object representing the type of the type-id. If the type of the type-id is a reference to a possibly cv-qualified type, the result of the typeid expression refers to a std::type_info object representing the cv-unqualified referenced type. If the type of the type-id is a class type or a reference to a class type, the class shall be completely-defined. Types shall not be defined in the type-id.

5 The top-level cv-qualifiers of the lvalue expression or the type-id that is the operand of typeid are always ignored. [Example:

```cpp
class D { ... };
D d1;
const D d2;

typeid(d1) == typeid(d2); // yields true
typeid(D) == typeid(const D); // yields true
 typeid(D) == typeid(d2); // yields true
 typeid(D) == typeid(const D&); // yields true
```

— end example ]

6 If the header <typeinfo> (18.6.1) is not included prior to a use of typeid, the program is ill-formed.

7 [Note: 12.7 describes the behavior of typeid applied to an object under construction or destruction. — end note]

5.2.9 Static cast [expr.static.cast]

1 The result of the expression static_cast<T>(v) is the result of converting the expression v to type T. If T is a reference type, the result is an lvalue; otherwise, the result is an rvalue. Types shall not be defined in a static_cast. The static_cast operator shall not cast away constness (5.2.11).

2 An lvalue of type cv1 B, where B is a class type, can be cast to type “reference to cv2 D, where D is a class derived (clause 10) from B, if a valid standard conversion from “pointer to D” to “pointer to B” exists (4.10), cv2 is the same cv-qualification as, or greater cv-qualification than, cv1, and B is not a virtual base class of D. The result is an lvalue of type cv2 D. If the lvalue of type cv1 B is actually a subobject of an object of type D, the lvalue refers to the enclosing object of type D. Otherwise, the result of the cast is undefined. [Example:

```cpp
66) The recommended name for such a class is extended_type_info.
67) If p is an expression of pointer type, then *p, (**p), (*p), ((*p)), *(p)), and so on all meet this requirement.

Draft
struct B {}
struct D : public B {}
D d;
B &br = d;

static_cast<D&>(br); // produces lvalue to the original d object

— end example ]

Otherwise, an expression e can be explicitly converted to a type T using a static_cast of the form static_cast<T>(e) if the declaration T t(e); is well-formed, for some invented temporary variable t (8.5). The effect of such an explicit conversion is the same as performing the declaration and initialization and then using the temporary variable as the result of the conversion. The result is an lvalue if T is a reference type (8.3.2), and an rvalue otherwise. The expression e is used as an lvalue if and only if the initialization uses it as an lvalue.

Otherwise, the static_cast shall perform one of the conversions listed below. No other conversion shall be performed explicitly using a static_cast.

Any expression can be explicitly converted to type cv void. The expression value is discarded. [ Note: however, if the value is in a temporary variable (12.2), the destructor for that variable is not executed until the usual time, and the value of the variable is preserved for the purpose of executing the destructor. — end note ] The lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are not applied to the expression.

The inverse of any standard conversion sequence (clause 4), other than the lvalue-to-rvalue (4.1), array-to-pointer (4.2), function-to-pointer (4.3), and boolean (4.12) conversions, can be performed explicitly using static_cast. A program is ill-formed if it uses static_cast to perform the inverse of an ill-formed standard conversion sequence. [ Example:

struct B {}
struct D : private B {}
void f() {
    static_cast<D*>(D::*)0); // Error: B is a private base of D.
    static_cast<int B::*>(D::*); // Error: B is a private base of D.
}

— end example ]

The lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) conversions are applied to the operand. Such a static_cast is subject to the restriction that the explicit conversion does not cast away constness (5.2.11), and the following additional rules for specific cases:

A value of integral or enumeration type can be explicitly converted to an enumeration type. The value is unchanged if the original value is within the range of the enumeration values (7.2). Otherwise, the resulting enumeration value is unspecified.

An rvalue of type “pointer to cv I B,” where B is a class type, can be converted to an rvalue of type “pointer to cv2 D,” where D is a class derived (clause 10) from B, if a valid standard conversion from “pointer to D” to “pointer to B” exists (4.10), cv2 is the same cv-qualification as, or greater cv-qualification than, cv I, and B is not a virtual base class of D. The null pointer value (4.10) is converted to the null pointer value of the destination type. If the rvalue of type “pointer to cv I B” points to a B that is actually a subobject of an object of type D, the resulting pointer points to the enclosing object of type D. Otherwise, the result of the cast is undefined.

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An rvalue of type “pointer to member of D of type cv1 T” can be converted to an rvalue of type “pointer to member of B” of type cv2 T, where B is a base class (clause 10) of D, if a valid standard conversion from “pointer to member of B of type T” to “pointer to member of D of type T” exists (4.11), and cv2 is the same cv-qualification as, or greater cv-qualification than, cv1. The null member pointer value (4.11) is converted to the null member pointer value of the destination type. If class B contains the original member, or is a base or derived class of the class containing the original member, the resulting pointer to member points to the original member. Otherwise, the result of the cast is undefined. [Note: although class B need not contain the original member, the dynamic type of the object on which the pointer to member is dereferenced must contain the original member; see 5.5. — end note]

An rvalue of type “pointer to cv1 void” can be converted to an rvalue of type “pointer to cv2 T,” where T is an object type and cv2 is the same cv-qualification as, or greater cv-qualification than, cv1. The null pointer value is converted to the null pointer value of the destination type. A value of type pointer to object converted to “pointer to cv void” and back, possibly with different cv-qualification, shall have its original value. [Example:

```cpp
t* p1 = new T;
const T* p2 = static_cast<const T*>(static_cast<void*>(p1));
bool b = p1 == p2;  // b will have the value true.
```

— end example ]

5.2.10 Reinterpret cast

The result of the expression reinterpret_cast<T>(v) is the result of converting the expression v to type T. If T is a reference type, the result is an lvalue; otherwise, the result is an rvalue and the lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are performed on the the expression v. Types shall not be defined in a reinterpret_cast. Conversions that can be performed explicitly using reinterpret_cast are listed below. No other conversion can be performed explicitly using reinterpret_cast.

The reinterpret_cast operator shall not cast away constness. [Note: see 5.2.11 for the definition of “casting away constness”. Subject to the restrictions in this section, an expression may be cast to its own type using a reinterpret_cast operator. — end note]

The mapping performed by reinterpret_cast is implementation-defined. [Note: it might, or might not, produce a representation different from the original value. — end note]

A pointer can be explicitly converted to any integral type large enough to hold it. The mapping function is implementation-defined. [Note: it is intended to be unsurprising to those who know the addressing structure of the underlying machine. — end note]

A value of integral type or enumeration type can be explicitly converted to a pointer. A pointer converted to an integer of sufficient size (if any such exists on the implementation) and back to the same pointer type will have its original value; mappings between pointers and integers are otherwise implementation-defined.

A pointer to a function can be explicitly converted to a pointer to a function of a different type. The effect of calling a function through a pointer to a function type (8.3.5) that is not the same as the type used in the definition of the function is undefined. Except that converting an rvalue of type “pointer to T1" to the type “pointer to T2” (where T1 and T2 are function types) and back to its original type yields the original pointer value, the result of such a pointer conversion is unspecified. [Note: see also 4.10 for more details of pointer conversions. — end note]

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69) removed footnote
5.2 Postfix expressions

A pointer to an object can be explicitly converted to a pointer to an object of different type.\(^{70}\) Except that converting an rvalue of type “pointer to T1” to the type “pointer to T2” (where T1 and T2 are object types and where the alignment requirements of T2 are no stricter than those of T1) and back to its original type yields the original pointer value, the result of such a pointer conversion is unspecified.

Converting a pointer to a function into a pointer to an object type or vice versa is conditionally-supported. The meaning of such a conversion is implementation defined, except that if an implementation supports conversions in both directions, converting an rvalue of one type to the other type and back, possibly with different cv-qualification, shall yield the original pointer value.

The null pointer value (4.10) is converted to the null pointer value of the destination type. [Note: A null pointer constant, which has integral type, is not necessarily converted to a null pointer value. — end note ]

An rvalue of type “pointer to member of X of type T1” can be explicitly converted to an rvalue of type “pointer to member of Y of type T2” if T1 and T2 are both function types or both object types.\(^{71}\) The null member pointer value (4.11) is converted to the null member pointer value of the destination type. The result of this conversion is unspecified, except in the following cases:

- converting an rvalue of type “pointer to member function” to a different pointer to member function type and back to its original type yields the original pointer to member value.
- converting an rvalue of type “pointer to data member of X of type T1” to the type “pointer to data member of Y of type T2” (where the alignment requirements of T2 are no stricter than those of T1) and back to its original type yields the original pointer to member value.

An lvalue expression of type T1 can be cast to the type “reference to T2” if an expression of type “pointer to T1” can be explicitly converted to the type “pointer to T2” using a reinterpret_cast. That is, a reference cast reinterpret_cast<T&>(x) has the same effect as the conversion *reinterpret_cast<T*>(x) with the built-in & and * operators. The result is an lvalue that refers to the same object as the source lvalue, but with a different type. No temporary is created, no copy is made, and constructors (12.1) or conversion functions (12.3) are not called.\(^{72}\)

5.2.11 Const cast

The result of the expression const_cast<T>(v) is of type T. If T is a reference type, the result is an lvalue; otherwise, the result is an rvalue and, the lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are performed on the expression v. Types shall not be defined in a const_cast. Conversions that can be performed explicitly using const_cast are listed below. No other conversion shall be performed explicitly using const_cast.

[Note: Subject to the restrictions in this section, an expression may be cast to its own type using a const_cast operator. — end note ]

For two pointer types T1 and T2 where

\[ T1 \text{ is } cv_{1,0} \text{ pointer to } cv_{1,1} \text{ pointer to } \cdots \text{ } cv_{1,n-1} \text{ pointer to } cv_{1,n} \text{ } T \]

\(^{70}\) The types may have different cv-qualifiers, subject to the overall restriction that a reinterpret_cast cannot cast away constness.

\(^{71}\) T1 and T2 may have different cv-qualifiers, subject to the overall restriction that a reinterpret_cast cannot cast away constness.

\(^{72}\) This is sometimes referred to as a type pun.
where T is any object type or the void type and where cv_{1,k} and cv_{2,k} may be different cv-qualifications, an rvalue of type T1 may be explicitly converted to the type T2 using a const_cast. The result of a pointer const_cast refers to the original object.

4 An lvalue of type T1 can be explicitly converted to an lvalue of type T2 using the cast const_cast<T2&> (where T1 and T2 are object types) if a pointer to T1 can be explicitly converted to the type pointer to T2 using a const_cast. The result of a reference const_cast refers to the original object.

5 For a const_cast involving pointers to data members, multi-level pointers to data members and multi-level mixed pointers and pointers to data members (4.4), the rules for const_cast are the same as those used for pointers; the “member” aspect of a pointer to member is ignored when determining where the cv-qualifiers are added or removed by the const_cast. The result of a pointer to data member const_cast refers to the same member as the original (uncast) pointer to data member.

6 A null pointer value (4.10) is converted to the null pointer value of the destination type. The null member pointer value (4.11) is converted to the null member pointer value of the destination type.

7 [Note: Depending on the type of the object, a write operation through the pointer, lvalue or pointer to data member resulting from a const_cast that casts away a const-qualifier\(^73\) may produce undefined behavior (7.1.5.1). — end note]

8 The following rules define the process known as casting away constness. In these rules T\(n\) and X\(n\) represent types. For two pointer types:

\[ \begin{align*}
X1 & = T1cv_{1,1} \star \cdots \star cv_{1,N} \star \text{ where } T1 \text{ is not a pointer type} \\
X2 & = T2cv_{2,1} \star \cdots \star cv_{2,M} \star \text{ where } T2 \text{ is not a pointer type} \\
K & = \min(N, M)
\end{align*} \]

casting from X1 to X2 casts away constness if, for a non-pointer type T there does not exist an implicit conversion (clause 4) from:

\[ \begin{align*}
Tcv_{1,(N-K+1)} \star \cdots \star cv_{1,N} \star
\end{align*} \]

to

\[ \begin{align*}
Tcv_{2,(M-K+1)} \star \cdots \star cv_{2,M} \star
\end{align*} \]

9 Casting from an lvalue of type T1 to an lvalue of type T2 using a reference cast casts away constness if a cast from an rvalue of type “pointer to T1” to the type “pointer to T2” casts away constness.

10 Casting from an rvalue of type “pointer to data member of X of type T1” to the type “pointer to data member of Y of type T2” casts away constness if a cast from an rvalue of type “pointer to T1” to the type “pointer to T2” casts away constness.

11 For multi-level pointer to members and multi-level mixed pointers and pointer to members (4.4), the “member” aspect of a pointer to member level is ignored when determining if a const cv-qualifier has been cast away.

12 [Note: some conversions which involve only changes in cv-qualification cannot be done using const_cast. For instance, conversions between pointers to functions are not covered because such conversions lead to values whose use

\(^73\) const_cast is not limited to conversions that cast away a const-qualifier.
causes undefined behavior. For the same reasons, conversions between pointers to member functions, and in particular, the conversion from a pointer to a const member function to a pointer to a non-const member function, are not covered.

--- end note ---

### 5.3 Unary expressions

Expressions with unary operators group right-to-left.

```plaintext
unary-expression:
  postfix-expression
  ++ cast-expression
  -- cast-expression
  unary-operator cast-expression
  sizeof unary-expression
  sizeof ( type-id )
  new-expression
  delete-expression
```

**unary-operator:** one of
- `*` & `+` - `!` `∼`

#### 5.3.1 Unary operators

1. The unary `*` operator performs *indirection*: the expression to which it is applied shall be a pointer to an object type, or a pointer to a function type and the result is an lvalue referring to the object or function to which the expression points. If the type of the expression is “pointer to T,” the type of the result is “T.” [*Note: a pointer to an incomplete type (other than cv void) can be dereferenced. The lvalue thus obtained can be used in limited ways (to initialize a reference, for example); this lvalue must not be converted to an rvalue, see 4.1. — end note*]

2. The result of the unary `&` operator is a pointer to its operand. The operand shall be an lvalue or a qualified-id. In the first case, if the type of the expression is “T,” the type of the result is “pointer to T.” In particular, the address of an object of type “cv T” is “pointer to cv T,” with the same cv-qualifiers. For a qualified-id, if the member is a static member of type “T,” the type of the result is plain “pointer to T.” If the member is a non-static member of class C of type T, the type of the result is “pointer to member of class C of type T.” [*Example:*

   ```c
   struct A { int i; };  
   struct B : A { };  
   ... &B::i ...  // has type int A::*
   ```

   [*Note: a pointer to member formed from a mutable non-static data member (7.1.1) does not reflect the mutable specifier associated with the non-static data member. — end note*]

3. A pointer to member is only formed when an explicit `&` is used and its operand is a qualified-id not enclosed in parentheses. [*Note: that is, the expression &qualified-id, where the qualified-id is enclosed in parentheses, does not form an expression of type “pointer to member.” Neither does qualified-id, because there is no implicit conversion from a qualified-id for a non-static member function to the type “pointer to member function” as there is from an lvalue of function type to the type “pointer to function” (4.3). Nor is &unqualified-id a pointer to member, even within the scope of the unqualified-id’s class. — end note*]

4. The address of an object of incomplete type can be taken, but if the complete type of that object is a class type that declares operator&() as a member function, then the behavior is undefined (and no diagnostic is required).
operand of & shall not be a bit-field.

The address of an overloaded function (clause 13) can be taken only in a context that uniquely determines which version of the overloaded function is referred to (see 13.4). [Note: since the context might determine whether the operand is a static or non-static member function, the context can also affect whether the expression has type “pointer to function” or “pointer to member function.” — end note]

The operand of the unary + operator shall have arithmetic, enumeration, or pointer type and the result is the value of the argument. Integral promotion is performed on integral or enumeration operands. The type of the result is the type of the promoted operand.

The operand of the unary − operator shall have arithmetic or enumeration type and the result is the negation of its operand. Integral promotion is performed on integral or enumeration operands. The negative of an unsigned quantity is computed by subtracting its value from $2^n$, where $n$ is the number of bits in the promoted operand. The type of the result is the type of the promoted operand.

The operand of the logical negation operator ! is implicitly converted to bool (clause 4); its value is true if the converted operand is false and false otherwise. The type of the result is bool.

The operand of ~ shall have integral or enumeration type; the result is the one’s complement of its operand. Integral promotions are performed. The type of the result is the type of the promoted operand. There is an ambiguity in the unary-expression ~X(), where X is a class-name. The ambiguity is resolved in favor of treating ~ as a unary complement rather than treating ~X as referring to a destructor.

### 5.3.2 Increment and decrement

The operand of prefix ++ is modified by adding 1, or set to true if it is bool (this use is deprecated). The operand shall be a modifiable lvalue. The type of the operand shall be an arithmetic type or a pointer to a completely-defined object type. The result is the updated operand; it is an lvalue, and it is a bit-field if the operand is a bit-field. If x is not of type bool, the expression ++x is equivalent to x+=1 [Note: see the discussions of addition (5.7) and assignment operators (5.17) for information on conversions. — end note]

The operand of prefix – is modified by subtracting 1. The operand shall not be of type bool. The requirements on the operand of prefix – and the properties of its result are otherwise the same as those of prefix ++. [Note: For postfix increment and decrement, see 5.2.6. — end note]

### 5.3.3 Sizeof

The sizeof operator yields the number of bytes in the object representation of its operand. The operand is either an expression, which is not evaluated, or a parenthesized type-id. The sizeof operator shall not be applied to an expression that has function or incomplete type, or to an enumeration type before all its enumerators have been declared, or to the parenthesized name of such types, or to an lvalue that designates a bit-field. sizeof(char), sizeof(signed char) and sizeof(unsigned char) are 1. The result of sizeof applied to any other fundamental type (3.9.1) is implementation-defined. [Note: in particular, sizeof(bool) and sizeof(wchar_t) are implementation-defined.74] — end note] [Note: See 1.7 for the definition of byte and 3.9 for the definition of object representation. — end note]

When applied to a reference or a reference type, the result is the size of the referenced type. When applied to a class, the result is the number of bytes in an object of that class including any padding required for placing objects of that type in an array. The size of a most derived class shall be greater than zero (1.8). The result of applying sizeof to a base

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74) sizeof(bool) is not required to be 1.
5.3 Unary expressions

Expressions 90

class subobject is the size of the base class type. When applied to an array, the result is the total number of bytes in the array. This implies that the size of an array of \( n \) elements is \( n \) times the size of an element.

3 The \texttt{sizeof} operator can be applied to a pointer to a function, but shall not be applied directly to a function.

4 The \texttt{lvalue-to-rvalue (4.1)}, \texttt{array-to-pointer (4.2)}, and \texttt{function-to-pointer (4.3)} standard conversions are not applied to the operand of \texttt{sizeof}.

5 Types shall not be defined in a \texttt{sizeof} expression.

6 The result is a constant of type \texttt{std::size_t}. [Note: \texttt{std::size_t} is defined in the standard header \texttt{<cstdlib>} (18.1). — end note]

5.3.4 New

The \texttt{new-expression} attempts to create an object of the \texttt{type-id (8.1)} or \texttt{new-type-id} to which it is applied. The type of that object is the \textit{allocated type}. This type shall be a complete object type, but not an abstract class type or array thereof (1.8, 3.9, 10.4). [Note: because references are not objects, references cannot be created by \texttt{new-expression}s. — end note]

[Note: the \texttt{type-id} may be a \texttt{cv}-qualified type, in which case the object created by the \texttt{new-expression} has a \texttt{cv}-qualified type. — end note]

\begin{verbatim}
new-expression:
  ::opt new new-placement\_opt new-type-id new-initializer\_opt
  ::opt new new-placement\_opt (type-id) new-initializer\_opt
new-placement:
  (expression-list)
new-type-id:
  type-specifier-seq new-declarator\_opt
new-declarator:
  ptr-operator new-declarator\_opt
  direct-new-declarator
direct-new-declarator:
  [expression]
  direct-new-declarator [constant-expression]
new-initializer:
  (expression-list)\_opt
\end{verbatim}

Entities created by a \texttt{new-expression} have dynamic storage duration (3.7.3). [Note: the lifetime of such an entity is not necessarily restricted to the scope in which it is created. — end note] If the entity is a non-array object, the \texttt{new-expression} returns a pointer to the object created. If it is an array, the \texttt{new-expression} returns a pointer to the initial element of the array.

2 If the \texttt{auto} \texttt{type-specifier} appears in the \texttt{type-specifier-seq} of a \texttt{new-type-id} or \texttt{type-id} of a \texttt{new-expression}, the \texttt{type-specifier-seq} shall contain no other \texttt{type-specifiers} except \texttt{cv}-qualifiers, and the \texttt{new-expression} shall contain a \texttt{new-initializer} of the form

\begin{verbatim}
  (assignment-expression)
\end{verbatim}

\footnote{The actual size of a base class subobject may be less than the result of applying \texttt{sizeof} to the subobject, due to virtual base classes and less strict padding requirements on base class subobjects.}

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The allocated type is deduced from the new-initializer as follows: Let (e) be the new-initializer and T be the new-type-id or type-id of the new-expression, then the allocated type is the type deduced for the variable x in the invented declaration (7.1.5.4):

\[ T \ x = e; \]

**Example:**

```c
new auto(1); // allocated type is int
auto x = new auto('a'); // allocated type is char, x is of type char*
```

— end example —

3 The new-type-id in a new-expression is the longest possible sequence of new-declarators. [Note: this prevents ambiguities between declarator operators &, *, [], and their expression counterparts. — end note] [Example:

```c
new int * i; // syntax error: parsed as (new int*) i
// not as (new int)*i
```

The * is the pointer declarator and not the multiplication operator. — end example —

4 [Note: parentheses in a new-type-id of a new-expression can have surprising effects. [Example:

```c
new int(*[10])(); // error
```

is ill-formed because the binding is

```c
(new int) (*[10])(); // error
```

Instead, the explicitly parenthesized version of the new operator can be used to create objects of compound types (3.9.2):

```c
new (int (*[10])());
```

allocates an array of 10 pointers to functions (taking no argument and returning int. — end example] — end note —

5 The type-specifier-seq shall not contain class declarations, or enumeration declarations.

6 When the allocated object is an array (that is, the direct-new-declarator syntax is used or the new-type-id or type-id denotes an array type), the new-expression yields a pointer to the initial element (if any) of the array. [Note: both new int and new int[10] have type int* and the type of new int[i][10] is int (*)[10] — end note]

7 Every constant-expression in a direct-new-declarator shall be an integral constant expression (5.19) and evaluate to a strictly positive value. The expression in a direct-new-declarator shall be of integral type, enumeration type, or a class type for which a single conversion function to integral or enumeration type exists (12.3). If the expression is of class type, the expression is converted by calling that conversion function, and the result of the conversion is used in place of the original expression. If the value of the expression is negative, the behavior is undefined. [Example: if n is a variable of type int, then new float[n][5] is well-formed (because n is the expression of a direct-new-declarator), but new float[5][n] is ill-formed (because n is not a constant-expression). If n is negative, the effect of new float[n][5] is undefined. — end example]

8 When the value of the expression in a direct-new-declarator is zero, the allocation function is called to allocate an array with no elements.
5.3 Unary expressions

A new-expression obtains storage for the object by calling an allocation function (3.7.3.1). If the new-expression terminates by throwing an exception, it may release storage by calling a deallocation function (3.7.3.2). If the allocated type is a non-array type, the allocation function’s name is operator new and the deallocation function’s name is operator delete. If the allocated type is an array type, the allocation function’s name is operator new[] and the deallocation function’s name is operator delete[]. [Note: an implementation shall provide default definitions for the global allocation functions (3.7.3, 18.5.1.1, 18.5.1.2). A C++ program can provide alternative definitions of these functions (17.4.3.4) and/or class-specific versions (12.5). — end note]

If the new-expression begins with a unary :: operator, the allocation function’s name is looked up in the global scope. Otherwise, if the allocated type is a class type T or array thereof, the allocation function’s name is looked up in the scope of T If this lookup fails to find the name, or if the allocated type is not a class type, the allocation function’s name is looked up in the global scope.

A new-expression passes the amount of space requested to the allocation function as the first argument of type std::size_t. That argument shall be no less than the size of the object being created; it may be greater than the size of the object being created only if the object is an array. For arrays of char and unsigned char, the difference between the result of the new-expression and the address returned by the allocation function shall be an integral multiple of the most stringent alignment requirement (3.9) of any object type whose size is no greater than the size of the array being created. [Note: Because allocation functions are assumed to return pointers to storage that is appropriately aligned for objects of any type, this constraint on array allocation overhead permits the common idiom of allocating character arrays into which objects of other types will later be placed. — end note]

The new-placement syntax is used to supply additional arguments to an allocation function. If used, overload resolution is performed on a function call created by assembling an argument list consisting of the amount of space requested (the first argument) and the expressions in the new-placement part of the new-expression (the second and succeeding arguments). The first of these arguments has type std::size_t and the remaining arguments have the corresponding types of the expressions in the new-placement.

[Example:

- new T results in a call of operator new(sizeof(T)),
- new(2,f) T results in a call of operator new(sizeof(T),2,f),
- new T[5] results in a call of operator new[](sizeof(T)*5+x), and
- new(2,f) T[5] results in a call of operator new[](sizeof(T)*5+y,2,f).

Here, x and y are non-negative unspecified values representing array allocation overhead: the result of the new-expression will be offset by this amount from the value returned by operator new[]. This overhead may be applied in all array new-expressions, including those referencing the library function operator new[](std::size_t, void*) and other placement allocation functions. The amount of overhead may vary from one invocation of new to another. — end example]

[Note: unless an allocation function is declared with an empty exception-specification (15.4), throw(), it indicates failure to allocate storage by throwing a bad_alloc exception (clause 15, 18.5.2.1); it returns a non-null pointer otherwise. If the allocation function is declared with an empty exception-specification, throw(), it returns null to indicate failure to allocate storage and a non-null pointer otherwise. —end note] If the allocation function returns null, initialization shall not be done, the deallocation function shall not be called, and the value of the new-expression shall be null.

[Note: when the allocation function returns a value other than null, it must be a pointer to a block of storage in which
space for the object has been reserved. The block of storage is assumed to be appropriately aligned and of the requested size. The address of the created object will not necessarily be the same as that of the block if the object is an array.
— end note ]

16 A new-expression that creates an object of type $T$ initializes that object as follows:

— If the new-initializer is omitted:

— If $T$ is a (possibly cv-qualified) non-POD class type (or array thereof), the object is default-initialized (8.5). If $T$ is a const-qualified type, the underlying class type shall have a user-declared default constructor.

— Otherwise, the object created has indeterminate value. If $T$ is a const-qualified type, or a (possibly cv-qualified) POD class type (or array thereof) containing (directly or indirectly) a member of const-qualified type, the program is ill-formed;

— If the new-initializer is of the form $()$, the item is value-initialized (8.5);

— If the new-initializer is of the form (expression-list) and $T$ is a class type, the appropriate constructor is called, using expression-list as the arguments (8.5);

— If the new-initializer is of the form (expression-list) and $T$ is an arithmetic, enumeration, pointer, or pointer-to-member type and expression-list comprises exactly one expression, then the object is initialized to the (possibly converted) value of the expression (8.5);

— Otherwise the new-expression is ill-formed.

17 If the new-expression creates an object or an array of objects of class type, access and ambiguity control are done for the allocation function, the deallocation function (12.5), and the constructor (12.1). If the new expression creates an array of objects of class type, access and ambiguity control are done for the destructor (12.4).

18 If any part of the object initialization described above terminates by throwing an exception and a suitable deallocation function can be found, the deallocation function is called to free the memory in which the object was being constructed, after which the exception continues to propagate in the context of the new-expression. If no unambiguous matching deallocation function can be found, propagating the exception does not cause the object’s memory to be freed. [ Note: This is appropriate when the called allocation function does not allocate memory; otherwise, it is likely to result in a memory leak. — end note ]

19 If the new-expression begins with a unary :: operator, the deallocation function’s name is looked up in the global scope. Otherwise, if the allocated type is a class type $T$ or an array thereof, the deallocation function’s name is looked up in the scope of $T$. If this lookup fails to find the name, or if the allocated type is not a class type or array thereof, the deallocation function’s name is looked up in the global scope.

20 A declaration of a placement deallocation function matches the declaration of a placement allocation function if it has the same number of parameters and, after parameter transformations (8.3.5), all parameter types except the first are identical. Any non-placement deallocation function matches a non-placement allocation function. If the lookup finds a single matching deallocation function, that function will be called; otherwise, no deallocation function will be called. If the lookup finds the two-parameter form of a usual deallocation function (3.7.3.2) and that function, considered as a placement deallocation function, would have been selected as a match for the allocation function, the program is ill-formed. [ Example: 

This may include evaluating a new-initializer and/or calling a constructor.

Draft
5.3 Unary expressions

struct S {
    // Placement allocation function:
    static void* operator new(std::size_t, std::size_t);

    // Usual (non-placement) deallocation function:
    static void operator delete(void*, std::size_t);
};

S* p = new (0) S;  // ill-formed: non-placement deallocation function matches placement allocation function

— end example ]

21 If a new-expression calls a deallocation function, it passes the value returned from the allocation function call as the first argument of type void*. If a placement deallocation function is called, it is passed the same additional arguments as were passed to the placement allocation function, that is, the same arguments as those specified with the new-placement syntax. If the implementation is allowed to make a copy of any argument as part of the call to the allocation function, it is allowed to make a copy (of the same original value) as part of the call to the deallocation function or to reuse the copy made as part of the call to the allocation function. If the copy is elided in one place, it need not be elided in the other.

22 Whether the allocation function is called before evaluating the constructor arguments or after evaluating the constructor arguments but before entering the constructor is unspecified. It is also unspecified whether the arguments to a constructor are evaluated if the allocation function returns the null pointer or exits using an exception.

5.3.5 Delete [expr.delete]

1 The delete-expression operator destroys a most derived object (1.8) or array created by a new-expression.

    delete-expression:
        ::opt delete cast-expression
        ::opt delete [ ] cast-expression

The first alternative is for non-array objects, and the second is for arrays. The operand shall have a pointer type, or a class type having a single conversion function (12.3.2) to a pointer type. The result has type void.

2 If the operand has a class type, the operand is converted to a pointer type by calling the above-mentioned conversion function, and the converted operand is used in place of the original operand for the remainder of this section. In either alternative, the value of the operand of delete may be a null pointer value. If it is not a null pointer value, in the first alternative (delete object), the value of the operand of delete shall be a pointer to a non-array object or a pointer to a subobject (1.8) representing a base class of such an object (clause 10). If not, the behavior is undefined. In the second alternative (delete array), the value of the operand of delete shall be the pointer value which resulted from a previous array new-expression.77) If not, the behavior is undefined. [ Note: this means that the syntax of the delete-expression must match the type of the object allocated by new, not the syntax of the new-expression. — end note ] [ Note: a pointer to a const type can be the operand of a delete-expression; it is not necessary to cast away the constness (5.2.11) of the pointer expression before it is used as the operand of the delete-expression. — end note ]

77) For non-zero-length arrays, this is the same as a pointer to the first element of the array created by that new-expression. Zero-length arrays do not have a first element.
In the first alternative (`delete object`), if the static type of the operand is different from its dynamic type, the static type shall be a base class of the operand’s dynamic type and the static type shall have a virtual destructor or the behavior is undefined. In the second alternative (`delete array`) if the dynamic type of the object to be deleted differs from its static type, the behavior is undefined.78)

The `cast-expression` in a `delete-expression` shall be evaluated exactly once.

If the object being deleted has incomplete class type at the point of deletion and the complete class has a non-trivial destructor or a deallocation function, the behavior is undefined.

If the value of the operand of the `delete-expression` is not a null pointer value, the `delete-expression` will invoke the destructor (if any) for the object or the elements of the array being deleted. In the case of an array, the elements will be destroyed in order of decreasing address (that is, in reverse order of the completion of their constructor; see 12.6.2).

If the value of the operand of the `delete-expression` is not a null pointer value, the `delete-expression` will call a deallocation function (3.7.3.2). Otherwise, it is unspecified whether the deallocation function will be called. [Note: The deallocation function is called regardless of whether the destructor for the object or some element of the array throws an exception. — end note]

[Note: An implementation provides default definitions of the global deallocation functions `operator delete()` for non-arrays (18.5.1.1) and `operator delete[]()` for arrays (18.5.1.2). A C++ program can provide alternative definitions of these functions (17.4.3.4), and/or class-specific versions (12.5). — end note] When the keyword `delete` in a `delete-expression` is preceded by the unary `::` operator, the global deallocation function is used to deallocate the storage.

Access and ambiguity control are done for both the deallocation function and the destructor (12.4, 12.5).

5.4 Explicit type conversion (cast notation) [expr.cast]

The result of the expression `(T)` `cast-expression` is of type T. The result is an lvalue if T is a reference type, otherwise the result is an rvalue. [Note: if T is a non-class type that is cv-qualified, the cv-qualifiers are ignored when determining the type of the resulting rvalue; see 3.10. — end note]

An explicit type conversion can be expressed using functional notation (5.2.3), a type conversion operator (dynamic_cast, static_cast, reinterpret_cast, const_cast), or the cast notation.

```
cast-expression:
  unary-expression
  ( type-id ) cast-expression
```

Types shall not be defined in casts.

Any type conversion not mentioned below and not explicitly defined by the user (12.3) is ill-formed.

The conversions performed by

- a `const_cast` (5.2.11),
- a `static_cast` (5.2.9),
- a `static_cast` followed by a `const_cast`,
- a `reinterpret_cast` (5.2.10), or
- a `reinterpret_cast` followed by a `const_cast`,

78) This implies that an object cannot be deleted using a pointer of type `void*` because there are no objects of type `void`. Draft
5.5 Pointer-to-member operators

Expressions

5.5 Pointer-to-member operators

The pointer-to-member operators \( \to \ast \) and \( \ast \) group left-to-right.

\[
\text{cast-expression} \\
\text{pm-expression} \to \ast \text{cast-expression} \\
\text{pm-expression} \ast \text{cast-expression}
\]

The binary operator \( \ast \) binds its second operand, which shall be of type “pointer to member of \( T \)” (where \( T \) is a completely-defined class type) to its first operand, which shall be of class \( T \) or of a class of which \( T \) is an unambiguous and accessible base class. The result is an object or a function of the type specified by the second operand.

The binary operator \( \to \ast \) binds its second operand, which shall be of type “pointer to member of \( T \)” (where \( T \) is a completely-defined class type) to its first operand, which shall be of type “pointer to \( T \)” or “pointer to a class of which \( T \) is an unambiguous and accessible base class.” The result is an object or a function of the type specified by the second operand.

If the dynamic type of the object does not contain the member to which the pointer refers, the behavior is undefined.
The restrictions on cv-qualification, and the manner in which the cv-qualifiers of the operands are combined to produce the cv-qualifiers of the result, are the same as the rules for E1.E2 given in 5.2.5. [ Note: it is not possible to use a pointer to member that refers to a mutable member to modify a const class object. For example,

```c
struct S {
    S() : i(0) { }
    mutable int i;
};
void f()
{
    const S cs;
    int S::* pm = &S::i;        // pm refers to mutable member S::i
    cs.*pm = 88;                // ill-formed: cs is a const object
}
```
— end note ]

If the result of .* or ->* is a function, then that result can be used only as the operand for the function call operator (). [ Example:

```c
(ptr_to_obj->*ptr_to_mfct)(10);
```

calls the member function denoted by ptr_to_mfct for the object pointed to by ptr_to_obj. — end example ] The result of a .* expression is an lvalue only if its first operand is an lvalue and its second operand is a pointer to data member. The result of an ->* expression is an lvalue only if its second operand is a pointer to data member. If the second operand is the null pointer to member value (4.11), the behavior is undefined.

### 5.6 Multiplicative operators

The multiplicative operators *, /, and % group left-to-right.

```
multiplicative-expression:
    pm-expression
    multiplicative-expression * pm-expression
    multiplicative-expression / pm-expression
    multiplicative-expression % pm-expression
```

The operands of * and / shall have arithmetic or enumeration type; the operands of % shall have integral or enumeration type. The usual arithmetic conversions are performed on the operands and determine the type of the result.

3 The binary * operator indicates multiplication.

4 The binary / operator yields the quotient, and the binary % operator yields the remainder from the division of the first expression by the second. If the second operand of / or % is zero the behavior is undefined; otherwise \((a/b)*b + a\%b\) is equal to \(a\). If both operands are nonnegative then the remainder is nonnegative; if not, the sign of the remainder is implementation-defined\(^{(79)}\).

### 5.7 Additive operators

The additive operators + and - group left-to-right. The usual arithmetic conversions are performed for operands of

\(^{(79)}\) According to work underway toward the revision of ISO C, the preferred algorithm for integer division follows the rules defined in the ISO Fortran standard, ISO/IEC 1539:1991, in which the quotient is always rounded toward zero.

Draft
5.7 Additive operators

Expressions 98

Additive operators Expressions

additive-expression
multiplicative-expression
additive-expression " multiplicative-expression
additive-expression " multiplicative-expression

For addition, either both operands shall have arithmetic or enumeration type, or one operand shall be a pointer to a completely defined object type and the other shall have integral or enumeration type.

For subtraction, one of the following shall hold:

— both operands have arithmetic or enumeration type; or
— both operands are pointers to cv-qualified or cv-unqualified versions of the same completely defined object type; or
— the left operand is a pointer to a completely defined object type and the right operand has integral or enumeration type.

The result of the binary + operator is the sum of the operands. The result of the binary - operator is the difference resulting from the subtraction of the second operand from the first.

For the purposes of these operators, a pointer to a nonarray object behaves the same as a pointer to the first element of an array of length one with the type of the object as its element type.

When an expression that has integral type is added to or subtracted from a pointer, the result has the type of the pointer operand. If the pointer operand points to an element of an array object, and the array is large enough, the result points to an element offset from the original element such that the difference of the subscripts of the resulting and original array elements equals the integral expression. In other words, if the expression P points to the i-th element of an array object, the expressions (P)+n (equivalently, N+(P)) and (P)-n (where N has the value n) point to, respectively, the i+n-th and i−n-th elements of the array object, provided they exist. Moreover, if the expression P points to the last element of an array object, the expression (P)+1 points one past the last element of the array object, and if the expression Q points one past the last element of an array object, the expression (Q)-1 points to the last element of the array object. If both the pointer operand and the result point to elements of the same array object, or one past the last element of the array object, the evaluation shall not produce an overflow; otherwise, the behavior is undefined.

When two pointers to elements of the same array object are subtracted, the result is the difference of the subscripts of the two array elements. The type of the result is an implementation-defined signed integral type; this type shall be the same type that is defined as std::ptrdiff_t in the <cassert> header (18.1). As with any other arithmetic overflow, if the result does not fit in the space provided, the behavior is undefined. In other words, if the expressions P and Q point to, respectively, the i-th and j-th elements of an array object, the expression (P)-(Q) has the value i−j provided the value fits in an object of type std::ptrdiff_t. Moreover, if the expression P points either to an element of an array object or one past the last element of an array object, and the expression Q points to the last element of the same array object, the expression ((Q)+1)-(P) has the same value as ((Q)-(P))+1 and as −((P)-((Q)+1)), and has the value zero if the expression P points one past the last element of the array object, even though the expression (Q)+1 does not point to an element of the array object. Unless both pointers point to elements of the same array object, or one past the last element of the array object, the behavior is undefined.\(^{80}\)

Another way to approach pointer arithmetic is first to convert the pointer(s) to character pointer(s): In this scheme the integral value of the expression added to or subtracted from the converted pointer is first multiplied by the size of the object originally pointed to, and the resulting pointer

Draft
If the value 0 is added to or subtracted from a pointer value, the result compares equal to the original pointer value.
If two pointers point to the same object or both point one past the end of the same array or both are null, and the two
pointers are subtracted, the result compares equal to the value 0 converted to the type `std::ptrdiff_t`.

### 5.8 Shift operators

The shift operators `<<` and `>>` group left-to-right.

```
shift-expression:
  additive-expression
  shift-expression << additive-expression
  shift-expression >> additive-expression
```

The operands shall be of integral or enumeration type and integral promotions are performed. The type of the result is
that of the promoted left operand. The behavior is undefined if the right operand is negative, or greater than or equal to
the length in bits of the promoted left operand.

The value of `E1 << E2` is `E1` (interpreted as a bit pattern) left-shifted `E2` bit positions; vacated bits are zero-filled. If `E1`
has an unsigned type, the value of the result is `E1` multiplied by the quantity 2 raised to the power `E2`, reduced modulo
`ULLONG_MAX+1` if `E1` has type unsigned long long int, `ULONG_MAX+1` if `E1` has type unsigned long int, `UINT_MAX+1` otherwise. [Note: the constants `ULLONG_MAX`, `ULONG_MAX`, and `UINT_MAX` are defined in the header `<climits>`. — end note]

The value of `E1 >> E2` is `E1` right-shifted `E2` bit positions. If `E1` has an unsigned type or if `E1` has a signed type and a
nonnegative value, the value of the result is the integral part of the quotient of `E1` divided by the quantity 2 raised to the
power `E2`. If `E1` has a signed type and a negative value, the resulting value is implementation-defined.

### 5.9 Relational operators

The relational operators group left-to-right. [Example: `a<b<c` means `(a<b)<c` and not `(a<b)&&b<c`). — end example]

```
relational-expression:
  shift-expression
  relational-expression < shift-expression
  relational-expression > shift-expression
  relational-expression <= shift-expression
  relational-expression >= shift-expression
```

The operands shall have arithmetic, enumeration or pointer type. The operators `<` (less than), `>` (greater than), `<=` (less
than or equal to), and `>=` (greater than or equal to) all yield `false` or `true`. The type of the result is `bool`.

The usual arithmetic conversions are performed on operands of arithmetic or enumeration type. Pointer conversions
(4.10) and qualification conversions (4.4) are performed on pointer operands (or on a pointer operand and a null pointer
constant) to bring them to their composite pointer type. If one operand is a null pointer constant, the composite pointer
type is the type of the other operand. Otherwise, if one of the operands has type “pointer to cv1 void,” then the other

is converted back to the original type. For pointer subtraction, the result of the difference between the character pointers is similarly divided by the size of the object originally pointed to.

When viewed in this way, an implementation need only provide one extra byte (which might overlap another object in the program) just after the end of the object in order to satisfy the “one past the last element” requirements.
5.10 Equality operators

Expressions

has type “pointer to cv2 T” and the composite pointer type is “pointer to cv12 void,” where cv12 is the union of cv1 and cv2. Otherwise, the composite pointer type is a pointer type similar (4.4) to the type of one of the operands, with a cv-qualification signature (4.4) that is the union of the cv-qualification signatures of the operand types. [Note: this implies that any pointer can be compared to a null pointer constant and that any object pointer can be compared to a pointer to (possibly cv-qualified) void. — end note] [Example:

```c
void *p;
const int *q;
int **pi;
const int *const *pci;
void ct()
{
    p <= q; // Both converted to const void* before comparison
    pi <= pci; // Both converted to const int *const * before comparison
}
```

— end example] Pointers to objects or functions of the same type (after pointer conversions) can be compared, with a result defined as follows:

— If two pointers p and q of the same type point to the same object or function, or both point one past the end of the same array, or are both null, then p<q and p>q both yield true and p<q and p>q both yield false.

— If two pointers p and q of the same type point to different objects that are not members of the same object or elements of the same array or to different functions, or if only one of them is null, the results of p<q, p>q, p<eq, and p>eq are unspecified.

— If two pointers point to non-static data members of the same object, or to subobjects or array elements of such members, recursively, the pointer to the later declared member compares greater provided the two members are not separated by an access-specifier label (11.1) and provided their class is not a union.

— If two pointers point to non-static data members of the same object separated by an access-specifier label (11.1) the result is unspecified.

— If two pointers point to data members of the same union object, they compare equal (after conversion to void*, if necessary). If two pointers point to elements of the same array or one beyond the end of the array, the pointer to the object with the higher subscript compares higher.

— Other pointer comparisons are unspecified.

5.10 Equality operators

equality-expression:
relational-expression
equality-expression == relational-expression
equality-expression != relational-expression

1 The == (equal to) and the != (not equal to) operators have the same semantic restrictions, conversions, and result type as the relational operators except for their lower precedence and truth-value result. [Note: a<b == c<d is true whenever a<b and c<d have the same truth-value. — end note] Pointers to objects or functions of the same type (after pointer
conversions) can be compared for equality. Two pointers of the same type compare equal if and only if they are both null, both point to the same function, or both represent the same address (3.9.2).

In addition, pointers to members can be compared, or a pointer to member and a null pointer constant. Pointer to member conversions (4.11) and qualification conversions (4.4) are performed to bring them to a common type. If one operand is a null pointer constant, the common type is the type of the other operand. Otherwise, the common type is a pointer to member type similar (4.4) to the type of one of the operands, with a cv-qualification signature (4.4) that is the union of the cv-qualification signatures of the operand types. [Note: this implies that any pointer to member can be compared to a null pointer constant. —end note] If both operands are null, they compare equal. Otherwise if only one is null, they compare unequal. Otherwise if either is a pointer to a virtual member function, the result is unspecified. Otherwise they compare equal if and only if they would refer to the same member of the same most derived object (1.8) or the same subobject if they were dereferenced with a hypothetical object of the associated class type. [Example:

```c
struct B {
    int f();
};
struct L : B {  };
struct R : B {  };
struct D : L, R {  };

int (B::*pb)() = &B::f;
int (L::*pl)() = pb;
int (R::*pr)() = pb;
int (D::*pdl)() = pl;
int (D::*pdr)() = pr;
bool x = (pdl == pdr);  //false
```

—end example]

5.11 Bitwise AND operator [expr.bit.and]

and-expression:
equality-expression
and-expression & equality-expression

The usual arithmetic conversions are performed; the result is the bitwise AND function of the operands. The operator applies only to integral or enumeration operands.

5.12 Bitwise exclusive OR operator [expr.xor]

exclusive-or-expression:
and-expression
exclusive-or-expression ^ and-expression

The usual arithmetic conversions are performed; the result is the bitwise exclusive OR function of the operands. The operator applies only to integral or enumeration operands.

5.13 Bitwise inclusive OR operator [expr.or]

inclusive-or-expression:
exclusive-or-expression
inclusive-or-expression | exclusive-or-expression

Draft
5.14 Logical AND operator

The usual arithmetic conversions are performed; the result is the bitwise inclusive OR function of its operands. The operator applies only to integral or enumeration operands.

5.14 Logical AND operator

\[
\text{logical-and-expression:}
\]\n
\[
\begin{align*}
\text{inclusive-or-expression} \\
\text{logical-and-expression} \&\& \text{inclusive-or-expression}
\end{align*}
\]

1 The \&\& operator groups left-to-right. The operands are both implicitly converted to type \text{bool} (clause 4). The result is \text{true} if both operands are \text{true} and \text{false} otherwise. Unlike \&, \&\& guarantees left-to-right evaluation: the second operand is not evaluated if the first operand is \text{false}.

2 The result is a \text{bool}. All side effects of the first expression except for destruction of temporaries (12.2) happen before the second expression is evaluated.

5.15 Logical OR operator

\[
\text{logical-or-expression:}
\]\n
\[
\begin{align*}
\text{logical-and-expression} \\
\text{logical-or-expression} || \text{logical-and-expression}
\end{align*}
\]

1 The || operator groups left-to-right. The operands are both implicitly converted to \text{bool} (clause 4). It returns \text{true} if either of its operands is \text{true}, and \text{false} otherwise. Unlike |, || guarantees left-to-right evaluation; moreover, the second operand is not evaluated if the first operand evaluates to \text{true}.

2 The result is a \text{bool}. All side effects of the first expression except for destruction of temporaries (12.2) happen before the second expression is evaluated.

5.16 Conditional operator

\[
\text{conditional-expression:}
\]\n
\[
\begin{align*}
\text{logical-or-expression} \\
\text{logical-or-expression} \text{ ? expression : assignment-expression}
\end{align*}
\]

1 Conditional expressions group right-to-left. The first expression is implicitly converted to \text{bool} (clause 4). It is evaluated and if it is \text{true}, the result of the conditional expression is the value of the second expression, otherwise that of the third expression. All side effects of the first expression except for destruction of temporaries (12.2) happen before the second or third expression is evaluated. Only one of the second and third expressions is evaluated.

2 If either the second or the third operand has type (possibly cv-qualified) \text{void}, then the lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are performed on the second and third operands, and one of the following shall hold:

- The second or the third operand (but not both) is a \text{throw-expression} (15.1); the result is of the type of the other and is an rvalue.

- Both the second and the third operands have type \text{void} the result is of type \text{void} and is an rvalue. [\text{Note: this includes the case where both operands are throw-expressions. — end note}]  

3 Otherwise, if the second and third operand have different types, and either has (possibly cv-qualified) class type, an attempt is made to convert each of those operands to the type of the other. The process for determining whether an operand expression \text{E1} of type \text{T1} can be converted to match an operand expression \text{E2} of type \text{T2} is defined as follows:
If \( E_2 \) is an lvalue: \( E_1 \) can be converted to match \( E_2 \) if \( E_1 \) can be implicitly converted (clause 4) to the type “reference to \( T_2 \)”, subject to the constraint that in the conversion the reference must bind directly (8.5.3) to \( E_1 \).

If \( E_2 \) is an rvalue, or if the conversion above cannot be done:

- If \( E_1 \) and \( E_2 \) have class type, and the underlying class types are the same or one is a base class of the other: \( E_1 \) can be converted to match \( E_2 \) if the class of \( T_2 \) is the same type as, or a base class of, the class of \( T_1 \), and the cv-qualification of \( T_2 \) is the same cv-qualification as, or a greater cv-qualification than, the cv-qualification of \( T_1 \). If the conversion is applied, \( E_1 \) is changed to an rvalue of type \( T_2 \) by copy-initializing a temporary of type \( T_2 \) from \( E_1 \) and using that temporary as the converted operand.

- Otherwise (i.e., if \( E_1 \) or \( E_2 \) has a nonclass type, or if they both have class types but the underlying classes are not either the same or one a base class of the other): \( E_1 \) can be converted to match \( E_2 \) if \( E_1 \) can be implicitly converted to the type that expression \( E_2 \) would have if \( E_2 \) were converted to an rvalue (or the type it has, if \( E_2 \) is an rvalue).

Using this process, it is determined whether the second operand can be converted to match the third operand, and whether the third operand can be converted to match the second operand. If both can be converted, or one can be converted but the conversion is ambiguous, the program is ill-formed. If neither can be converted, the operands are left unchanged and further checking is performed as described below. If exactly one conversion is possible, that conversion is applied to the chosen operand and the converted operand is used in place of the original operand for the remainder of this section.

4 If the second and third operands are lvalues and have the same type, the result is of that type and is an lvalue and it is a bit-field if the second or the third operand is a bit-field, or if both are bit-fields.

5 Otherwise, the result is an rvalue. If the second and third operands do not have the same type, and either has (possibly cv-qualified) class type, overload resolution is used to determine the conversions (if any) to be applied to the operands (13.3.1.2, 13.6). If the overload resolution fails, the program is ill-formed. Otherwise, the conversions thus determined are applied, and the converted operands are used in place of the original operands for the remainder of this section.

6 Lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are performed on the second and third operands. After those conversions, one of the following shall hold:

- The second and third operands have the same type; the result is of that type. If the operands have class type, the result is an rvalue temporary of the result type, which is copy-initialized from either the second operand or the third operand depending on the value of the first operand.

- The second and third operands have arithmetic or enumeration type; the usual arithmetic conversions are performed to bring them to a common type, and the result is of that type.

- The second and third operands have pointer type, or one has pointer type and the other is a null pointer constant; pointer conversions (4.10) and qualification conversions (4.4) are performed to bring them to their composite pointer type (5.9). The result is of the composite pointer type.

- The second and third operands have pointer to member type, or one has pointer to member type and the other is a null pointer constant; pointer to member conversions (4.11) and qualification conversions (4.4) are performed to bring them to a common type, whose cv-qualification shall match the cv-qualification of either the second or the third operand. The result is of the common type.
5.17 Assignment and compound assignment operators

The assignment operator (\(=\)) and the compound assignment operators all group right-to-left. All require a modifiable lvalue as their left operand and return an lvalue with the type and value of the left operand after the assignment has taken place. The result in all cases is a bit-field if the left operand is a bit-field.

```
assignment-expression:
  conditional-expression
  logical-or-expression assignment-operator assignment-expression
  throw-expression

assignment-operator: one of
  = *= /= %= += -= >>= <<= &= ^= |=
```

In simple assignment (\(=\)), the value of the expression replaces that of the object referred to by the left operand.

3 If the left operand is not of class type, the expression is implicitly converted (clause 4) to the cv-unqualified type of the left operand.

4 If the left operand is of class type, the class shall be complete. Assignment to objects of a class is defined by the copy assignment operator (12.8, 13.5.3).

[Note: For class objects, assignment is not in general the same as initialization (8.5, 12.1, 12.6, 12.8). — end note]

5 When the left operand of an assignment operator denotes a reference to \(T\), the operation assigns to the object of type \(T\) denoted by the reference.

6 The behavior of an expression of the form \(E1 \ op = E2\) is equivalent to \(E1 = E1 \ op E2\) except that \(E1\) is evaluated only once. In \(+=\) and \(-=\), \(E1\) shall either have arithmetic type or be a pointer to a possibly cv-qualified completely defined object type. In all other cases, \(E1\) shall have arithmetic type.

7 If the value being stored in an object is accessed from another object that overlaps in any way the storage of the first object, then the overlap shall be exact and the two objects shall have the same type, otherwise the behavior is undefined.

5.18 Comma operator

The comma operator groups left-to-right.

```
expression:
  assignment-expression

expression , assignment-expression
```

A pair of expressions separated by a comma is evaluated left-to-right and the value of the left expression is discarded. The lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are not applied to the left expression. All side effects (1.9) of the left expression, except for the destruction of temporaries (12.2), are performed before the evaluation of the right expression. The type and value of the result are the type and value of the right operand; the result is an lvalue if its right operand is an lvalue, and is a bit-field if its right operand is an lvalue and a bit-field.

2 In contexts where comma is given a special meaning, [Example: in lists of arguments to functions (5.2.2) and lists of initializers (8.5) — end example] the comma operator as described in clause 5 can appear only in parentheses. [Example:]

\[f(a, (t=3, t+2), c);\]
has three arguments, the second of which has the value 5. — end example }

5.19 Constant expressions

In several places, C++ requires expressions that evaluate to an integral or enumeration constant: as array bounds (8.3.4, 5.3.4), as case expressions (6.4.2), as bit-field lengths (9.6), as enumerator initializers (7.2), as static member initializers (9.4.2), and as integral or enumeration non-type template arguments (14.3).

constant-expression:
  conditional-expression

An integral constant-expression can involve only literals of arithmetic types (2.13, 3.9.1), enumerators, non-volatile const variables or static data members of integral or enumeration types initialized with constant expressions (8.5), non-type template parameters of integral or enumeration types, and sizeof expressions. Floating literals (2.13.3) can appear only if they are cast to integral or enumeration types. Only type conversions to integral or enumeration types can be used. In particular, except in sizeof expressions, functions, class objects, pointers, or references shall not be used, and assignment, increment, decrement, function-call, or comma operators shall not be used.

Other expressions are considered constant-expressions only for the purpose of non-local static object initialization (3.6.2). Such constant expressions shall evaluate to one of the following:

— a null pointer value (4.10),
— a null member pointer value (4.11),
— an arithmetic constant expression,
— an address constant expression,
— a reference constant expression,
— an address constant expression for a complete object type, plus or minus an integral constant expression, or
— a pointer to member constant expression.

An arithmetic constant expression shall satisfy the requirements for an integral constant expression, except that

— floating literals need not be cast to integral or enumeration type, and
— conversions to floating point types are permitted.

An address constant expression is a pointer to an lvalue designating an object of static storage duration, a string literal (2.13.4), or a function. The pointer shall be created explicitly, using the unary & operator, or implicitly using a non-type template parameter of pointer type, or using an expression of array (4.2) or function (4.3) type. The subscripting operator [] and the class member access . and -> operators, the & and * unary operators, and pointer casts (except dynamic_casts, 5.2.7) can be used in the creation of an address constant expression, but the value of an object shall not be accessed by the use of these operators. If the subscripting operator is used, one of its operands shall be an integral constant expression. An expression that designates the address of a subobject of a non-POD class object (clause 9) is not an address constant expression (12.7). Function calls shall not be used in an address constant expression, even if the function is inline and has a reference return type.

A reference constant expression is an lvalue designating an object of static storage duration, a non-type template parameter of reference type, or a function. The subscripting operator [], the class member access . and -> operators, the & and * unary operators, and reference casts (except those invoking user-defined conversion functions (12.3.2) and except
dynamic_casts (5.2.7)) can be used in the creation of a reference constant expression, but the value of an object shall not be accessed by the use of these operators. If the subscripting operator is used, one of its operands shall be an integral constant expression. An lvalue expression that designates a member or base class of a non-POD class object (clause 9) is not a reference constant expression (12.7). Function calls shall not be used in a reference constant expression, even if the function is `inline` and has a reference return type.

6 A `pointer to member constant expression` shall be created using the unary & operator applied to a `qualified-id` operand (5.3.1), optionally preceded by a pointer to member cast (5.2.9).
Chapter 6  Statements

1  Except as indicated, statements are executed in sequence.

    statement:
        labeled-statement
        expression-statement
        compound-statement
        selection-statement
        iteration-statement
        jump-statement
        declaration-statement
        try-block

6.1 Labeled statement

1  A statement can be labeled.

    labeled-statement:
        identifier : statement
        case constant-expression : statement
        default : statement

An identifier label declares the identifier. The only use of an identifier label is as the target of a goto. The scope of a label is the function in which it appears. Labels shall not be redeclared within a function. A label can be used in a goto statement before its definition. Labels have their own name space and do not interfere with other identifiers.

2  Case labels and default labels shall occur only in switch statements.

6.2 Expression statement

1  Expression statements have the form

    expression-statement:
        expression
        opt ;

The expression is evaluated and its value is discarded. The lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are not applied to the expression. All side effects from an expression statement are completed before the next statement is executed. An expression statement with the expression missing is called a null statement. [Note: Most statements are expression statements — usually assignments or function calls. A null statement is useful to carry a label just before the } of a compound statement and to supply a null body to an iteration statement such as a while statement (6.5.1). — end note]

6.3 Compound statement or block

1  So that several statements can be used where one is expected, the compound statement (also, and equivalently, called
6.4 Selection statements

“A block”) is provided.

\[
\text{compound-statement:}
\begin{align*}
\{ & \text{statement-seqopt} \\
\text{statement-seq:} & \\
\text{statement} & \text{statement-seq statement}
\end{align*}
\]

A compound statement defines a local scope (3.3). [ Note: a declaration is a statement (6.7). — end note ]

6.4 Selection statements

Selection statements choose one of several flows of control.

\[
\text{selection-statement:}
\begin{align*}
\text{if (condition) statement} \\
\text{if (condition) statement else statement} \\
\text{switch (condition) statement}
\end{align*}
\]

\[
\text{condition:}
\begin{align*}
\text{expression} \\
\text{type-specifier-seq declarator = assignment-expression}
\end{align*}
\]

In clause 6, the term substatement refers to the contained statement or statements that appear in the syntax notation. The substatement in a selection-statement (each substatement, in the else form of the if statement) implicitly defines a local scope (3.3). If the substatement in a selection-statement is a single statement and not a compound-statement, it is as if it was rewritten to be a compound-statement containing the original substatement. [ Example:

\[
\begin{align*}
\text{if (x)} \\
\text{int i;}
\end{align*}
\]

can be equivalently rewritten as

\[
\begin{align*}
\text{if (x) } \\
\text{int i;}
\end{align*}
\]

Thus after the if statement, i is no longer in scope. — end example ]

1 The rules for conditions apply both to selection-statements and to the for and while statements (6.5). The declarator shall not specify a function or an array. The type-specifier-seq shall not contain typedef and shall not declare a new class or enumeration. If the auto type-specifier appears in the type-specifier-seq, the type-specifier-seq shall contain no other type-specifiers except cv-qualifiers, and the type of the identifier being declared is deduced from the assignment-expression as described in 7.1.5.4.

2 A name introduced by a declaration in a condition (either introduced by the type-specifier-seq or the declarator of the condition) is in scope from its point of declaration until the end of the substatements controlled by the condition. If the name is re-declared in the outermost block of a substatement controlled by the condition, the declaration that re-declares the name is ill-formed. [ Example:

\[
\begin{align*}
\text{if (int x = f()) } \\
\text{int x; // ill-formed, redeclaration of x}
\end{align*}
\]

else {

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4 The value of a \textit{condition} that is an initialized declaration in a statement other than a \texttt{switch} statement is the value of the declared variable implicitly converted to type \texttt{bool}. If that conversion is ill-formed, the program is ill-formed. The value of a \textit{condition} that is an initialized declaration in a \texttt{switch} statement is the value of the declared variable if it has integral or enumeration type, or of that variable implicitly converted to integral or enumeration type otherwise. The value of a \textit{condition} that is an expression is the value of the expression, implicitly converted to \texttt{bool} for statements other than \texttt{switch} if that conversion is ill-formed, the program is ill-formed. The value of the condition will be referred to as simply “the condition” where the usage is unambiguous.

5 If a \textit{condition} can be syntactically resolved as either an expression or the declaration of a local name, it is interpreted as a declaration.

6.4.1 The \texttt{if} statement

1 If the condition (6.4) yields \texttt{true} the first substatement is executed. If the \texttt{else} part of the selection statement is present and the condition yields \texttt{false}, the second substatement is executed. In the second form of \texttt{if} statement (the one including \texttt{else}), if the first substatement is also an \texttt{if} statement then that inner \texttt{if} statement shall contain an \texttt{else} part.\footnote{In other words, the \texttt{else} is associated with the nearest un-elsed \texttt{if}.}

6.4.2 The \texttt{switch} statement

1 The \texttt{switch} statement causes control to be transferred to one of several statements depending on the value of a condition.

2 The condition shall be of integral type, enumeration type, or of a class type for which a single conversion function to integral or enumeration type exists (12.3). If the condition is of class type, the condition is converted by calling that conversion function, and the result of the conversion is used in place of the original condition for the remainder of this section. Integral promotions are performed. Any statement within the \texttt{switch} statement can be labeled with one or more case labels as follows:

\begin{verbatim}
    case constant-expression : 
\end{verbatim}

where the \texttt{constant-expression} shall be an integral \texttt{constant-expression}. The integral \texttt{constant-expression} (5.19) is implicitly converted to the promoted type of the \texttt{switch} condition. No two of the case constants in the same \texttt{switch} shall have the same value after conversion to the promoted type of the \texttt{switch} condition.

3 There shall be at most one label of the form

\begin{verbatim}
    default : 
\end{verbatim}

within a \texttt{switch} statement.

4 Switch statements can be nested; a \texttt{case} or \texttt{default} label is associated with the smallest \texttt{switch} enclosing it.

5 When the \texttt{switch} statement is executed, its condition is evaluated and compared with each case constant. If one of the case constants is equal to the value of the condition, control is passed to the statement following the matched case label. If no case constant matches the condition, and if there is a \texttt{default} label, control passes to the statement labeled by the \texttt{default} label. If no case matches and if there is no \texttt{default} then none of the statements in the \texttt{switch} is executed.

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6.5 Iteration statements

Iteration statements specify looping.

iteration-statement:
  while (condition) statement
  do statement while (expression) ;
  for (for-init-statement condition; expression; expression; ) statement

for-init-statement:
  expression-statement
  simple-declaration

[Note: a for-init-statement ends with a semicolon. — end note]

2 The substatement in an iteration-statement implicitly defines a local scope (3.3) which is entered and exited each time through the loop.

If the substatement in an iteration-statement is a single statement and not a compound-statement, it is as if it was rewritten to be a compound-statement containing the original statement. [Example:

```c
while (--x >= 0)
  int i;
```

can be equivalently rewritten as

```c
while (--x >= 0) {
  int i;
}
```

Thus after the while statement, i is no longer in scope. — end example]

4 [Note: The requirements on conditions in iteration statements are described in 6.4. — end note]

6.5.1 The while statement

In the while statement the substatement is executed repeatedly until the value of the condition (6.4) becomes false. The test takes place before each execution of the substatement.

When the condition of a while statement is a declaration, the scope of the variable that is declared extends from its point of declaration (3.3.1) to the end of the while statement. A while statement of the form

```c
while (T t = x) statement
```

is equivalent to

```c
label:
{
  // start of condition scope
  T t = x;
  if (t) {
```
The object created in a condition is destroyed and created with each iteration of the loop. [Example:

```c
struct A {
    int val;
    A(int i) : val(i) { }
    ~A() { }
    operator bool() { return val != 0; }
};
int i = 1;
while (A a = i) {
    // ...
    i = 0;
}
```

In the while-loop, the constructor and destructor are each called twice, once for the condition that succeeds and once for the condition that fails. —end example]

### 6.5.2 The do statement

1 The expression is implicitly converted to bool; if that is not possible, the program is ill-formed.

2 In the do statement the substatement is executed repeatedly until the value of the expression becomes false. The test takes place after each execution of the statement.

### 6.5.3 The for statement

1 The for statement

```c
for (for-init-statement condition_opt ; expression_opt) statement
```

is equivalent to

```c
{
    for-init-statement
    while (condition) {
        statement
        expression ;
    }
}
```

except that names declared in the for-init-statement are in the same declarative-region as those declared in the condition, and except that a continue in statement (not enclosed in another iteration statement) will execute expression before re-evaluating condition. [Note: Thus the first statement specifies initialization for the loop; the condition (6.4) specifies a test, made before each iteration, such that the loop is exited when the condition becomes false; the expression often specifies incrementing that is done after each iteration. —end note]

2 Either or both of the condition and the expression can be omitted. A missing condition makes the implied while clause equivalent to while(true).
6.6 Jump statements

If the for-init-statement is a declaration, the scope of the name(s) declared extends to the end of the for-statement.

[Example:

```c
int i = 42;
int a[10];

for (int i = 0; i < 10; i++)
    a[i] = i;

int j = i;  // j = 42
```
— end example ]

6.6 Jump statements

Jump statements unconditionally transfer control.

```
jump-statement:
    break ;
    continue ;
    return expression_opt ;
    goto identifier ;
```

On exit from a scope (however accomplished), destructors (12.4) are called for all constructed objects with automatic storage duration (3.7.2) (named objects or temporaries) that are declared in that scope, in the reverse order of their declaration. Transfer out of a loop, out of a block, or back past an initialized variable with automatic storage duration involves the destruction of variables with automatic storage duration that are in scope at the point transferred from but not at the point transferred to. (See 6.7 for transfers into blocks). [Note: However, the program can be terminated (by calling std::exit() or std::abort() (18.4), for example) without destroying class objects with automatic storage duration. — end note]

6.6.1 The break statement

The break statement shall occur only in an iteration-statement or a switch statement and causes termination of the smallest enclosing iteration-statement or switch statement; control passes to the statement following the terminated statement, if any.

6.6.2 The continue statement

The continue statement shall occur only in an iteration-statement and causes control to pass to the loop-continuation portion of the smallest enclosing iteration-statement, that is, to the end of the loop. More precisely, in each of the statements

```c
while (foo) {
}
```
```
do {
}
```
```
for (;;) {
    // ...
    // ...
    }
```
```
contin: ;
```
a `continue` not contained in an enclosed iteration statement is equivalent to `goto continue`.

### 6.6.3 The `return` statement  
A function returns to its caller by the `return` statement.

1. A return statement without an expression can be used only in functions that do not return a value, that is, a function with the return type `void`, a constructor (12.1), or a destructor (12.4). A return statement with an expression of non-void type can be used only in functions returning a value; the value of the expression is returned to the caller of the function. The expression is implicitly converted to the return type of the function in which it appears. A return statement can involve the construction and copy of a temporary object (12.2). Flowing off the end of a function is equivalent to a `return` with no value; this results in undefined behavior in a value-returning function.

2. A return statement with an expression of type "cv void" can be used only in functions with a return type of `cv void`; the expression is evaluated just before the function returns to its caller.

### 6.6.4 The `goto` statement
The `goto` statement unconditionally transfers control to the statement labeled by the identifier. The identifier shall be a label (6.1) located in the current function.

### 6.7 Declaration statement
A declaration statement introduces one or more new identifiers into a block; it has the form

```
declaration-statement:
  block-declaration
```

If an identifier introduced by a declaration was previously declared in an outer block, the outer declaration is hidden for the remainder of the block, after which it resumes its force.

1. Variables with automatic storage duration (3.7.2) are initialized each time their `declaration-statement` is executed. Variables with automatic storage duration declared in the block are destroyed on exit from the block (6.6).

2. It is possible to transfer into a block, but not in a way that bypasses declarations with initialization. A program that jumps\(^\text{82}\) from a point where a local variable with automatic storage duration is not in scope to a point where it is in scope is ill-formed unless the variable has POD type (3.9) and is declared without an `initializer` (8.5).

[Example:

```c
void f()
{
  // ...
  goto lx; // ill-formed: jump into scope of a
  // ...
  ly:
  X a = 1;
  // ...
  lx:
  goto ly; // OK, jump implies destructor
             // call for a followed by construction
             // again immediately following label ly
```

\(^\text{82}\) The transfer from the condition of a `switch` statement to a `case` label is considered a jump in this respect.

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The zero-initialization (8.5) of all local objects with static storage duration (3.7.1) is performed before any other initialization takes place. A local object of POD type (3.9) with static storage duration initialized with constant-expressions is initialized before its block is first entered. An implementation is permitted to perform early initialization of other local objects with static storage duration under the same conditions that an implementation is permitted to statically initialize an object with static storage duration in namespace scope (3.6.2). Otherwise such an object is initialized the first time control passes through its declaration; such an object is considered initialized upon the completion of its initialization. If the initialization exits by throwing an exception, the initialization is not complete, so it will be tried again the next time control enters the declaration. If control re-enters the declaration (recursively) while the object is being initialized, the behavior is undefined. [Example:]

```c
int foo(int i)
{
    static int s = foo(2*i); // recursive call - undefined
    return i+1;
}
```

The destructor for a local object with static storage duration will be executed if and only if the variable was constructed. [Note: 3.6.3 describes the order in which local objects with static storage duration are destroyed. —end note]

6.8 Ambiguity resolution

There is an ambiguity in the grammar involving expression-statements and declarations: An expression-statement with a function-style explicit type conversion (5.2.3) as its leftmost subexpression can be indistinguishable from a declaration where the first declarator starts with a `. In those cases the statement is a declaration. [Note: To disambiguate, the whole statement might have to be examined to determine if it is an expression-statement or a declaration. This disambiguates many examples. [Example: assuming T is a simple-type-specifier (7.1.5),

```c
T(a)->m = 7; // expression-statement
T(a)++; // expression-statement
T(a,5)<<c; // expression-statement
T(*d)(int); // declaration
T(e)[5]; // declaration
T(f) = { 1, 2 }; // declaration
T(*g)(double(3)); // declaration
```

In the last example above, g, which is a pointer to T, is initialized to `double(3)`. This is of course ill-formed for semantic reasons, but that does not affect the syntactic analysis. —end example ]

The remaining cases are declarations. [Example:]

```c
class T {
    // ...
    public:
    T();
    T(int);
    T(int, int);
```

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The disambiguation is purely syntactic; that is, the meaning of the names occurring in such a statement, beyond whether they are type-names or not, is not generally used in or changed by the disambiguation. Class templates are instantiated as necessary to determine if a qualified name is a type-name. Disambiguation precedes parsing, and a statement disambiguated as a declaration may be an ill-formed declaration. If, during parsing, a name in a template parameter is bound differently than it would be bound during a trial parse, the program is ill-formed. No diagnostic is required. [Note: This can occur only when the name is declared earlier in the declaration.] — end note [ Example:]

```c
struct T1 {
  T1 operator()(int x) { return T1(x); }
  int operator=(int x) { return x; }
  T1(int) { }
};
struct T2 { T2(int) { });
int a, (T1(T2)(int), c, d;

void f() {
  // disambiguation requires this to be parsed
  // as a declaration
  T1(a) = 3,
  T2(4),
  (T1(T2)(int)(int(d)); // a variable of type T1
  // but this will not allow
  // the last part of the
  // declaration to parse
  // properly since it depends
  // on T2 being a type-name
}
```

— end example ]
1 Declarations specify how names are to be interpreted. Declarations have the form

```
declaration-seq:
  declaration
  declaration-seq declaration

declaration:
  block-declaration
  function-definition
  template-declaration
  explicit-instantiation
  explicit-specialization
  linkage-specification
  namespace-definition

block-declaration:
  simple-declaration
  asm-definition
  namespace-alias-definition
  using-declaration
  using-directive
  static_assert-declaration

simple-declaration:
  decl-specifier-seq, init-declarator-list;

static_assert-declaration:
  static_assert ( constant-expression, string-literal ) ;
```

[Note: asm-definition are described in 7.4, and linkage-specification are described in 7.5. Function-definition are described in 8.4 and template-declarations are described in clause 14. Namespace-definition are described in 7.3.1, using-declarations are described in 7.3.3 and using-directives are described in 7.3.4. — end note] The simple-declaration

```
decl-specifier-seq, init-declarator-list;
```

is divided into two parts: decl-specifiers, the components of a decl-specifier-seq, are described in 7.1 and declarators, the components of an init-declarator-list, are described in clause 8.

2 A declaration occurs in a scope (3.3); the scope rules are summarized in 3.4. A declaration that declares a function or defines a class, namespace, template, or function also has one or more scopes nested within it. These nested scopes, in turn, can have declarations nested within them. Unless otherwise stated, utterances in clause 7 about components in, of, or contained by a declaration or subcomponent thereof refer only to those components of the declaration that are not nested within scopes nested within the declaration.
In a simple-declaration, the optional init-declarator-list can be omitted only when declaring a class (clause 9) or enumeration (7.2), that is, when the decl-specifier-seq contains either a class-specifier, an elaborated-type-specifier with a class-key (9.1), or an enum-specifier. In these cases and whenever a class-specifier or enum-specifier is present in the decl-specifier-seq, the identifiers in these specifiers are among the names being declared by the declaration (as class-names, enum-names, or enumerators, depending on the syntax). In such cases, and except for the declaration of an unnamed bit-field (9.6), the decl-specifier-seq shall introduce one or more names into the program, or shall redeclare a name introduced by a previous declaration. [Example:

```c
enum { };                     // ill-formed
typedef class { };           // ill-formed
```

— end example ]

In a static_assert-declaration the constant-expression shall be an integral constant expression (5.19). If the value of the expression when converted to bool is true, the declaration has no effect. Otherwise, the program is ill-formed, and the resulting diagnostic message (1.4) shall include the text of the string-literal, except that characters not in the basic source character set (2.2) are not required to appear in the diagnostic message. [Example:

```c
static_assert(sizeof(long) >= 8, "64-bit code generation not supported.");
```

— end example ]

Each init-declarator in the init-declarator-list contains exactly one declarator-id, which is the name declared by that init-declarator and hence one of the names declared by the declaration. The type-specifiers (7.1.5) in the decl-specifier-seq and the recursive declarator structure of the init-declarator describe a type (8.3), which is then associated with the name being declared by the init-declarator.

If the decl-specifier-seq contains the typedef specifier, the declaration is called a typedef declaration and the name of each init-declarator is declared to be a typedef-name, synonymous with its associated type (7.1.3). If the decl-specifier-seq contains no typedef specifier, the declaration is called a function declaration if the type associated with the name is a function type (8.3.5) and an object declaration otherwise.

Syntactic components beyond those found in the general form of declaration are added to a function declaration to make a function-definition. An object declaration, however, is also a definition unless it contains the extern specifier and has no initializer (3.1). A definition causes the appropriate amount of storage to be reserved and any appropriate initialization (8.5) to be done.

Only in function declarations for constructors, destructors, and type conversions can the decl-specifier-seq be omitted.\(^{83}\)

7.1 Specifiers

The specifiers that can be used in a declaration are

\[\text{decl-specifier:}\]
\[\text{storage-class-specifier}\]
\[\text{type-specifier}\]
\[\text{function-specifier}\]
\[\text{friend}\]
\[\text{typedef}\]

\(^{83}\) The “implicit int” rule of C is no longer supported.
The longest sequence of decl-specifiers that could possibly be a type name is taken as the decl-specifier-seq of a declaration. The sequence shall be self-consistent as described below. [Example:

typedef char* Pc;
static Pc;                  // error: name missing

Here, the declaration static Pc is ill-formed because no name was specified for the static variable of type Pc. To get a variable called Pc, a type-specifier (other than const or volatile) has to be present to indicate that the typedef-name Pc is the name being (re)declared, rather than being part of the decl-specifier sequence. For another example,

void f(const Pc);            // void f(char* const) (not const char*)
void g(const int Pc);        // void g(const int)

— end example ]

[Note: since signed, unsigned, long, and short by default imply int, a type-name appearing after one of those specifiers is treated as the name being (re)declared. [Example:

void h(unsigned Pc);        // void h(unsigned int)
void k(unsigned int Pc);    // void k(unsigned int)

— end example ] — end note ]

7.1.1 Storage class specifiers

The storage class specifiers are

storage-class-specifier:
  auto
  register
  static
  extern
  mutable

At most one storage-class-specifier shall appear in a given decl-specifier-seq. If a storage-class-specifier appears in a decl-specifier-seq, there can be no typedef specifier in the same decl-specifier-seq and the init-declarator-list of the declaration shall not be empty (except for global anonymous unions, which shall be declared static (9.5)). The storage-class-specifier applies to the name declared by each init-declarator in the list and not to any names declared by other specifiers. A storage-class-specifier shall not be specified in an explicit specialization (14.7.3) or an explicit instantiation (14.7.2) directive.

The auto or register specifiers can shall be applied only to names of objects declared in a block (6.3) or to function parameters (8.4). They specify that the named object has automatic storage duration (3.7.2). An object declared without a storage-class-specifier at block scope or declared as a function parameter has automatic storage duration by default. [Note: hence, the auto specifier is always redundant and not often used; one use of auto is to distinguish a declaration statement from an expression statement explicitly rather than relying on the disambiguation rules (6.8), which may aid readers. — end note]

A register specifier has the same semantics as an auto specifier together with a hint to the implementation that the object so declared will be heavily used. [Note: the hint can be ignored and in most implementations it will be ignored if the address of the object is taken. — end note]
7.1 Specifiers

4 The static specifier can be applied only to names of objects and functions and to anonymous unions (9.5). There can be no static function declarations within a block, nor any static function parameters. A static specifier used in the declaration of an object declares the object to have static storage duration (3.7.1). A static specifier can be used in declarations of class members; 9.4 describes its effect. For the linkage of a name declared with a static specifier, see 3.5.

5 The extern specifier can be applied only to the names of objects and functions. The extern specifier cannot be used in the declaration of class members or function parameters. For the linkage of a name declared with an extern specifier, see 3.5. [Note: The extern keyword can also be used in explicit-instantiations and linkage-specifications, but it is not a storage-class-specifier in such contexts. — end note]

6 A name declared in a namespace scope without a storage-class-specifier has external linkage unless it has internal linkage because of a previous declaration and provided it is not declared const. Objects declared const and not explicitly declared extern have internal linkage.

7 The linkages implied by successive declarations for a given entity shall agree. That is, within a given scope, each declaration declaring the same object name or the same overloading of a function name shall imply the same linkage. Each function in a given set of overloaded functions can have a different linkage, however. [Example:

```c
static char* f(); // f() has internal linkage
char* f(); // f() still has internal linkage
    { /* ... */ }

char* g(); // g() has external linkage
static char* g(); // error: inconsistent linkage
    { /* ... */ }

void h();
inline void h(); // external linkage

inline void l();
void l(); // external linkage

inline void m();
extern void m(); // external linkage

static void n();
inline void n(); // internal linkage

static int a; // a has internal linkage
int a; // error: two definitions

static int b; // b has internal linkage
extern int b; // b still has internal linkage

int c; // c has external linkage
static int c; // error: inconsistent linkage

extern int d; // d has external linkage
static int d; // error: inconsistent linkage
```
8 The name of a declared but undefined class can be used in an `extern` declaration. Such a declaration can only be used in ways that do not require a complete class type. [Example:

```cpp
struct S;
extern S a;
extern S f();
extern void g(S);

void h()
{
  g(a); // error: S is incomplete
  f();  // error: S is incomplete
}
```

— end example ] The `mutable` specifier can be applied only to names of class data members (9.2) and cannot be applied to names declared `const` or `static`, and cannot be applied to reference members. [Example:

```cpp
class X {
  mutable const int* p; // OK
  mutable int* const q; // ill-formed
};
```

— end example ]

9 The `mutable` specifier on a class data member nullifies a `const` specifier applied to the containing class object and permits modification of the mutable class member even though the rest of the object is `const` (7.1.5.1).

7.1.2 Function specifiers [dcl.fct.spec]

1 Function-specifiers can be used only in function declarations.

```cpp
function-specifier:
  inline
  virtual
  explicit
```

2 A function declaration (8.3.5, 9.3, 11.4) with an `inline` specifier declares an `inline function`. The `inline` specifier indicates to the implementation that inline substitution of the function body at the point of call is to be preferred to the usual function call mechanism. An implementation is not required to perform this inline substitution at the point of call; however, even if this inline substitution is omitted, the other rules for inline functions defined by 7.1.2 shall still be respected.

3 A function defined within a class definition is an inline function. The `inline` specifier shall not appear on a block scope function declaration. If the `inline` specifier is used in a friend declaration, that declaration shall be a definition or the function shall have previously been declared inline.

4 An inline function shall be defined in every translation unit in which it is used and shall have exactly the same definition in every case (3.2). [Note: a call to the inline function may be encountered before its definition appears in the translation unit. — end note ] If the definition of a function appears in a translation unit before its first declaration as inline, the

---

84) The `inline` keyword has no effect on the linkage of a function.
7.1 Specifiers

program is ill-formed. If a function with external linkage is declared inline in one translation unit, it shall be declared inline in all translation units in which it appears; no diagnostic is required. An inline function with external linkage shall have the same address in all translation units. A static local variable in an extern inline function always refers to the same object. A string literal in an extern inline function is the same object in different translation units.

5 The virtual specifier shall only be used in declarations of non-static class member functions that appear within a member-specification of a class definition; see 10.3.

6 The explicit specifier shall be used only in declarations of constructors within a class definition; see 12.3.1.

7.1.3 The typedef specifier

1 Declarations containing the decl-specifier typedef declare identifiers that can be used later for naming fundamental (3.9.1) or compound (3.9.2) types. The typedef specifier shall not be used in a function-definition (8.4), and it shall not be combined in a decl-specifier-seq with any other kind of specifier except a type-specifier.

   typedef-name:
   identifier

A name declared with the typedef specifier becomes a typedef-name. Within the scope of its declaration, a typedef-name is syntactically equivalent to a keyword and names the type associated with the identifier in the way described in clause 8. A typedef-name is thus a synonym for another type. A typedef-name does not introduce a new type the way a class declaration (9.1) or enum declaration does. [Example: after

   typedef int MILES, *KLICKSP;

the constructions

   MILES distance;
   extern KLICKSP metricp;

are all correct declarations; the type of distance is int that of metricp is “pointer to int.” — end example]

2 In a given non-class scope, a typedef specifier can be used to redefine the name of any type declared in that scope to refer to the type to which it already refers. [Example:

   typedef struct s { /* ... */ } s;
   typedef int I;
   typedef int I;
   typedef I I;

   — end example]

3 In a give class scope, a typedef specifier can be used to redefine any class-name declared in that scope that is not also a typedef-name to refer to the type to which it already refers.

   [Example:

   struct S {
   typedef struct A {} A; // OK
   typedef struct B B; // OK
   typedef A A; // error

   Draft
In a given scope, a typedef specifier shall not be used to redefine the name of any type declared in that scope to refer to a different type. [Example:

```c
class complex { /* ... */};
typedef int complex; // error: redefinition
```
— end example ]

Similarly, in a given scope, a class or enumeration shall not be declared with the same name as a typedef-name that is declared in that scope and refers to a type other than the class or enumeration itself. [Example:

```c
typedef int complex;
class complex { /* ... */}; // error: redefinition
```
— end example ]

[Note: A typedef-name that names a class type, or a cv-qualified version thereof, is also a class-name (9.1). If a typedef-name is used to identify the subject of an elaborated-type-specifier (7.1.5.3), a class definition (clause 9), a constructor declaration (12.1), or a destructor declaration (12.4), the program is ill-formed. — end note ]

```c
struct S {
  S();
  ~S();
};
typedef struct S T;
S a = T(); // OK
struct T * p; // error
```
— end example ]

If the typedef declaration defines an unnamed class (or enum), the first typedef-name declared by the declaration to be that class type (or enum type) is used to denote the class type (or enum type) for linkage purposes only (3.5). [Example:

```c
typedef struct {} *ps, S; // S is the class name for linkage purposes
```
— end example ]

[Note: if the typedef-name is used where a class-name (or enum-name) is required, the program is ill-formed. For example,

```c
typedef struct {
  S(); // error: requires a return type because S is
  // an ordinary member function, not a constructor
} S;
```
— end note ]
7.1 Specifiers

If a typedef TD names a type “reference to cv1 S”, an attempt to create the type “reference to cv2 TD” creates the type “reference to cv12 S”, where cv12 is the union of the cv-qualifiers cv1 and cv2. Redundant qualifiers are ignored. [Example:

```c
int i;
typedef int& RI;
RI& r1 = i;    // r1 has the type int&
const RI& r2 = i; // r2 has the type const int&
```
— end example ]

7.1.4 The friend specifier

The friend specifier is used to specify access to class members; see 11.4.

7.1.5 Type specifiers

The type-specifiers are

- simple-type-specifier
- class-specifier
- enum-specifier
- elaborated-type-specifier
- typename-specifier
- cv-qualifier

As a general rule, at most one type-specifier is allowed in the complete decl-specifier-seq of a declaration. The only exceptions to this rule are the following:

- const or volatile can be combined with any other type-specifier. However, redundant cv-qualifiers are prohibited except when introduced through the use of typedefs (7.1.3) or template type arguments (14.3), in which case the redundant cv-qualifiers are ignored.

- signed or unsigned can be combined with char, long, short, or int.

- short or long can be combined with int.

- long can be combined with double.

- long can be combined with long.

- auto can be combined with any type specifier except itself.

At least one type-specifier that is not a cv-qualifier is required in a declaration unless it declares a constructor, destructor or conversion function.85)

[Note: class-specifiers and enum-specifiers are discussed in clause 9 and 7.2, respectively. The remaining type-specifiers are discussed in the rest of this section. — end note ]

85) There is no special provision for a decl-specifier-seq that lacks a type-specifier or that has a type-specifier that only specifies cv-qualifiers. The “implicit int” rule of C is no longer supported.
7.1.5.1 The cv-qualifiers

There are two cv-qualifiers, const and volatile. If a cv-qualifier appears in a decl-specifier-seq, the init-declarator-list of the declaration shall not be empty. [Note: 3.9.3 describes how cv-qualifiers affect object and function types. — end note]

An object declared in namespace scope with a const-qualified type has internal linkage unless it is explicitly declared extern or unless it was previously declared to have external linkage. A variable of non-volatile const-qualified integral or enumeration type initialized by an integral constant expression can be used in integral constant expressions (5.19). [Note: as described in 8.5, the definition of an object or subobject of const-qualified type must specify an initializer or be subject to default-initialization. — end note]

A pointer or reference to a cv-qualified type need not actually point or refer to a cv-qualified object, but it is treated as if it does; a const-qualified access path cannot be used to modify an object even if the object referenced is a non-const object and can be modified through some other access path. [Note: cv-qualifiers are supported by the type system so that they cannot be subverted without casting (5.2.11). — end note]

Except that any class member declared mutable (7.1.1) can be modified, any attempt to modify a const object during its lifetime (3.8) results in undefined behavior.

[Example:]

```c
const int ci = 3; // cv-qualified (initialized as required)
ci = 4; // ill-formed: attempt to modify const

int i = 2; // not cv-qualified
cont int* cip; // pointer to const int
cip = &i; // OK: cv-qualified access path to unqualified
*cip = 4; // ill-formed: attempt to modify through ptr to const

int* ip;
ip = const_cast<int*>(cip); // cast needed to convert const int* to int*
*ip = 4; // defined: *ip points to i, a non-const object

const int* ciq = new const int (3); // initialized as required
int* iq = const_cast<int*>(ciq); // cast required
*iq = 4; // undefined: modifies a const object
```

For another example

```c
class X {
    public:
        mutable int i;
        int j;
};
class Y {
    public:
        X x;
        Y();
};
```
const Y y;
y.x.i++; // well-formed: mutable member can be modified
y.x.j++; // ill-formed: const-qualified member modified
Y* p = const_cast<Y*>(y);
// cast away const-ness of y
p->x.i = 99; // well-formed: mutable member can be modified
p->x.j = 99; // undefined: modifies a const member

— end example ]

6 If an attempt is made to refer to an object defined with a volatile-qualified type through the use of an lvalue with a non-volatile-qualified type, the program behaviour is undefined.

7 [ Note: volatile is a hint to the implementation to avoid aggressive optimization involving the object because the value of the object might be changed by means undetectable by an implementation. See 1.9 for detailed semantics. In general, the semantics of volatile are intended to be the same in C++ as they are in C. — end note ]

7.1.5.2 Simple type specifiers

The simple type specifiers are

\[ simple-type-specifier: \]
\[ ::opt nested-name-specifier_opt type-name \]
\[ ::opt nested-name-specifier template template-id \]
char
wchar_t
bool
short
int
long
signed
unsigned
float
double
void
auto
type-name:
class-name
enum-name
typedef-name

The auto specifier is a placeholder for a type to be deduced (7.1.5.4). The other simple-type-specifiers specify either a previously-declared user-defined type or one of the fundamental types (3.9.1). Table 8 summarizes the valid combinations of simple-type-specifiers and the types they specify.

<table>
<thead>
<tr>
<th>Specifier(s)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>type-name</td>
<td>the type named</td>
</tr>
<tr>
<td>char</td>
<td>“char”</td>
</tr>
<tr>
<td>unsigned char</td>
<td>“unsigned char”</td>
</tr>
<tr>
<td>signed char</td>
<td>“signed char”</td>
</tr>
</tbody>
</table>

Table 8: simple-type-specifiers and the types they specify
<table>
<thead>
<tr>
<th>Specifier(s)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>type-name</td>
<td>the type named</td>
</tr>
<tr>
<td>bool</td>
<td>“bool”</td>
</tr>
<tr>
<td>unsigned</td>
<td>“unsigned int”</td>
</tr>
<tr>
<td>unsigned int</td>
<td>“unsigned int”</td>
</tr>
<tr>
<td>signed</td>
<td>“int”</td>
</tr>
<tr>
<td>signed int</td>
<td>“int”</td>
</tr>
<tr>
<td>int</td>
<td>“int”</td>
</tr>
<tr>
<td>unsigned short int</td>
<td>“unsigned short int”</td>
</tr>
<tr>
<td>unsigned short</td>
<td>“unsigned short int”</td>
</tr>
<tr>
<td>unsigned long int</td>
<td>“unsigned long int”</td>
</tr>
<tr>
<td>unsigned long</td>
<td>“unsigned long int”</td>
</tr>
<tr>
<td>unsigned long long</td>
<td>“unsigned long long int”</td>
</tr>
<tr>
<td>signed long int</td>
<td>“long int”</td>
</tr>
<tr>
<td>signed long</td>
<td>“long int”</td>
</tr>
<tr>
<td>signed long long int</td>
<td>“long long int”</td>
</tr>
<tr>
<td>signed long long</td>
<td>“long long int”</td>
</tr>
<tr>
<td>long long int</td>
<td>“long long int”</td>
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<tr>
<td>long long</td>
<td>“long long int”</td>
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<tr>
<td>long int</td>
<td>“long int”</td>
</tr>
<tr>
<td>long</td>
<td>“long int”</td>
</tr>
<tr>
<td>signed short int</td>
<td>“short int”</td>
</tr>
<tr>
<td>signed short</td>
<td>“short int”</td>
</tr>
<tr>
<td>short int</td>
<td>“short int”</td>
</tr>
<tr>
<td>short</td>
<td>“short int”</td>
</tr>
<tr>
<td>wchar_t</td>
<td>“wchar_t”</td>
</tr>
<tr>
<td>float</td>
<td>“float”</td>
</tr>
<tr>
<td>double</td>
<td>“double”</td>
</tr>
<tr>
<td>long double</td>
<td>“long double”</td>
</tr>
<tr>
<td>void</td>
<td>“void”</td>
</tr>
<tr>
<td>auto</td>
<td>placeholder for a type to be deduced</td>
</tr>
</tbody>
</table>

When multiple simple-type-specifiers are allowed, they can be freely intermixed with other decl-specifiers in any order. It is implementation-defined whether bit-fields and objects of char type are represented as signed or unsigned quantities. The signed specifier forces char objects and bit-fields to be signed; it is redundant with other integral types.

### 7.1.5.3 Elaborated type specifiers

elaborated-type-specifier:

```
elaborated-type-specifier:
  class-key :: opt nested-name-specifier opt identifier
  class-key :: opt nested-name-specifier opt template opt template-id
  enum :: opt nested-name-specifier opt identifier
```

1. If an elaborated-type-specifier is the sole constituent of a declaration, the declaration is ill-formed unless it is an explicit specialization (14.7.3), an explicit instantiation (14.7.2) or it has one of the following forms:
class-key identifier;
friend class-key ::opt identifier;
friend class-key ::opt template-id;
friend class-key ::opt nested-name-specifier identifier;
friend class-key ::opt nested-name-specifier template::opt template-id;

3.4.4 describes how name lookup proceeds for the identifier in an elaborated-type-specifier. If the identifier resolves to a class-name or enum-name, the elaborated-type-specifier introduces it into the declaration the same way a simple-type-specifier introduces its type-name. If the identifier resolves to a typedef-name, the elaborated-type-specifier is ill-formed. [ Note: this implies that, within a class template with a template type-parameter T, the declaration

friend class T;

is ill-formed. — end note ]

The class-key or enum keyword present in the elaborated-type-specifier shall agree in kind with the declaration to which the name in the elaborated-type-specifier refers. This rule also applies to the form of elaborated-type-specifier that declares a class-name or friend class since it can be construed as referring to the definition of the class. Thus, in any elaborated-type-specifier, the enum keyword shall be used to refer to an enumeration (7.2), the union class-key shall be used to refer to a union (clause 9), and either the class or struct class-key shall be used to refer to a class (clause 9) declared using the class or struct class-key.

7.1.5.4 auto specifier

The auto type-specifier has two meanings depending on the context of its use. In a decl-specifier-seq that contains at least one type-specifier (in addition to auto) that is not a cv-qualifier, the auto type-specifier specifies that the object named in the declaration has automatic storage duration. The decl-specifier-seq shall contain no storage-class-specifiers. This use of the auto specifier shall only be applied to names of objects declared in a block (6.3) or to function parameters (8.4).

Otherwise (auto appearing with no type specifiers other than cv-qualifiers), the auto type-specifier signifies that the type of an object being declared shall be deduced from its initializer. The name of the object being declared shall not appear in the initializer expression.

This use of auto is allowed when declaring objects in a block (6.3), in namespace scope (3.3.5), and in a for-init-statement (6.5.3). The decl-specifier-seq shall be followed by one or more init-declarators, each of which shall have a non-empty initializer of either of the following forms:

= assignment-expression  
{ assignment-expression }

[ Example:
auto x = 5; // OK: x has type int
const auto *v = &x, u = 6; // OK: v has type const int*, u has type const int
static auto y = 0.0; // OK: y has type double
static auto int z; // error: auto and static conflict
auto int r; // OK: r has type int

— end example ]

The auto type-specifier can also be used in declaring an object in the condition of a selection statement (6.4) or an iteration statement (6.5), in the type-specifier-seq in a new-type-id (5.3.4), and in declaring a static data member with a constant-initializer that appears within the member-specification of a class definition (9.4.2).
A program that uses `auto` in a context not explicitly allowed in this section is ill-formed.

Once the type of a declarator-id has been determined according to 8.3, the type of the declared variable using the declarator-id is determined from the type of its initializer using the rules for template argument deduction. Let \( T \) be the type that has been determined for a variable identifier \( d \). Obtain \( P \) from \( T \) by replacing the occurrences of `auto` with a new invented type template parameter \( U \). Let \( A \) be the type of the initializer expression for \( d \). The type deduced for the variable \( d \) is then the deduced type determined using the rules of template argument deduction from a function call (14.8.2.1), where \( P \) is a function template parameter type and \( A \) is the corresponding argument type. If the deduction fails, the declaration is ill-formed.

If the list of declarators contains more than one declarator, the type of each declared variable is determined as described above. If the type deduced for the template parameter \( U \) is not the same in each deduction, the program is ill-formed.

**Example:**
```c
const auto &i = expr;
```
The type of \( i \) is the deduced type of the parameter \( u \) in the call \( f(expr) \) of the following invented function template:
```c
template <class U> void f(const U& u);
```

— end example ]

### 7.2 Enumeration declarations [dcl.enum]

An enumeration is a distinct type (3.9.1) with named constants. Its name becomes an *enum-name*, within its scope.

```c
enum-name:
  identifier
enum-specifier:
  enum
identifier
opt
{ enumerator-list opt
  }
enumerator-list:
  enumerator-definition
enumerator-list ,
enumerator-definition:
  enumerator
  enumerator-definition
enumerator-definition:
  enumerator
enumerator = constant-expression
enumerator:
  identifier
```

The identifiers in an *enumerator-list* are declared as constants, and can appear wherever constants are required. An *enumerator-definition* with `=` gives the associated *enumerator* the value indicated by the *constant-expression*. The *constant-expression* shall be of integral or enumeration type. If the first *enumerator* has no *initializer*, the value of the corresponding constant is zero. An *enumerator-definition* without an *initializer* gives the *enumerator* the value obtained by increasing the value of the previous *enumerator* by one.

**Example:**
```c
enum { a, b, c=0 
};
enum { d, e, f=e+2 
};
```
defines \( a \), \( c \), and \( d \) to be zero, \( b \) and \( e \) to be 1, and \( f \) to be 3. — end example ]

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The point of declaration for an enumerator is immediately after its *enumerator-definition*.

```
const int x = 12;
{ enum { x = x }; }
```

Here, the enumerator `x` is initialized with the value of the constant `x`, namely 12.

Each enumeration defines a type that is different from all other types. Following the closing brace of an *enum-specifier*, each enumerator has the type of its enumeration. Prior to the closing brace, the type of each enumerator is the type of its initializing value. If an initializer is specified for an enumerator, the initializing value has the same type as the expression. If no initializer is specified for the first enumerator, the type is an unspecified integral type. Otherwise, the type is the same as the type of the initializing value of the preceding enumerator unless the incremented value is not representable in that type, in which case the type is an unspecified integral type sufficient to contain the incremented value.

The *underlying type* of an enumeration is an integral type that can represent all the enumerator values defined in the enumeration. If no integral type can represent all the enumerator values, the enumeration is ill-formed. It is implementation-defined which integral type is used as the underlying type for an enumeration except that the underlying type shall not be larger than `int` unless the value of an enumerator cannot fit in an `int` or `unsigned int`. If the *enumerator-list* is empty, the underlying type is as if the enumeration had a single enumerator with value 0. The value of `sizeof()` applied to an enumeration type, an object of enumeration type, or an enumerator, is the value of `sizeof()` applied to the underlying type.

For an enumeration where $e_{\text{min}}$ is the smallest enumerator and $e_{\text{max}}$ is the largest, the values of the enumeration are the values of the underlying type in the range $b_{\text{min}}$ to $b_{\text{max}}$, where $b_{\text{min}}$ and $b_{\text{max}}$ are, respectively, the smallest and largest values of the smallest bit-field that can store $e_{\text{min}}$ and $e_{\text{max}}$.

Two enumeration types are layout-compatible if they have the same *underlying type*. The value of an enumerator or an object of an enumeration type is converted to an integer by integral promotion (4.5).

```
enum color { red, yellow, green=20, blue };
color col = red;
color* cp = &col;
if (*cp == blue)  // ...
```

makes `color` a type describing various colors, and then declares `col` as an object of that type, and `cp` as a pointer to an object of that type. The possible values of an object of type `color` are `red`, `yellow`, `green`, `blue` these values can be converted to the integral values 0, 1, 20, and 21. Since enumerations are distinct types, objects of type `color` can be assigned only values of type `color`.

```
color c = 1;  // error: type mismatch,
              // no conversion from int to color

int i = yellow;  // OK: yellow converted to integral value 1
                 // integral promotion
```

---

86) On a two’s-complement machine, $b_{\text{max}}$ is the smallest value greater than or equal to \(\max(|e_{\text{min}}| - 1, |e_{\text{max}}|)\) of the form \(2^{M-1}\); $b_{\text{min}}$ is zero if $e_{\text{min}}$ is non-negative and $-(b_{\text{max}} + 1)$ otherwise.
An expression of arithmetic or enumeration type can be converted to an enumeration type explicitly. The value is unchanged if it is in the range of enumeration values of the enumeration type; otherwise the resulting enumeration value is unspecified.

The enum-name and each enumerator declared by an enum-specifier is declared in the scope that immediately contains the enum-specifier. These names obey the scope rules defined for all names in (3.3) and (3.4). An enumerator declared in class scope can be referred to using the class member access operators (: : , (dot) and -> (arrow)), see 5.2.5. [Example: class X {
    public:
    enum direction { left='l', right='r' };
    int f(int i)
    { return i==left ? 0 : i==right ? 1 : 2; }
};

    void g(X* p)
    {
        direction d;
        // error: direction not in scope
        int i;
        i = p->f(left);
        // error: left not in scope
        i = p->f(X::right);
        // OK
        i = p->f(p->left);
        // OK
        // ...
    }

— end example ]

7.3 Namespaces [basic.namespace]

A namespace is an optionally-named declarative region. The name of a namespace can be used to access entities declared in that namespace; that is, the members of the namespace. Unlike other declarative regions, the definition of a namespace can be split over several parts of one or more translation units.

The outermost declarative region of a translation unit is a namespace; see 3.3.5.

7.3.1 Namespace definition [namespace.def]

The grammar for a namespace-definition is
7.3 Namespaces

namespace-name:
  original-namespace-name
  namespace-alias
original-namespace-name:
  identifier
namespace-definition:
  named-namespace-definition
  unnamed-namespace-definition
named-namespace-definition:
  original-namespace-definition
  extension-namespace-definition
original-namespace-definition:
  namespace identifier { namespace-body }
extension-namespace-definition:
  namespace original-namespace-name { namespace-body }
unnamed-namespace-definition:
  namespace { namespace-body }
namespace-body:
  declaration-seq
opt

2 The identifier in an original-namespace-definition shall not have been previously defined in the declarative region in which the original-namespace-definition appears. The identifier in an original-namespace-definition is the name of the namespace. Subsequently in that declarative region, it is treated as an original-namespace-name.

3 The original-namespace-name in an extension-namespace-definition shall have previously been defined in an original-namespace-definition in the same declarative region.

4 Every namespace-definition shall appear in the global scope or in a namespace scope (3.3.5).

5 Because a namespace-definition contains declarations in its namespace-body and a namespace-definition is itself a declaration, it follows that namespace-declarations can be nested. [Example:

```cpp
namespace Outer {
  int i;
  namespace Inner {
    void f() { i++; } // Outer::i
    int i;
    void g() { i++; } // Inner::i
  }
}
```

— end example ]

6 The enclosing namespaces of a declaration are those namespaces in which the declaration lexically appears, except for a redeclaration of a namespace member outside its original namespace (e.g., a definition as specified in 7.3.1.2). Such a redeclaration has the same enclosing namespaces as the original declaration. [Example:

```cpp
namespace Q {
  namespace V {
    void f(); // enclosing namespaces are the global namespace, Q, and Q::V
    class C { void m(); };
  }
  void V::f() { // enclosing namespaces are the global namespace, Q, and Q::V
```
extern void h();  // ... so this declares Q::V::h
}
void V::C::m() {  // enclosing namespaces are the global namespace, Q, and Q::V
}

— end example ]

7.3.1.1 Unnamed namespaces

An unnamed-namespace-definition behaves as if it were replaced by

    namespace unique { /* empty body */ }
    using namespace unique;
    namespace unique { namespace-body }

where all occurrences of unique in a translation unit are replaced by the same identifier and this identifier differs from all other identifiers in the entire program.\(^{87}\) [ Example:

```
namespace { int i; }  // unique::i
void f() { i++; }    // unique::i++

namespace A {
    namespace {
        int i;   // A::unique::i
        int j;   // A::unique::j
    }
    void g() { i++; }  // A::unique::i++
}

using namespace A;
void h() {
    i++;             // error: unique::i or A::unique::i
    A::i++;          // A::unique::i
    j++;             // A::unique::j
}

— end example ]
```

The use of the static keyword is deprecated when declaring objects in a namespace scope (see annex D); the unnamed-namespace provides a superior alternative.

7.3.1.2 Namespace member definitions

Members (including explicit specializations of templates (14.7.3)) of a namespace can be defined within that namespace. [ Example:

```
namespace X {
    void f() { /* ... */ }
}
```

\(^{87}\) Although entities in an unnamed namespace might have external linkage, they are effectively qualified by a name unique to their translation unit and therefore can never be seen from any other translation unit.

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Members (including explicit specializations of templates (14.7.3)) of a named namespace can also be defined outside that namespace by explicit qualification (3.4.3.2) of the name being defined, provided that the entity being defined was already declared in the namespace and the definition appears after the point of declaration in a namespace that encloses the declaration’s namespace. [Example:

```cpp
namespace Q {
    namespace V {
        void f();
    }
    void V::f() { /* ... */ } // OK
    void V::g() { /* ... */ } // error: g() is not yet a member of V
    namespace V {
        void g();
    }
}

namespace R {
    void Q::V::g() { /* ... */ } // error: R doesn’t enclose Q
}
```

— end example ]

Every name first declared in a namespace is a member of that namespace. If a friend declaration in a non-local class first declares a class or function the friend class or function is a member of the innermost enclosing namespace. The name of the friend is not found by simple name lookup until a matching declaration is provided in that namespace scope (either before or after the class definition granting friendship). If a friend function is called, its name may be found by the name lookup that considers functions from namespaces and classes associated with the types of the function arguments (3.4.2). If the name in a friend declaration is neither qualified nor a template-id and the declaration is a function or an elaborated-type-specifier, the lookup to determine whether the entity has been previously declared shall not consider any scopes outside the innermost enclosing namespace. [Note: the other forms of friend declarations cannot declare a new member of the innermost enclosing namespace and thus follow the usual lookup rules.— end note ] [Example:

```cpp
// Assume f and g have not yet been defined.
void h(int);
template <class T> void f2(T);
namespace A {
    class X {
        friend void f(X); // A::f(X) is a friend
    }
    class Y {
        friend void g(); // h::g is a friend
        friend void h(int); // h::h is a friend
        friend void f2<int>(); // ::f2<int>() is a friend
    }
}
```

// A::f, h::g and A::h are not visible here

88) this implies that the name of the class or function is unqualified.
X x;
void g() { f(x); } // definition of A::g
void f(X) { /* ... */ } // definition of k::f
void h(int) { /* ... */ } // definition of A::h
// A::f, A::g and A::h are visible here and known to be friends
}

using A::x;

void h()
{
    A::f(x);
    A::X::f(x); // error: f is not a member of A::X
    A::X::Y::g(); // error: g is not a member of A::X::Y
}

— end example ]

7.3.2 Namespace alias [namespace.alias]

1 A namespace-alias-definition declares an alternate name for a namespace according to the following grammar:

   namespace-alias-definition:
       identifier

   namespace-alias-definition:
       qualified-name-specifier

   namespace-alias-definition:
       namespace identifier = qualified-name-specifier;

   qualified-name-specifier:
       ::opt nested-name-specifier opt namespace-name

2 The identifier in a namespace-alias-definition is a synonym for the name of the namespace denoted by the qualified-name-specifier and becomes a namespace-alias. [Note: when looking up a namespace-name in a namespace-alias-definition, only namespace names are considered, see 3.4.6. — end note ]

3 In a declarative region, a namespace-alias-definition can be used to redefine a namespace-alias declared in that declarative region to refer only to the namespace to which it already refers. [Example: the following declarations are well-formed:

    namespace Company_with_very_long_name { /* ... */ }
    namespace CWVLN = Company_with_very_long_name;
    namespace CWVLN = Company_with_very_long_name; // OK: duplicate
    namespace CWVLN = CWVLN;

    — end example ]

4 A namespace-name or namespace-alias shall not be declared as the name of any other entity in the same declarative region. A namespace-name defined at global scope shall not be declared as the name of any other entity in any global scope of the program. No diagnostic is required for a violation of this rule by declarations in different translation units.

7.3.3 The using declaration [namespace.udecl]

1 A using-declaration introduces a name into the declarative region in which the using-declaration appears. That name is a synonym for the name of some entity declared elsewhere.
using-declaration:
  using typename_opt ::opt nested-name-specifier unqualified-id ;
  using :: unqualified-id ;

The member name specified in a using-declaration is declared in the declarative region in which the using-declaration appears. [Note: only the specified name is so declared; specifying an enumeration name in a using-declaration does not declare its enumerators in the using-declaration’s declarative region. — end note]

2 Every using-declaration is a declaration and a member-declaration and so can be used in a class definition. [Example:

```cpp
struct B {
    void f(char);
    void g(char);
    enum E { e };
    union { int x; };
};

struct D : B {
    using B::f;
    void f(int) { f('c'); } // calls B::f(char)
    void g(int) { g('c'); } // recursively calls D::g(int)
};
```

— end example ]

3 In a using-declaration used as a member-declaration, the nested-name-specifier shall name a base class of the class being defined. Such a using-declaration introduces the set of declarations found by member name lookup (10.2, 3.4.3.1). [Example:

```cpp
class C {
    int g();
};

class D2 : public B {
    using B::f; // OK: B is a base of D2
    using B::e; // OK: e is an enumerator of base B
    using B::x; // OK: x is a union member of base B
    using C::g; // error: C isn’t a base of D2
};
```

— end example ]

4 [Note: since constructors and destructors do not have names, a using-declaration cannot refer to a constructor or a destructor for a base class. Since specializations of member templates for conversion functions are not found by name lookup, they are not considered when a using-declaration specifies a conversion function (14.5.2). — end note] If an assignment operator brought from a base class into a derived class scope has the signature of a copy-assignment operator for the derived class (12.8), the using-declaration does not by itself suppress the implicit declaration of the derived class copy-assignment operator; the copy-assignment operator from the base class is hidden or overridden by the implicitly-declared copy-assignment operator of the derived class, as described below.

5 A using-declaration shall not name a template-id. [Example:
class A {
public:
    template <class T> void f(T);
    template <class T> struct X { };
};
class B : public A {
public:
    using A::f<double>;   // ill-formed
    using A::X<int>;      // ill-formed
};

— end example ]

6 A using-declaration shall not name a namespace.

7 A using-declaration for a class member shall be a member-declaration. [Example:

struct X {
    int i;
    static int s;
};

void f()
{
    using X::i;  // error: X::i is a class member
    using X::s;  // error: X::s is a class member
}

— end example ]

8 Members declared by a using-declaration can be referred to by explicit qualification just like other member names (3.4.3.2). In a using-declaration, a prefix :: refers to the global namespace. [Example:

void f();

namespace A {
    void g();
}

namespace X {
    using ::f;    // global f
    using A::g;   // A's g
}

void h()
{
    X::f();     // calls ::f
    X::g();     // calls A::g
}

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A using-declaration is a declaration and can therefore be used repeatedly where (and only where) multiple declarations are allowed. [Example:

```cpp
namespace A {
    int i;
}

namespace A1 {
    using A::i;
    using A::i; // OK: double declaration
}

void f()
{
    using A::i;
    using A::i; // error: double declaration
}

class B {
public:
    int i;
};

class X : public B {
    using B::i;
    using B::i; // error: double member declaration
};

--- end example ]

The entity declared by a using-declaration shall be known in the context using it according to its definition at the point of the using-declaration. Definitions added to the namespace after the using-declaration are not considered when a use of the name is made. [Example:

```cpp
namespace A {
    void f(int);
}

using A::f; // f is a synonym for A::f;
// that is, for A::f(int).

namespace A {
    void f(char);
}

void foo()
{
    f('a'); // calls f(int),
    // even though f(char) exists.
}

--- end example ]
void bar()
{
    using A::f;  // f is a synonym for A::f;
    // that is, for A::f(int) and A::f(char).
    f('a');     // calls f(char)
}

— end example ]

[ Note: partial specializations of class templates are found by looking up the primary class template and then considering all partial specializations of that template. If a using-declaration names a class template, partial specializations introduced after the using-declaration are effectively visible because the primary template is visible (14.5.4). — end note ]

Since a using-declaration is a declaration, the restrictions on declarations of the same name in the same declarative region (3.3) also apply to using-declarations. [ Example:

```c
namespace A {
    int x;
}

namespace B {
    int i;
    struct g { };  // OK: hides struct g
    struct x { };  // OK: hides struct x
    void f(int);
    void f(double);
    void g(char);
}

void func()
{
    int i;
    using B::i;  // error: i declared twice
    void f(char);
    using B::f;  // OK: each f is a function
    f(3.5);      // calls B::f(double)
    using B::g;
    g('a');      // calls B::g(char)
    struct g g1;  // g1 has class type B::g
    using B::x;
    using A::x;  // OK: hides struct B::x
    x = 99;      // assigns to A::x
    struct x x1;  // x1 has class type B::x
}

— end example ]

If a function declaration in namespace scope or block scope has the same name and the same parameter types as a function introduced by a using-declaration, and the declarations do not declare the same function, the program is ill-formed. [ Note: two using-declarations may introduce functions with the same name and the same parameter types.
If, for a call to an unqualified function name, function overload resolution selects the functions introduced by such
using-declarations, the function call is ill-formed.

[Example:

```cpp
namespace B {
    void f(int);
    void f(double);
}
namespace C {
    void f(int);
    void f(double);
    void f(char);
}
void h()
{
    using B::f;    //B::f(int) and B::f(double)
    using C::f;    //C::f(int), C::f(double), and C::f(char)
    f('h');       //calls C::f(char)
    f(1);          //error: ambiguous: B::f(int) or C::f(int)?
    void f(int);   //error:
                    //f(int) conflicts with C::f(int) and B::f(int)
}
```
— end example ] — end note ]

14 When a using-declaration brings names from a base class into a derived class scope, member functions and member
function templates in the derived class override and/or hide member functions and member function templates with the
same name, parameter-type-list (8.3.5), and cv-qualification in a base class (rather than conflicting).

[Example:

```cpp
struct B {
    virtual void f(int);
    virtual void f(char);
    void g(int);
    void h(int);
};

struct D : B {
    using B::f;                 //OK: D::f(int) overrides B::f(int);
    void f(int);                //OK
    using B::g;
    void g(char);

    using B::h;
    void h(int);                //OK: D::h(int) hides B::h(int)
};
```

void k(D* p)
{
    p->f(1);       // calls D::f(int)
    p->f('a');     // calls B::f(char)
    p->g(1);       // calls B::g(int)
    p->g('a');     // calls D::g(char)
}

— end example ]

[ Note: two using-declarations may introduce functions with the same name and the same parameter types. If, for a call to an unqualified function name, function overload resolution selects the functions introduced by such using-declarations, the function call is ill-formed. — end note ]

For the purpose of overload resolution, the functions which are introduced by a using-declaration into a derived class will be treated as though they were members of the derived class. In particular, the implicit this parameter shall be treated as if it were a pointer to the derived class rather than to the base class. This has no effect on the type of the function, and in all other respects the function remains a member of the base class.

All instances of the name mentioned in a using-declaration shall be accessible. In particular, if a derived class uses a using-declaration to access a member of a base class, the member name shall be accessible. If the name is that of an overloaded member function, then all functions named shall be accessible. The base class members mentioned by a using-declaration shall be visible in the scope of at least one of the direct base classes of the class where the using-declaration is specified. [ Note: because a using-declaration designates a base class member (and not a member subobject or a member function of a base class subobject), a using-declaration cannot be used to resolve inherited member ambiguities. For example,

struct A { int x(); };  
struct B : A { };  
struct C : A {
    using A::x;
    int x(int);
};  
struct D : B, C {
    using C::x;
    int x(double);
};  
int f(D* d) {
    return d->x();   // ambiguous: B::x or C::x
}

— end note ]

The alias created by the using-declaration has the usual accessibility for a member-declaration. [ Example: class A {
    private:
        void f(char);  
    public:
        void f(int);
}
protected:
    void g();
};

class B : public A {
    using A::f;                 // error: A::f(char) is inaccessible
public:
    using A::g;                 // B::g is a public synonym for A::g
};

— end example ]

[ Note: use of access-declarations (11.3) is deprecated; member using-declarations provide a better alternative. — end note ]

If a using-declaration uses the keyword typename and specifies a dependent name (14.6.2), the name introduced by the using-declaration is treated as a typedef-name (7.1.3).

7.3.4 Using directive

using-directive:
    using namespace ::opt nested-name-specifieropt namespace-name ;

1 A using-directive shall not appear in class scope, but may appear in namespace scope or in block scope. [ Note: when looking up a namespace-name in a using-directive, only namespace names are considered, see 3.4.6. — end note ]

2 A using-directive specifies that the names in the nominated namespace can be used in the scope in which the using-directive appears after the using-directive. During unqualified name lookup (3.4.1), the names appear as if they were declared in the nearest enclosing namespace which contains both the using-directive and the nominated namespace. [ Note: in this context, “contains” means “contains directly or indirectly”. — end note ]

3 A using-directive does not add any members to the declarative region in which it appears. [ Example:

    namespace A {
        int i;
        namespace B {
            namespace C {
                int i;
            }
            using namespace A::B::C;
            void f1() {
                i = 5;          // OK, C::i visible in B and hides A::i
            }
        }
        namespace D {
            using namespace B;
            using namespace C;
            void f2() {
                i = 5;          // ambiguous, B::C::i or A::i?
            }
        }
    }
    void f3() {

Draft
i = 5; // uses A::i
}
void f4() {
    i = 5; // ill-formed; neither i is visible
}

— end example ]

4 The using-directive is transitive: if a scope contains a using-directive that nominates a second namespace that itself contains using-directives, the effect is as if the using-directives from the second namespace also appeared in the first.

[Example:

namespace M {
    int i;
}
namespace N {
    int i;
    using namespace M;
}
void f() {
    using namespace N;
    i = 7; // error: both M::i and N::i are visible
}

For another example,

namespace A {
    int i;
}
namespace B {
    int i;
    int j;
    namespace C {
        namespace D {
            using namespace A;
            int j;
            int k;
            int a = i; // B::i hides A::i
        }
        using namespace D;
        int k = 89; // no problem yet
        int l = k; // ambiguous: C::k or D::k
        int m = i; // B::i hides A::i
        int n = j; // D::j hides B::j
    }
}

Draft
If a namespace is extended by an `extension-namespace-definition` after a `using-directive` for that namespace is given, the additional members of the extended namespace and the members of namespaces nominated by `using-directives` in the `extension-namespace-definition` can be used after the `extension-namespace-definition`.

If name lookup finds a declaration for a name in two different namespaces, and the declarations do not declare the same entity and do not declare functions, the use of the name is ill-formed. [Note: in particular, the name of an object, function or enumerator does not hide the name of a class or enumeration declared in a different namespace. For example,

```cpp
namespace A {
  class X {
  }
  extern "C" int g();
  extern "C++" int h();
}
namespace B {
  void X(int);
  extern "C" int g();
  extern "C++" int h();
}
using namespace A;
using namespace B;

void f() {
  X(1);  // error: name X found in two namespaces
  g();   // okay: name g refers to the same entity
  h();   // error: name h found in two namespaces
}
```

— end note ]

During overload resolution, all functions from the transitive search are considered for argument matching. The set of declarations found by the transitive search is unordered. [Note: in particular, the order in which namespaces were considered and the relationships among the namespaces implied by the `using-directives` do not cause preference to be given to any of the declarations found by the search. —end note] An ambiguity exists if the best match finds two functions with the same signature, even if one is in a namespace reachable through `using-directives` in the namespace of the other.89]

[Example:

```cpp
namespace D {
  int d1;
  void f(char);
}
using namespace D;

int d1;  // OK: no conflict with D::d1

namespace E {
```

89) During name lookup in a class hierarchy, some ambiguities may be resolved by considering whether one member hides the other along some paths (10.2). There is no such disambiguation when considering the set of names found as a result of following `using-directives`. 

Draft
145 Declarations

7.4 The \texttt{asm} declaration

\begin{verbatim}
int e;
void f(int);
}

namespace D { // namespace extension
int d2;
using namespace E;
void f(int);
}

void f()
{
    d1++;
    // error: ambiguous \texttt{::d1} or \texttt{D::d1}?
    ::d1++;
    // OK
    D::d1++;
    // OK
    d2++;
    // OK: D::d2
    e++;
    // OK: E::e
    f(1);
    // error: ambiguous: \texttt{D::f(int)} or \texttt{E::f(int)}?
    f('a');
    // OK: D::f(char)
}
\end{verbatim}

— end example ]

7.4 The \texttt{asm} declaration [dcl.asm]

An \texttt{asm} declaration has the form

\begin{verbatim}
asm-definition:
    asm ( string-literal ) ;
\end{verbatim}

The \texttt{asm} declaration is conditionally-supported; its meaning is implementation-defined. [Note: Typically it is used to pass information through the implementation to an assembler. — end note]

7.5 Linkage specifications [dcl.link]

All function types, function names with external linkage, and variable names with external linkage have a \textit{language linkage}. [Note: Some of the properties associated with an entity with language linkage are specific to each implementation and are not described here. For example, a particular language linkage may be associated with a particular form of representing names of objects and functions with external linkage, or with a particular calling convention, etc. — end note] The default language linkage of all function types, function names, and variable names is \texttt{C++} language linkage. Two function types with different language linkages are distinct types even if they are otherwise identical.

2 Linkage (3.5) between \texttt{C++} and non-\texttt{C++} code fragments can be achieved using a \textit{linkage-specification}:

\begin{verbatim}
linkage-specification:
    extern string-literal { declaration-seq_opt }
    extern string-literal declaration
\end{verbatim}

The \texttt{string-literal} indicates the required language linkage. This International Standard specifies the semantics for the \texttt{string-literals} "\texttt{C}" and "\texttt{C++}". Use of a \texttt{string-literal} other than "\texttt{C}" or "\texttt{C++}" is conditionally-supported, with implementation-defined semantics. [Note: Therefore, a linkage-specification with a \texttt{string-literal} that is unknown to the implementation requires a diagnostic. — end note] [Note: It is recommended that the spelling of the \texttt{string-literal} be
taken from the document defining that language. For example, Ada (not ADA) and Fortran or FORTRAN, depending on the vintage. — end note]

3 Every implementation shall provide for linkage to functions written in the C programming language, "C", and linkage to C++ functions, "C++". [Example:

```c
complex sqrt(complex);       // C++ linkage by default
extern "C" {
    double sqrt(double);   // C linkage
}
```

— end example]

4 Linkage specifications nest. When linkage specifications nest, the innermost one determines the language linkage. A linkage specification does not establish a scope. A linkage-specification shall occur only in namespace scope (3.3). In a linkage-specification, the specified language linkage applies to the function types of all function declarators, function names with external linkage, and variable names with external linkage declared within the linkage-specification. [Example:

```c
extern "C" void f1(void(*)(int));
    // the name f1 and its function type have C language
    // linkage; pf is a pointer to a C function
extern "C" typedef void FUNC();
    // the name f2 has C++ language linkage and the
    // function’s type has C language linkage
extern "C" FUNC f2;
    // the name of function f2 and the function’s type
    // have C language linkage
void (*pf2)(FUNC*);
    // the name of the variable pf2 has C++ linkage and
    // the type of pf2 is pointer to C++ function that
    // takes one parameter of type pointer to C function
extern "C" {
    static void f4();
        // the name of the function f4 has
        // internal linkage (not C language
        // linkage) and the function’s type
        // has C language linkage.
}
extern "C" void f5() {
    extern void f4();
        // OK: Name linkage (internal)
        // and function type linkage (C
        // language linkage) gotten from
        // previous declaration.
}
extern void f4();
    // OK: Name linkage (internal)
    // and function type linkage (C
    // language linkage) gotten from
    // previous declaration.
}
void f6() {
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5 If two declarations of the same function or object specify different linkage-specifications (that is, the linkage-specifications of these declarations specify different string-literals), the program is ill-formed if the declarations appear in the same translation unit, and the one definition rule (3.2) applies if the declarations appear in different translation units. Except for functions with C++ linkage, a function declaration without a linkage specification shall not precede the first linkage specification for that function. A function can be declared without a linkage specification after an explicit linkage specification has been seen; the linkage explicitly specified in the earlier declaration is not affected by such a function declaration.

6 At most one function with a particular name can have C language linkage. Two declarations for a function with C language linkage with the same function name (ignoring the namespace names that qualify it) that appear in different namespace scopes refer to the same function. Two declarations for an object with C language linkage with the same name (ignoring the namespace names that qualify it) that appear in different namespace scopes refer to the same object. [ Note: because of the one definition rule (3.2), only one definition for a function or object with C linkage may appear in the program; that is, such a function or object must not be defined in more than one namespace scope. For example, ]
7.5 Linkage specifications

```cpp
extern "C" int g() { return 1; }
extern "C" int h();
}

namespace B {
extern "C" int f();  // A::f and B::f refer
               // to the same function
extern "C" int g() { return 1; }  // ill-formed, the function g
               // with C language linkage
               // has two definitions
}

int A::f() { return 98; }  // definition for the function f
               // with C language linkage
extern "C" int h() { return 97; }  // definition for the function h
               // with C language linkage
               // A::h and ::h refer to the same function
```

— end note ]

A declaration directly contained in a linkage-specification is treated as if it contains the extern specifier (7.1.1) for the purpose of determining the linkage of the declared name and whether it is a definition. Such a declaration shall not specify a storage class. [ Example:

```cpp
extern "C" double f();
static double f();  // error
extern "C" int i;  // declaration
extern "C" {
    int i;  // definition
}
extern "C" static void g();  // error
```

— end example ]

[ Note: because the language linkage is part of a function type, when a pointer to C function (for example) is dereferenced, the function to which it refers is considered a C function. — end note ]

Linkage from C++ to objects defined in other languages and to objects defined in C++ from other languages is implementation-defined and language-dependent. Only where the object layout strategies of two language implementations are similar enough can such linkage be achieved.
Chapter 8  Declarators

1  A declarator declares a single object, function, or type, within a declaration. The *init-declarator-list* appearing in a declaration is a comma-separated sequence of declarators, each of which can have an initializer.

   *init-declarator-list*:
   
   init-declarator
   init-declarator-list , init-declarator

   init-declarator:
   declarator initializer_opt

2  The two components of a *declaration* are the specifiers (*decl-specifier-seq*; 7.1) and the declarators (*init-declarator-list*). The specifiers indicate the type, storage class or other properties of the objects, functions or typedefs being declared. The declarators specify the names of these objects, functions or typedefs, and (optionally) modify the type of the specifiers with operators such as * (pointer to) and () (function returning). Initial values can also be specified in a declarator; initializers are discussed in 8.5 and 12.6.

3  Each *init-declarator* in a declaration is analyzed separately as if it was in a declaration by itself.\(^90\)

4  Declarators have the syntax

   declarator:
   direct-declarator
   ptr-operator declarator

   direct-declarator:
   declarator-id
   direct-declarator ( parameter-declaration-clause ) cv-qualifier-seq_opt exception-specification_opt
   direct-declarator [ constant-expression_opt ]
   ( declarator )

\(^90\) A declaration with several declarators is usually equivalent to the corresponding sequence of declarations each with a single declarator. That is

   T D1, D2, ... Dn;

   is usually equivalent to

   T D1; T D2; ... T Dn;

   where T is a *decl-specifier-seq* and each Di is an *init-declarator*. The exception occurs when a name introduced by one of the declarators hides a type name used by the *decl-specifiers*, so that when the same *decl-specifiers* are used in a subsequent declaration, they do not have the same meaning, as in

   struct S { ... };
   S S, T; // declare two instances of struct S

   which is not equivalent to

   struct S { ... };
   S S;
   S T; // error
8.1 Type names

ptr-operator:

* cv-qualifier-seq<sub>opt</sub>
&
::<sub>opt</sub> nested-name-specifier * cv-qualifier-seq<sub>opt</sub>
cv-qualifier-seq:

cv-qualifier cv-qualifier-seq<sub>opt</sub>
cv-qualifier:

const
volatile
declarator-id:

id-expression
::<sub>opt</sub> nested-name-specifier<sub>opt</sub> class-name

A class-name has special meaning in a declaration of the class of that name and when qualified by that name using the scope resolution operator :: (5.1, 12.1, 12.4).

8.1 Type names

To specify type conversions explicitly, and as an argument of sizeof, new, or typeid, the name of a type shall be specified. This can be done with a type-id, which is syntactically a declaration for an object or function of that type that omits the name of the object or function.

type-id:

type-specifier-seq abstract-declarator<sub>opt</sub>
type-specifier-seq:

type-specifier type-specifier-seq<sub>opt</sub>
abstract-declarator:

ptr-operator abstract-declarator<sub>opt</sub>
direct-abstract-declarator

direct-abstract-declarator:

direct-abstract-declarator<sub>opt</sub>
( parameter-declaration-clause ) cv-qualifier-seq<sub>opt</sub> exception-specification<sub>opt</sub>
direct-abstract-declarator<sub>opt</sub> [ constant-expression<sub>opt</sub> ]
 ( abstract-declarator )

It is possible to identify uniquely the location in the abstract-declarator where the identifier would appear if the construction were a declarator in a declaration. The named type is then the same as the type of the hypothetical identifier.

[ Example: ]

```c
int    // int i
int *   // int *pi
int *[3] // int *p[3]
int (*)(double) // int (*pf)(double)
```

name respectively the types “int,” “pointer to int,” “array of 3 pointers to int,” “pointer to array of 3 int,” “function of (no parameters) returning pointer to int,” and “pointer to a function of (double) returning int.” — end example }
A type can also be named (often more easily) by using a `typedef` (7.1.3).

### 8.2 Ambiguity resolution

The ambiguity arising from the similarity between a function-style cast and a declaration mentioned in 6.8 can also occur in the context of a declaration. In that context, the choice is between a function declaration with a redundant set of parentheses around a parameter name and an object declaration with a function-style cast as the initializer. Just as for the ambiguities mentioned in 6.8, the resolution is to consider any construct that could possibly be a declaration a declaration. 

**Note:** a declaration can be explicitly disambiguated by a nonfunction-style cast, by an = to indicate initialization or by removing the redundant parentheses around the parameter name. — *end note* 

#### Example:

```cpp
struct S {
    S(int);
};

void foo(double a)
{
    S w(int(a)); // function declaration
    S x(int());  // function declaration
    S y((int)a);  // object declaration
    S z = int(a); // object declaration
}

/* end example */
```

The ambiguity arising from the similarity between a function-style cast and a *type-id* can occur in different contexts. The ambiguity appears as a choice between a function-style cast expression and a declaration of a type. The resolution is that any construct that could possibly be a *type-id* in its syntactic context shall be considered a *type-id*.

#### Example:

```cpp
#include <cstdlib>
char *p;
void *operator new(std::size_t, int);
void foo() {
    const int x = 63;
    new (int(*p)) int;       // new-placement expression
    new (int(*[x]));         // new type-id
}

/* end example */
```

For another example,

```cpp
template <class T>
struct S {
    T *p;
};
S<int()> x;       //type-id
S<int(1)> y;      // expression (ill-formed)
```

For another example,
void foo()
{
    sizeof(int(1));  // expression
    sizeof(int());  // type-id (ill-formed)
}

For another example,
void foo()
{
    (int(1));  // expression
    (int())1;  // type-id (ill-formed)
}

— end example ]

Another ambiguity arises in a parameter-declaration-clause of a function declaration, or in a type-id that is the operand of a sizeof or typeid operator, when a type-name is nested in parentheses. In this case, the choice is between the declaration of a parameter of type pointer to function and the declaration of a parameter with redundant parentheses around the declarator-id. The resolution is to consider the type-name as a simple-type-specifier rather than a declarator-id. [ Example:

class C { };  
void f(int(C)) { }  // void f(int(*fp)(C c)) { }  // not: void f(int C);

int g(C);

void foo() {
    f(1);  // error: cannot convert 1 to function pointer
    f(g);  // OK
}

For another example,

class C { }
void h(int *(C[10]));  // void h(int *(fp)(C _parm[10]));  // not: void h(int *C[10]);

— end example ]

8.3 Meaning of declarators [dcl.meaning]

A list of declarators appears after an optional (clause 7) decl-specifier-seq (7.1). Each declarator contains exactly one declarator-id; it names the identifier that is declared. An unqualified-id occurring in a declarator-id shall be a simple identifier except for the declaration of some special functions (12.3, 12.4, 13.5) and for the declaration of template specializations or partial specializations (14.7). A declarator-id shall not be qualified except for the definition of a member function (9.3) or static data member (9.4) outside of its class, the definition or explicit instantiation of a function or variable member of a namespace outside of its namespace, or the definition of a previously declared explicit specialization outside of its namespace, or the declaration of a friend function that is a member of another class or namespace (11.4). When the declarator-id is qualified, the declaration shall refer to a previously declared member
of the class or namespace to which the qualifier refers, and the member shall not have been introduced by a using-declaration in the scope of the class or namespace nominated by the nested-name-specifier of the declarator-id. [Note: if the qualifier is the global :: scope resolution operator, the declarator-id refers to a name declared in the global namespace scope. — end note]

2 An auto, static, extern, register, mutable, friend, inline, virtual, or typedef specifier applies directly to each declarator-id in an init-declarator-list; the type specified for each declarator-id depends on both the decl-specifier-seq and its declarator.

3 Thus, a declaration of a particular identifier has the form

\text{T D}

where T is a decl-specifier-seq and D is a declarator. Following is a recursive procedure for determining the type specified for the contained declarator-id by such a declaration.

4 First, the decl-specifier-seq determines a type. In a declaration

\text{T D}

the decl-specifier-seq T determines the type \text{T}. [Example: in the declaration

\text{int unsigned i;}

the type specifiers int unsigned determine the type “unsigned int” (7.1.5.2). — end example]

5 In a declaration T \text{D} where D is an unadorned identifier the type of this identifier is “T.”

6 In a declaration T D where D has the form

\text{( D1 )}

the type of the contained declarator-id is the same as that of the contained declarator-id in the declaration

\text{T D1}

Parentheses do not alter the type of the embedded declarator-id, but they can alter the binding of complex declarators.

8.3.1 Pointers \[dcl.ptr\]

1 In a declaration T D where D has the form

\text{\ast cv-qualifier-seq_{opt} D1}

and the type of the identifier in the declaration T D1 is “derived-declarator-type-list T,” then the type of the identifier of D is “derived-declarator-type-list cv-qualifier-seq pointer to T.” The cv-qualifiers apply to the pointer and not to the object pointed to.

2 [Example: the declarations

\text{const int ci = 10, \ast pc = \&ci, \ast const cpc = pc, \ast\ast ppc;}
\text{int i, \ast p, \ast const cp = \&i;}

Draft
8.3 Meaning of declarators

declare ci, a constant integer; pc, a pointer to a constant integer; cpc, a constant pointer to a constant integer; ppc, a pointer to a pointer to a constant integer; i, an integer; p, a pointer to integer; and cp, a constant pointer to integer. The value of ci, cpc, and cp cannot be changed after initialization. The value of pc can be changed, and so can the object pointed to by cp. Examples of some correct operations are

```c
i = ci;
*cp = ci;
pc++;
pc = cpc;
pc = p;
ppc = &pc;
```

Examples of ill-formed operations are

```c
ci = 1; // error
ci++; // error
*pc = 2; // error
cp = &ci; // error
cpc++; // error
p = pc; // error
ppc = &p; // error
```

Each is unacceptable because it would either change the value of an object declared const or allow it to be changed through a cv-unqualified pointer later, for example:

```c
*ppc = &ci; // OK, but would make p point to ci ...
   //... because of previous error
*p = 5; // clobber ci
```

— end example ]

3 See also 5.17 and 8.5.

4 [ Note: there are no pointers to references; see 8.3.2. Since the address of a bit-field (9.6) cannot be taken, a pointer can never point to a bit-field. — end note ]

8.3.2 References

1 In a declaration T D where D has the form

```c
&D1
```

and the type of the identifier in the declaration T D1 is “derived-declarator-type-list T,” then the type of the identifier of D is “derived-declarator-type-list reference to T.” Cv-qualified references are ill-formed except when the cv-qualifiers are introduced through the use of a typedef (7.1.3) or of a template type argument (14.3), in which case the cv-qualifiers are ignored. [ Example: in

```c
typedef int& A;
const A aref = 3; // ill-formed;
   // non-const reference initialized with rvalue
```

Draft
the type of aref is “reference to int”, not “const reference to int”. — end example] [Note: a reference can be thought of as a name of an object. — end note] A declarator that specifies the type “reference to cv void” is ill-formed.

2 [Example:

void f(double& a) { a += 3.14; }
// ... double d = 0;
f(d);

declarates a to be a reference parameter of f so the call f(d) will add 3.14 to d.

int v[20];
// ... int& g(int i) { return v[i]; }
// ... g(3) = 7;

declarates the function g() to return a reference to an integer so g(3)=7 will assign 7 to the fourth element of the array v. For another example,

struct link {
  link* next;
};

link* first;

void h(link*& p)  // p is a reference to pointer
{
  p->next = first;
  first = p;
  p = 0;
}

void k()
{
  link* q = new link;
  h(q);
}

declarates p to be a reference to a pointer to link so h(q) will leave q with the value zero. See also 8.5.3. — end example]

3 It is unspecified whether or not a reference requires storage (3.7).

4 There shall be no references to references, no arrays of references, and no pointers to references. The declaration of a reference shall contain an initializer (8.5.3) except when the declaration contains an explicit extern specifier (7.1.1), is a class member (9.2) declaration within a class definition, or is the declaration of a parameter or a return type (8.3.5); see 3.1. A reference shall be initialized to refer to a valid object or function. [Note: in particular, a null reference cannot exist in a well-defined program, because the only way to create such a reference would be to bind it to the “object”
obtained by dereferencing a null pointer, which causes undefined behavior. As described in 9.6, a reference cannot be bound directly to a bit-field. — end note ]

8.3.3 Pointers to members [dcl.mptr]

In a declaration T D where D has the form

```
D1 : opt nested-name-specifier * cv-qualifier-seq opt
```

and the nested-name-specifier names a class, and the type of the identifier in the declaration T D1 is “derived-declarator-type-list T,” then the type of the identifier of D is “derived-declarator-type-list cv-qualifier-seq pointer to member of class nested-name-specifier of type T.”

Example:

```c
class X {
public:
    void f(int);
    int a;
};
class Y;

int X::* pmi = &X::a;
void (X::* pmf)(int) = &X::f;
double X::* pmd;
char Y::* pmc;
```

declares pmi, pmf, pmd and pmc to be a pointer to a member of X of type int, a pointer to a member of X of type void(int), a pointer to a member of X of type double and a pointer to a member of Y of type char respectively. The declaration of pmd is well-formed even though X has no members of type double. Similarly, the declaration of pmc is well-formed even though Y is an incomplete type. pmi and pmf can be used like this:

```c
X obj;
// ...
obj.*pmi = 7; // assign 7 to an integer
// member of obj
(obj.*pmf)(7); // call a function member of obj
// with the argument 7
```

— end example ]

A pointer to member shall not point to a static member of a class (9.4), a member with reference type, or “cv void.” [Note: see also 5.3 and 5.5. The type “pointer to member” is distinct from the type “pointer”, that is, a pointer to member is declared only by the pointer to member declarator syntax, and never by the pointer declarator syntax. There is no “reference-to-member” type in C++. — end note ]

8.3.4 Arrays [dcl.array]

In a declaration T D where D has the form

```
D1 [ constant-expression opt ]
```
and the type of the identifier in the declaration T D1 is "derived-declarator-type-list T," then the type of the identifier of D is an array type; if the type of the identifier of D contains the auto type deduction type-specifier, the program is ill-formed. T is called the array element type; this type shall not be a reference type, the (possibly cv-qualified) type void, a function type or an abstract class type. If the constant-expression (5.19) is present, it shall be an integral constant expression and its value shall be greater than zero. The constant expression specifies the bound of (number of elements in) the array. If the value of the constant expression is N, the array has N elements numbered 0 to N−1, and the type of the identifier of D is "derived-declarator-type-list array of N T." An object of array type contains a contiguously allocated non-empty set of N subobjects of type T. If the constant expression is omitted, the type of the identifier of D is "derived-declarator-type-list array of unknown bound of T," an incomplete object type. The type "derived-declarator-type-list array of N T" is a different type from the type "derived-declarator-type-list array of unknown bound of T," see 3.9. Any type of the form "cv-qualifier-seq array of N T" is adjusted to "array of N cv-qualifier-seq T," and similarly for "array of unknown bound of T." [Example:

typedef int A[5], AA[2][3];
typedef const A CA; // type is "array of 5 const int"
typedef const AA CAA; // type is "array of 2 array of 3 const int"

— end example ] [ Note: an “array of N cv-qualifier-seq T” has cv-qualified type; see 3.9.3. — end note ]

2 An array can be constructed from one of the fundamental types (except void), from a pointer, from a pointer to member, from a class, from an enumeration type, or from another array.

3 When several “array of” specifications are adjacent, a multidimensional array is created; the constant expressions that specify the bounds of the arrays can be omitted only for the first member of the sequence. [ Note: this elision is useful for function parameters of array types, and when the array is external and the definition, which allocates storage, is given elsewhere. — end note ] The first constant-expression can also be omitted when the declarator is followed by an initializer (8.5). In this case the bound is calculated from the number of initial elements (say, N) supplied (8.5.1), and the type of the identifier of D is “array of N T.”

[ Example:

float fa[17], *afp[17];

declares an array of float numbers and an array of pointers to float numbers. For another example,

static int x3d[3][5][7];

declares a static three-dimensional array of integers, with rank 3 × 5 × 7. In complete detail, x3d is an array of three items; each item is an array of five arrays; each of the latter arrays is an array of seven integers. Any of the expressions x3d, x3d[i], x3d[i][j], x3d[i][j][k] can reasonably appear in an expression. — end example ]

[ Note: conversions affecting lvalues of array type are described in 4.2. Objects of array types cannot be modified, see 3.10. — end note ]

4 Except where it has been declared for a class (13.5.5), the subscript operator [] is interpreted in such a way that E1[E2] is identical to *((E1)+(E2)). Because of the conversion rules that apply to *, if E1 is an array and E2 an integer, then E1[E2] refers to the E2-th member of E1. Therefore, despite its asymmetric appearance, subscripting is a commutative operation.

5 A consistent rule is followed for multidimensional arrays. If E is an n-dimensional array of rank i × j × ... × k, then E appearing in an expression is converted to a pointer to an (n−1)-dimensional array with rank j × ... × k. If the *
operator, either explicitly or implicitly as a result of subscripting, is applied to this pointer, the result is the pointed-to
\((n-1)\)-dimensional array, which itself is immediately converted into a pointer.

8 [ Example: consider

\[
\text{int } x[3][5];
\]

Here \(x\) is a \(3 \times 5\) array of integers. When \(x\) appears in an expression, it is converted to a pointer to (the first of three)
five-membered arrays of integers. In the expression \(x[i]\) which is equivalent to \(*((x+i))\), \(x\) is first converted to a pointer
as described; then \(x+i\) is converted to the type of \(x\), which involves multiplying \(i\) by the length of the object to which
the pointer points, namely five integer objects. The results are added and indirection applied to yield an array (of five
integers), which in turn is converted to a pointer to the first of the integers. If there is another subscript the same argument
applies again; this time the result is an integer. — end example ]

9 [ Note: it follows from all this that arrays in C++ are stored row-wise (last subscript varies fastest) and that the first
subscript in the declaration helps determine the amount of storage consumed by an array but plays no other part in
subscript calculations. — end note ]

8.3.5 Functions [dcl.fct]

1 In a declaration \(T \ D\) where \(D\) has the form

\[
D1 \ ( \text{parameter-declaration-clause} ) \ \text{cv-qualifier-seq}_{opt} \ \text{exception-specification}_{opt} \quad \text{and the}
\]

the type of the contained declarator-id in the declaration \(T \ D1\) is “\(\text{derived-declarator-type-list} \ T\)” the type of the declarator-
id in \(D\) is “\(\text{derived-declarator-type-list} \ \text{function of} \ (\text{parameter-declaration-clause} ) \ \text{cv-qualifier-seq}_{opt} \ \text{returning} \ T\)” a type of
this form is a function type\(91)\).

\[
\text{parameter-declaration-clause:}
\]

\[
\text{parameter-declaration-list}_{opt} ..._{opt}
\]

\[
\text{parameter-declaration-list , ...}
\]

\[
\text{parameter-declaration:}
\]

\[
\text{parameter-declaration-list , parameter-declaration}
\]

\[
\text{parameter-declaration:}
\]

\[
\text{decl-specifier-seq declarator}
\]

\[
\text{decl-specifier-seq declarator} = \text{assignment-expression}
\]

\[
\text{decl-specifier-seq abstract-declarator}_{opt}
\]

\[
\text{decl-specifier-seq abstract-declarator}_{opt} = \text{assignment-expression}
\]

2 The parameter-declaration-clause determines the arguments that can be specified, and their processing, when the func-
tion is called. [ Note: the parameter-declaration-clause is used to convert the arguments specified on the function call;
see 5.2.2. — end note ] If the parameter-declaration-clause is empty, the function takes no arguments. The parameter
list (void) is equivalent to the empty parameter list. Except for this special case, void shall not be a parameter type
(though types derived from void, such as void*, can). If the parameter-declaration-clause terminates with an ellipsis,
the number of arguments shall be equal to or greater than the number of parameters that do not have a default argument.
Where syntactically correct, “...” is synonymous with “... “. [ Example: the declaration

\[
\text{int printf(const char*, ...);}
\]

declares a function that can be called with varying numbers and types of arguments.

\(91)\) As indicated by the syntax, cv-qualifiers are a significant component in function return types.
printf("hello world");
printf("a=%d b=%d", a, b);

However, the first argument must be of a type that can be converted to a `const char*` [Note: the standard header `<stdarg>` contains a mechanism for accessing arguments passed using the ellipsis (see 5.2.2 and 18.8). — end note]

3 A single name can be used for several different functions in a single scope; this is function overloading (clause 13). All declarations for a function shall agree exactly in both the return type and the parameter-type-list. The type of a function is determined using the following rules. The type of each parameter is determined from its own `decl-specifier-seq` and `declinator`. After determining the type of each parameter, any parameter of type “array of T” or “function returning T” is adjusted to be “pointer to T” or “pointer to function returning T,” respectively. After producing the list of parameter types, several transformations take place upon these types to determine the function type. Any `cv-qualifier` modifying a parameter type is deleted. [Example: the type `void(*)(const int)` becomes `void(*)(int)` — end example] Such `cv-qualifiers` affect only the definition of the parameter within the body of the function; they do not affect the function type. If a `storage-class-specifier` modifies a parameter type, the specifier is deleted. [Example: `register char*` becomes `char*` — end example] Such `storage-class-specifiers` affect only the definition of the parameter within the body of the function; they do not affect the function type. The resulting list of transformed parameter types and the presence or absence of the ellipsis is the function’s `parameter-type-list`.

4 A `cv-qualifier-seq` shall only be part of the function type for a non-static member function, the function type to which a pointer to member refers, or the top-level function type of a function typedef declaration. The effect of a `cv-qualifier-seq` in a function declarator is not the same as adding cv-qualification on top of the function type. In the latter case, the cv-qualifiers are ignored. [Example:
```c
typedef void F();
struct S {
    const F f;
};

— end example ] The return type, the parameter-type-list and the `cv-qualifier-seq`, but not the default arguments (8.3.6) or the exception specification (15.4), are part of the function type. [Note: function types are checked during the assignments and initializations of pointer-to-functions, reference-to-functions, and pointer-to-member-functions. — end note ]

5 [ Example: the declaration
```c
int fseek(FILE*, long, int);
```
defines a function taking three arguments of the specified types, and returning `int` (7.1.5). — end example ]

6 If the type of a parameter includes a type of the form “pointer to array of unknown bound of T” or “reference to array of unknown bound of T,” the program is ill-formed. Functions shall not have a return type of type array or function, although they may have a return type of type pointer or reference to such things. There shall be no arrays of functions, although there can be arrays of pointers to functions. Types shall not be defined in return or parameter types. The type of a parameter or the return type for a function definition shall not be an incomplete class type (possibly cv-qualified)
unless the function definition is nested within the member-specification for that class (including definitions in nested classes defined within the class).

7 A typedef of function type may be used to declare a function but shall not be used to define a function (8.4). [Example:

typedef void F();
F fv;  // OK: equivalent to void fv();
F fv { }  // ill-formed
void fv() { }  // OK: definition of fv

— end example] A typedef of a function type whose declarator includes a cv-qualifier-seq shall be used only to declare the function type for a non-static member function, to declare the function type to which a pointer to member refers, or to declare the top-level function type of another function typedef declaration. [Example:

typedef int FIC(int) const;
FIC f;  // ill-formed: does not declare a member function
struct S {
  FIC f;  // OK
};
FIC S::*pm = &S::f;  // OK

— end example]

8 An identifier can optionally be provided as a parameter name; if present in a function definition (8.4), it names a parameter (sometimes called “formal argument”). [Note: in particular, parameter names are also optional in function definitions and names used for a parameter in different declarations and the definition of a function need not be the same. If a parameter name is present in a function declaration that is not a definition, it cannot be used outside of the parameter-declaration-clause since it goes out of scope at the end of the function declarator (3.3). — end note]

9 [Example: the declaration

int i,
  *pi,
  f(),
  *fpi(int),
  (*fpi)(const char*, const char*),
  (*fpi(int))(int);

declares an integer i, a pointer pi to an integer, a function f taking no arguments and returning an integer, a function fpi taking an integer argument and returning a pointer to an integer, a pointer pif to a function which takes two pointers to constant characters and returns an integer, a function fpif taking an integer argument and returning a pointer to a function that takes an integer argument and returns an integer. It is especially useful to compare fpi and pif. The binding of *fpi(int) is *(fpi(int)), so the declaration suggests, and the same construction in an expression requires, the calling of a function fpi, and then using indirection through the (pointer) result to yield an integer. In the declarator (*fpi)(const char*, const char*), the extra parentheses are necessary to indicate that indirection through a pointer to a function yields a function, which is then called. — end example] [Note: typedefs are sometimes convenient when the return type of a function is complex. For example, the function fpif above could have been declared

typedef int IFUNC(int);
IFUNC* fpif(int);

Draft
8.3.6 Default arguments

If an expression is specified in a parameter declaration this expression is used as a default argument. Default arguments will be used in calls where trailing arguments are missing.

Example: the declaration

```c
void point(int = 3, int = 4);
```

declares a function that can be called with zero, one, or two arguments of type `int`. It can be called in any of these ways:

```
point(1,2); point(1); point();
```

The last two calls are equivalent to `point(1,4)` and `point(3,4)`, respectively. — end example

A default argument expression shall be specified only in the `parameter-declaration-clause` of a function declaration or in a `template-parameter` (14.1). If it is specified in a `parameter-declaration-clause`, it shall not occur within a `declarator` or `abstract-declarator` of a `parameter-declaration`.93)

For non-template functions, default arguments can be added in later declarations of a function in the same scope. Declarations in different scopes have completely distinct sets of default arguments. That is, declarations in inner scopes do not acquire default arguments from declarations in outer scopes, and vice versa. In a given function declaration, all parameters subsequent to a parameter with a default argument shall have default arguments supplied in this or previous declarations. A default argument shall not be redefined by a later declaration (not even to the same value). [Example:

```c
void g(int = 0, ...); // OK, ellipsis is not a parameter so it can follow
void f(int, int); // a parameter with a default argument
void f(int, int = 7);
void h()
{
  f(3); // OK, calls f(3, 7)
  void f(int = 1, int); // error: does not use default
  // from surrounding scope
}
```

```c
void m()
{
  void f(int, int); // has no defaults
  f(4); // error: wrong number of arguments
  void f(int, int = 5); // OK
  f(4); // OK, calls f(4, 5);
  void f(int, int = 5); // error: cannot redefine, even to
  // same value
}
```

93) This means that default arguments cannot appear, for example, in declarations of pointers to functions, references to functions, or `typedef` declarations.
8.3 Meaning of declarators

```c
f(6);  // OK, calls f(6, 7)
}
```

— end example] For a given inline function defined in different translation units, the accumulated sets of default arguments at the end of the translation units shall be the same; see 3.2. If a friend declaration specifies a default argument expression, that declaration must be a definition and shall be the only declaration of the function or function template in the translation unit.

A default argument expression is implicitly converted (clause 4) to the parameter type. The default argument expression has the same semantic constraints as the initializer expression in a declaration of a variable of the parameter type, using the copy-initialization semantics (8.5). The names in the expression are bound, and the semantic constraints are checked, at the point where the default argument expression appears. Name lookup and checking of semantic constraints for default arguments in function templates and in member functions of class templates are performed as described in 14.7.1. [Example: in the following code, `g` will be called with the value `f(2)`:

```c
int a = 1;
int f(int);
int g(int x = f(a));  // default argument: f(::a)

void h() {
  a = 2;
  {
    int a = 3;
    g();  // g(f(::a))
  }
}
```

— end example] [Note: in member function declarations, names in default argument expressions are looked up as described in 3.4.1. Access checking applies to names in default argument expressions as described in clause 11. — end note]

Except for member functions of class templates, the default arguments in a member function definition that appears outside of the class definition are added to the set of default arguments provided by the member function declaration in the class definition. Default arguments for a member function of a class template shall be specified on the initial declaration of the member function within the class template. [Example:

```c
class C {
  void f(int i = 3);
  void g(int i, int j = 99);
};

void C::f(int i = 3)  // error: default argument already
{ }
// specified in class scope
void C::g(int i = 88, int j)  // in this translation unit,
{ }  // C::g can be called with no argument

— end example]

Local variables shall not be used in default argument expressions. [Example:
void f()
{
    int i;
    extern void g(int x = i);  //error
    // ...
}

— end example ]

8 The keyword this shall not be used in a default argument of a member function. [ Example:

    class A {
    void f(A* p = this) { }    // error
    }

    — end example ]

9 Default arguments are evaluated each time the function is called. The order of evaluation of function arguments is unspecified. Consequently, parameters of a function shall not be used in default argument expressions, even if they are not evaluated. Parameters of a function declared before a default argument expression are in scope and can hide namespace and class member names. [ Example:

    int a;
    int f(int a, int b = a); // error: parameter a
    // used as default argument

typedef int I;
    int g(float I, int b = I(2)); // error: parameter I found
    int h(int a, int b = sizeof(a)); // error, parameter a used
    // in default argument

    — end example ] Similarly, a non-static member shall not be used in a default argument expression, even if it is not evaluated, unless it appears as the id-expression of a class member access expression (5.2.5) or unless it is used to form a pointer to member (5.3.1). [ Example: the declaration of X::mem1() in the following example is ill-formed because no object is supplied for the non-static member X::a used as an initializer.

    int b;
    class X {
        int a;
        int mem1(int i = a); // error: non-static member a
        // used as default member
        int mem2(int i = b); // OK; use X::b
        static int b;
    }

    — end example ]

The declaration of X::mem2() is meaningful, however, since no object is needed to access the static member X::b. Classes, objects, and members are described in clause 9. — end example ] A default argument is not part of the type of a function. [ Example:

    int f(int = 0);

    void h()
8.4 Function definitions

{   
    int j = f(1);  
    int k = f();   
    // OK, means f(0)  
}

int (*p1)(int) = &f;   
int (*p2)() = &f;       
// error: type mismatch

— end example —

When a declaration of a function is introduced by way of a using-declaration (7.3.3), any default argument information associated with the declaration is made known as well. If the function is redeclared thereafter in the namespace with additional default arguments, the additional arguments are also known at any point following the redeclaration where the using-declaration is in scope.

A virtual function call (10.3) uses the default arguments in the declaration of the virtual function determined by the static type of the pointer or reference denoting the object. An overriding function in a derived class does not acquire default arguments from the function it overrides. [Example:

```c
struct A {
    virtual void f(int a = 7);
};
struct B : public A {
    void f(int a);
};
void m() {
    B* pb = new B;
    A* pa = pb;
    pa->f();    
    // OK, calls pa->B::f(7)
    pb->f();    
    // error: wrong number of arguments for B::f()
}
```

— end example —

8.4 Function definitions

Function definitions have the form

function-definition:
    decl-specifier-seq_opt declarator ctor-initializer_opt function-body
    decl-specifier-seq_opt declarator function-try-block

function-body:
    compound-statement

The declarator in a function-definition shall have the form

D1 ( parameter-declaration-clause ) cv-qualifier-seq_opt exception-specification_opt

as described in 8.3.5. A function shall be defined only in namespace or class scope.

[Example: a simple example of a complete function definition is

```c
int max(int a, int b, int c) {
```
int m = (a > b) ? a : b;
return (m > c) ? m : c;
}

Here `int` is the `decl-specifier-seq`; `max(int a, int b, int c)` is the `declarator`; `{ /* ... */ }` is the `function-body`.  
— end example

4 A `ctor-initializer` is used only in a constructor; see 12.1 and 12.6.

5 A `cv-qualifier-seq` can be part of a non-static member function declaration, non-static member function definition, or pointer to member function only; see 9.3.2. It is part of the function type.

6 [Note: unused parameters need not be named. For example,

```c
void print(int a, int)
{
    std::printf("a = %d\n",a);
}
— end note]

8.5 Initializers

1 A declarator can specify an initial value for the identifier being declared. The identifier designates an object or reference being initialized. The process of initialization described in the remainder of 8.5 applies also to initializations specified by other syntactic contexts, such as the initialization of function parameters with argument expressions (5.2.2) or the initialization of return values (6.6.3).

```
initializer:
    = initializer-clause
    ( expression-list )
initializer-clause:
    assignment-expression
    { initializer-list ,opt }
    { }
initializer-list:
    initializer-clause
    initializer-list , initializer-clause
```

2 Automatic, register, static, and external variables of namespace scope can be initialized by arbitrary expressions involving literals and previously declared variables and functions. [Example:

```
int f(int);
int a = 2;
int b = f(a);
int c(b);
— end example]

3 [Note: default argument expressions are more restricted; see 8.3.6.

The order of initialization of static objects is described in 3.6 and 6.7. — end note]
4 To zero-initialize an object of type \( T \) means:
   — if \( T \) is a scalar type (3.9), the object is set to the value 0 (zero), taken as an integral constant expression, converted to \( T \);
   — if \( T \) is a non-union class type, each non-static data member and each base-class subobject is zero-initialized;
   — if \( T \) is a union type, the object’s first named data member\(^{95}\) is zero-initialized;
   — if \( T \) is an array type, each element is zero-initialized;
   — if \( T \) is a reference type, no initialization is performed.

5 To default-initialize an object of type \( T \) means:
   — if \( T \) is a non-POD class type (clause 9), the default constructor for \( T \) is called (and the initialization is ill-formed if \( T \) has no accessible default constructor);
   — if \( T \) is an array type, each element is default-initialized;
   — otherwise, the object is zero-initialized.

To value-initialize an object of type \( T \) means:
   — if \( T \) is a class type (clause 9) with a user-declared constructor (12.1), then the default constructor for \( T \) is called (and the initialization is ill-formed if \( T \) has no accessible default constructor);
   — if \( T \) is a non-union class type without a user-declared constructor, then every non-static data member and base-class component of \( T \) is value-initialized;\(^{96}\)
   — if \( T \) is an array type, then each element is value-initialized;
   — otherwise, the object is zero-initialized.

6 A program that calls for default-initialization or value-initialization of an entity of reference type is ill-formed. If \( T \) is a cv-qualified type, the cv-unqualified version of \( T \) is used for these definitions of zero-initialization, default-initialization, and value-initialization.

7 Every object of static storage duration shall be zero-initialized at program startup before any other initialization takes place. [Note: in some cases, additional initialization is done later. — end note]

8 An object whose initializer is an empty set of parentheses, i.e., (), shall be value-initialized.

   [Note: since () is not permitted by the syntax for initializer,]
   \[
   X \ a();
   \]

   is not the declaration of an object of class \( X \), but the declaration of a function taking no argument and returning an \( X \). The form () is permitted in certain other initialization contexts (5.3.4, 5.2.3, 12.6.2). — end note]

9 If no initializer is specified for an object, and the object is of (possibly cv-qualified) non-POD class type (or array thereof), the object shall be default-initialized; if the object is of const-qualified type, the underlying class type shall have a user-declared default constructor. Otherwise, if no initializer is specified for a non-static object, the object and

\(^{94}\) As specified in 4.10; converting an integral constant expression whose value is 0 to a pointer type results in a null pointer value.
\(^{95}\) This member must not be static, by virtue of the requirements in 9.5.
\(^{96}\) Value-initialization for such a class object may be implemented by zero-initializing the object and then calling the default constructor.
its subobjects, if any, have an indeterminate initial value\(^{97}\); if the object or any of its subobjects are of const-qualified type, the program is ill-formed.

10 An initializer for a static member is in the scope of the member’s class. [Example:

```c
int a;

struct X {
    static int a;
    static int b;
};

int X::a = 1;
int X::b = a;  // X::b = X::a
```

— end example ]

11 The form of initialization (using parentheses or =) is generally insignificant, but does matter when the entity being initialized has a class type; see below. A parenthesized initializer can be a list of expressions only when the entity being initialized has a class type.

12 The initialization that occurs in argument passing, function return, throwing an exception (15.1), handling an exception (15.3), and brace-enclosed initializer lists (8.5.1) is called \textit{copy-initialization} and is equivalent to the form

```
T x = a;
```

13 The initialization that occurs in \texttt{new} expressions (5.3.4), \texttt{static_cast} expressions (5.2.9), functional notation type conversions (5.2.3), and base and member initializers (12.6.2) is called \textit{direct-initialization} and is equivalent to the form

```
T x(a);
```

14 If \(T\) is a scalar type, then a declaration of the form

```
T x = { a };
```

is equivalent to

```
T x = a;
```

15 The semantics of initializers are as follows. The \textit{destination type} is the type of the object or reference being initialized and the \textit{source type} is the type of the initializer expression. The source type is not defined when the initializer is brace-enclosed or when it is a parenthesized list of expressions.

- If the destination type is a reference type, see 8.5.3.
- If the destination type is an array of characters or an array of \texttt{wchar_t}, and the initializer is a string literal, see 8.5.2.
- Otherwise, if the destination type is an array, see 8.5.1.
- If the destination type is a (possibly cv-qualified) class type:

\(^{97}\) This does not apply to aggregate objects with automatic storage duration initialized with an incomplete brace-enclosed \textit{initializer-list}; see 8.5.1.
If the class is an aggregate (8.5.1), and the initializer is a brace-enclosed list, see 8.5.1.

If the initialization is direct-initialization, or if it is copy-initialization where the cv-unqualified version of the source type is the same class as, or a derived class of, the class of the destination, constructors are considered. The applicable constructors are enumerated (13.3.1.3), and the best one is chosen through overload resolution (13.3). The constructor so selected is called to initialize the object, with the initializer expression(s) as its argument(s). If no constructor applies, or the overload resolution is ambiguous, the initialization is ill-formed.

Otherwise (i.e., for the remaining copy-initialization cases), user-defined conversion sequences that can convert from the source type to the destination type or (when a conversion function is used) to a derived class thereof are enumerated as described in 13.3.1.4, and the best one is chosen through overload resolution (13.3). If the conversion cannot be done or is ambiguous, the initialization is ill-formed. The function selected is called with the initializer expression as its argument; if the function is a constructor, the call initializes a temporary of the cv-unqualified version of the destination type. The temporary is an rvalue. The result of the call (which is the temporary for the constructor case) is then used to direct-initialize, according to the rules above, the object that is the destination of the copy-initialization. In certain cases, an implementation is permitted to eliminate the copying inherent in this direct-initialization by constructing the intermediate result directly into the object being initialized; see 12.2, 12.8.

Otherwise, if the source type is a (possibly cv-qualified) class type, conversion functions are considered. The applicable conversion functions are enumerated (13.3.1.5), and the best one is chosen through overload resolution (13.3). The user-defined conversion so selected is called to convert the initializer expression into the object being initialized. If the conversion cannot be done or is ambiguous, the initialization is ill-formed.

Otherwise, the initial value of the object being initialized is the (possibly converted) value of the initializer expression. Standard conversions (clause 4) will be used, if necessary, to convert the initializer expression to the cv-unqualified version of the destination type; no user-defined conversions are considered. If the conversion cannot be done, the initialization is ill-formed. [Note: an expression of type "cv1 T" can initialize an object of type "cv2 T" independently of the cv-qualifiers cv1 and cv2.

```c
int a;
const int b = a;
int c = b;
```
— end note ]
int i;
int j;
} b;
} a = { 1, { 2, 3 } }; initializes a.x with 1, a.b.i with 2, a.b.j with 3. — end example ]

3 An aggregate that is a class can also be initialized with a single expression not enclosed in braces, as described in 8.5.

4 An array of unknown size initialized with a brace-enclosed initializer-list containing n initializers, where n shall be greater than zero, is defined as having n elements (8.3.4). [Example:
int x[] = { 1, 3, 5 }; declares and initializes x as a one-dimensional array that has three elements since no size was specified and there are three initializers. — end example ] An empty initializer list {} shall not be used as the initializer for an array of unknown bound. [88]

5 Static data members are not considered members of the class for purposes of aggregate initialization. [ Example:
struct A {
    int i;
    static int s;
    int j;
} a = { 1, 2 }; Here, the second initializer 2 initializes a.j and not the static data member A::s — end example ]

6 An initializer-list is ill-formed if the number of initializers exceeds the number of members or elements to initialize. [ Example:
char cv[4] = { 'a', 's', 'd', 'f', 0 }; // error is ill-formed. — end example ]

7 If there are fewer initializers in the list than there are members in the aggregate, then each member not explicitly initialized shall be value-initialized (8.5). [ Example:
struct S { int a; char* b; int c; }; S ss = { 1, "asdf" }; initializes ss.a with 1, ss.b with "asdf", and ss.c with the value of an expression of the form int(), that is, 0. — end example ]

8 An initializer for an aggregate member that is an empty class shall have the form of an empty initializer-list {}. [ Example:
struct S { }; struct A {
    S s;
    int i;
} a = { { }, 3 };] [88] The syntax provides for empty initializer-lists, but nonetheless C++ does not have zero length arrays.
An empty initializer-list can be used to initialize any aggregate. If the aggregate is not an empty class, then each member of the aggregate shall be initialized with a value of the form \( T() \) (5.2.3), where \( T \) represents the type of the uninitialized member.

If an incomplete or empty initializer-list leaves a member of reference type uninitialized, the program is ill-formed.

When initializing a multi-dimensional array, the initializers initialize the elements with the last (rightmost) index of the array varying the fastest (8.3.4). [Example:

```c
int x[2][2] = { 3, 1, 4, 2 };
```

initializes \( x[0][0] \) to 3, \( x[0][1] \) to 1, \( x[1][0] \) to 4, and \( x[1][1] \) to 2. On the other hand,

```c
float y[4][3] = {
  { 1 }, { 2 }, { 3 }, { 4 }
};
```

initializes the first column of \( y \) (regarded as a two-dimensional array) and leaves the rest zero. — end example ]

Braces can be elided in an initializer-list as follows. If the initializer-list begins with a left brace, then the succeeding comma-separated list of initializers initializes the members of a subaggregate; it is erroneous for there to be more initializers than members. If, however, the initializer-list for a subaggregate does not begin with a left brace, then only enough initializers from the list are taken to initialize the members of the subaggregate; any remaining initializers are left to initialize the next member of the aggregate of which the current subaggregate is a member. [Example:

```c
float y[4][3] = {
  { 1, 3, 5 },
  { 2, 4, 6 },
  { 3, 5, 7 },
};
```

is a completely-braced initialization: 1, 3, and 5 initialize the first row of the array \( y[0] \), namely \( y[0][0] \), \( y[0][1] \), and \( y[0][2] \). Likewise the next two lines initialize \( y[1] \) and \( y[2] \). The initializer ends early and therefore \( y[3] \)'s elements are initialized as if explicitly initialized with an expression of the form \( float() \), that is, are initialized with 0.0. In the following example, braces in the initializer-list are elided; however the initializer-list has the same effect as the completely-braced initializer-list of the above example,

```c
float y[4][3] = {
  1, 3, 5, 2, 4, 6, 3, 5, 7
};
```

The initializer for \( y \) begins with a left brace, but the one for \( y[0] \) does not, therefore three elements from the list are used. Likewise the next three are taken successively for \( y[1] \) and \( y[2] \). — end example ]

All implicit type conversions (clause 4) are considered when initializing the aggregate member with an initializer from an initializer-list. If the initializer can initialize a member, the member is initialized. Otherwise, if the member is itself a non-empty subaggregate, brace elision is assumed and the initializer is considered for the initialization of the first member of the subaggregate.

[ Example:
struct A {
    int i;
    operator int();
};
struct B {
    A a1, a2;
    int z;
};
A a;
B b = { 4, a, a };

Braces are elided around the initializer for b.a1.i. b.a1.i is initialized with 4, b.a2 is initialized with a, b.z is initialized with whatever a.operator int() returns. — end example]

13 [ Note: An aggregate array or an aggregate class may contain members of a class type with a user-declared constructor (12.1). Initialization of these aggregate objects is described in 12.6.1. — end note ]

14 When an aggregate with static storage duration is initialized with a brace-enclosed initializer-list, if all the member initializer expressions are constant expressions, and the aggregate is a POD type, the initialization shall be done during the static phase of initialization (3.6.2); otherwise, it is unspecified whether the initialization of members with constant expressions takes place during the static phase or during the dynamic phase of initialization.

15 When a union is initialized with a brace-enclosed initializer, the braces shall only contain an initializer for the first member of the union. [ Example:

    union u { int a; char* b; };

    u a = { 1 };
    u b = a;
    u c = 1; // error
    u d = { 0, "asdf" }; // error
    u e = { "asdf" }; // error

    — end example ]

16 [ Note: as described above, the braces around the initializer for a union member can be omitted if the union is a member of another aggregate. — end note ]

8.5.2 Character arrays [decl.init.string]

1 A char array (whether plain char, signed char, or unsigned char) can be initialized by a string-literal (optionally enclosed in braces); a wchar_t array can be initialized by a wide string-literal (optionally enclosed in braces); successive characters of the string-literal initialize the members of the array. [ Example:

    char msg[] = "Syntax error on line %s\n";

    shows a character array whose members are initialized with a string-literal. Note that because ‘\n’ is a single character and because a trailing ‘\0’ is appended, sizeof(msg) is 25. — end example ]

2 There shall not be more initializers than there are array elements. [ Example:

    char cv[4] = "asdf"; // error

Draft
is ill-formed since there is no space for the implied trailing ‘\0’. — end example }

8.5.3 References

1 A variable declared to be a T&, that is “reference to type T (8.3.2), shall be initialized by an object, or function, of type T or by an object that can be converted into a T. [Example:

```c
int g(int);
void f()
{
    int i;
    int& r = i;  // r refers to i
    r = 1;       // the value of i becomes 1
    int* p = &r; // p points to i
    int& rr = r; // rr refers to what r refers to, that is, to i
    int (&rg)(int) = g; // rg refers to the function g
    rg(i);          // calls function g
    int a[3];
    int (&ra)[3] = a; // ra refers to the array a
    ra[1] = i;      // modifies a[1]
}
```
— end example ]

2 A reference cannot be changed to refer to another object after initialization. Note that initialization of a reference is treated very differently from assignment to it. Argument passing (5.2.2) and function value return (6.6.3) are initializations.

3 The initializer can be omitted for a reference only in a parameter declaration (8.3.5), in the declaration of a function return type, in the declaration of a class member within its class definition (9.2), and where the extern specifier is explicitly used. [Example:

```c
int& r1;                        // error: initializer missing
extern int& r2;                // OK
```
— end example ]

4 Given types “cv1 T1” and “cv2 T2,” “cv1 T1” is reference-related to “cv2 T2” if T1 is the same type as T2, or T1 is a base class of T2. “cv1 T1” is reference-compatible with “cv2 T2” if T1 is reference-related to T2 and cv1 is the same cv-qualification as, or greater cv-qualification than, cv2. For purposes of overload resolution, cases for which cv1 is greater cv-qualification than cv2 are identified as reference-compatible with added qualification (see 13.3.3.2). In all cases where the reference-related or reference-compatible relationship of two types is used to establish the validity of a reference binding, and T1 is a base class of T2, a program that necessitates such a binding is ill-formed if T1 is an inaccessible (clause 11) or ambiguous (10.2) base class of T2.

5 A reference to type “cv1 T1” is initialized by an expression of type “cv2 T2” as follows:

— If the initializer expression

— is an lvalue (but is not a bit-field), and “cv1 T1” is reference-compatible with “cv2 T2,” or
— has a class type (i.e., \( T_2 \) is a class type) and can be implicitly converted to an lvalue of type “\( \text{cv3 T3} \)” where “\( \text{cv1 T1} \)” is reference-compatible with “\( \text{cv3 T3} \)”\(^{99}\) (this conversion is selected by enumerating the applicable conversion functions (13.3.1.6) and choosing the best one through overload resolution (13.3)),

then the reference is bound directly to the initializer expression lvalue in the first case, and the reference is bound to the lvalue result of the conversion in the second case. In these cases the reference is said to bind directly to the initializer expression. [Note: the usual lvalue-to-rvalue (4.1), array-to-pointer (4.2), and function-to-pointer (4.3) standard conversions are not needed, and therefore are suppressed, when such direct bindings to lvalues are done. — end note]

[Example:

\[
\begin{align*}
\text{double } d &= 2.0; \\
\text{double}& \quad \text{rd} &= d; & \quad \text{// rd refers to d} \\
\text{const double}& \quad \text{rcd} &= d; & \quad \text{// rcd refers to d} \\
\text{struct A } & \{ \}; \\
\text{struct B : public A } & \{ \} b; \\
\text{A}& \quad \text{ra} &= b; & \quad \text{// ra refers to a subobject in b} \\
\text{const A}& \quad \text{rca} &= b; & \quad \text{// rca refers to a subobject in b}
\end{align*}
\]

— end example]

— Otherwise, the reference shall be to a non-volatile const type (i.e., \( \text{cv1} \) shall be \text{const}). [Example:

\[
\begin{align*}
\text{double}& \quad \text{rd2} &= 2.0; & \quad \text{// error: not an lvalue and reference not const} \\
\text{int } & \quad i &= 2; \\
\text{double}& \quad \text{rd3} &= i; & \quad \text{// error: type mismatch and reference not const}
\end{align*}
\]

— end example]

— If the initializer expression is an rvalue, with \( T_2 \) a class type, and “\( \text{cv1 T1} \)” is reference-compatible with “\( \text{cv2 T2} \)” the reference is bound to the object represented by the rvalue (see 3.10) or to a sub-object within that object.

—

— \(^{100}\)

[Example:

\[
\begin{align*}
\text{struct A } & \{ \}; \\
\text{struct B : public A } & \{ \} b; \\
\text{extern B } & \quad f() ; \\
\text{const A}& \quad \text{rca} &= f(); & \quad \text{// Bound to the \& subobject of the B rvalue.}
\end{align*}
\]

— end example]

\(^{99}\) This requires a conversion function (12.3.2) returning a reference type.

\(^{100}\) Draft
— If the initializer expression is an rvalue, with T2 an array type, and “cv1 T1” is reference-compatible with “cv2 T2,” the reference is bound to the object represented by the rvalue (see 3.10).

— Otherwise, a temporary of type “cv1 T1” is created and initialized from the initializer expression using the rules for a non-reference copy initialization (8.5). The reference is then bound to the temporary. If T1 is reference-related to T2, cv1 must be the same cv-qualification as, or greater cv-qualification than, cv2; otherwise, the program is ill-formed. [Example:

```c
const double& rcd2 = 2; // rcd2 refers to temporary with value 2.0
const volatile int cvi = 1;
const int& r = cvi; // error: type qualifiers dropped
```

— end example ]

6 [ Note: 12.2 describes the lifetime of temporaries bound to references. — end note ]
Chapter 9  Classes

1 A class is a type. Its name becomes a class-name (9.1) within its scope.

   class-name:
   identifier
   template-id

Class-specifiers and elaborated-type-specifiers (7.1.5.3) are used to make class-names. An object of a class consists of a (possibly empty) sequence of members and base class objects.

   class-specifier:
   class-head { member-specification_{opt} }

   class-head:
   class-key identifier_{opt} base-clause_{opt}
   class-key nested-name-specifier identifier base-clause_{opt}
   class-key nested-name-specifier_{opt} template-id base-clause_{opt}

   class-key:
   class
   struct
   union

A class-specifier where the class-head omits the optional identifier defines an unnamed class.

2 A class-name is inserted into the scope in which it is declared immediately after the class-name is seen. The class-name is also inserted into the scope of the class itself; this is known as the injected-class-name. For purposes of access checking, the injected-class-name is treated as if it were a public member name. A class-specifier is commonly referred to as a class definition. A class is considered defined after the closing brace of its class-specifier has been seen even though its member functions are in general not yet defined.

3 Complete objects and member subobjects of class type shall have nonzero size. [Note: class objects can be assigned, passed as arguments to functions, and returned by functions (except objects of classes for which copying has been restricted; see 12.8). Other plausible operators, such as equality comparison, can be defined by the user; see 13.5. — end note]

4 A structure is a class defined with the class-key struct; its members and base classes (clause 10) are public by default (clause 11). A union is a class defined with the class-key union; its members are public by default and it holds only one data member at a time (9.5). [Note: aggregates of class type are described in 8.5.1. — end note] A POD-struct is an aggregate class that has no non-static data members of type non-POD-struct, non-POD-union (or array of such types) or reference, and has no user-declared copy assignment operator and no user-declared destructor. Similarly, a POD-union

101) Base class subobjects are not so constrained.
9.1 Class names

is an aggregate union that has no non-static data members of type non-POD-struct, non-POD-union (or array of such
types) or reference, and has no user-declared copy assignment operator and no user-declared destructor. A POD class is
a class that is either a POD-struct or a POD-union.

5 If a class-head contains a nested-name-specifier, the class-specifier shall refer to a class that was previously declared
directly in the class or namespace to which the nested-name-specifier refers (i.e., neither inherited nor introduced by a
using-declaration), and the class-specifier shall appear in a namespace enclosing the previous declaration.

9.1 Class names

1 A class definition introduces a new type. [Example:

```c
struct X { int a; };
struct Y { int a; };
X a1;
Y a2;
int a3;
```

declares three variables of three different types. This implies that

```c
a1 = a2; // error: Y assigned to X
a1 = a3; // error: int assigned to X
```

are type mismatches, and that

```c
int f(X);
int f(Y);
```

declare an overloaded (clause 13) function f() and not simply a single function f() twice. For the same reason,

```c
struct S { int a; };
struct S { int a; }; // error, double definition
```

is ill-formed because it defines S twice. — end example ]

2 A class declaration introduces the class name into the scope where it is declared and hides any class, object, function,
or other declaration of that name in an enclosing scope (3.3). If a class name is declared in a scope where an object,
function, or enumerator of the same name is also declared, then when both declarations are in scope, the class can be
referred to only using an elaborated-type-specifier (3.4.4). [Example:

```c
struct stat {
    // ...
};

stat gstat; // use plain stat to
            // define variable

int stat(struct stat*); // redeclare stat as function

void f()
{
    struct stat* ps; // struct prefix needed

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A declaration consisting solely of class-key identifier; is either a redeclaration of the name in the current scope or a forward declaration of the identifier as a class name. It introduces the class name into the current scope. [Example:

```c
struct s { int a; }

void g()
{
    struct s; // hide global struct s
    // with a local declaration
    s* p; // refer to local struct s
    struct s { char* p; }; // define local struct s
    struct s; // redeclaration, has no effect
}
```

— end example ] [Note: Such declarations allow definition of classes that refer to each other. [Example:

```c
class Vector;

class Matrix {
    // ...
    friend Vector operator*(Matrix&, Vector&);
};

class Vector {
    // ...
    friend Vector operator*(Matrix&, Vector&);
};
```

Declaration of friends is described in 11.4, operator functions in 13.5. — end example ] — end note ]

[Note: An elaborated-type-specifier (7.1.5.3) can also be used as a type-specifier as part of a declaration. It differs from a class declaration in that if a class of the elaborated name is in scope the elaborated name will refer to it. — end note ]

```c
struct s { int a; }

void g(int s)
{
    struct s* p = new struct s; // global s
    p->a = s; // local s
}
```

— end example ]

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4  [Note: The declaration of a class name takes effect immediately after the identifier is seen in the class definition or elaborated-type-specifier. For example,]
   
   ```
   class A * A;
   ```
   
   first specifies A to be the name of a class and then redefines it as the name of a pointer to an object of that class. This means that the elaborated form `class A` must be used to refer to the class. Such artistry with names can be confusing and is best avoided. — end note ]

5  A typedef-name (7.1.3) that names a class type, or a cv-qualified version thereof, is also a class-name, but shall not be used as the identifier in a class-head.

9.2 Class members  [class.mem]

The member-specification in a class definition declares the full set of members of the class; no member can be added elsewhere. Members of a class are data members, member functions (9.3), nested types, and enumerators. Data members and member functions are static or non-static; see 9.4. Nested types are classes (9.1, 9.7) and enumerations (7.2) defined in the class, and arbitrary types declared as members by use of a typedef declaration (7.1.3). The enumerators of an enumeration (7.2) defined in the class are members of the class. Except when used to declare friends (11.4) or to introduce the name of a member of a base class into a derived class (7.3.3,11.3), member-declarations declare members of the class, and each such member-declaration shall declare at least one member name of the class. A member shall not be declared twice in the member-specification, except that a nested class or member class template can be declared and then later defined.

A class is considered a completely-defined object type (3.9) (or complete type) at the closing } of the class-specifier. Within the class member-specification, the class is regarded as complete within function bodies, default arguments,
exception-specifications, and constructor ctor-initializers (including such things in nested classes). Otherwise it is regarded as incomplete within its own class member-specification.

3 [Note: a single name can denote several function members provided their types are sufficiently different (clause 13). —end note]

4 A member-declarator can contain a constant-initializer only if it declares a static member (9.4) of const integral or const enumeration type, see 9.4.2.

5 A member can be initialized using a constructor; see 12.1. [Note: see clause 12 for a description of constructors and other special member functions. —end note]

6 A member shall not be auto, extern, or register. A member shall not be declared to have automatic storage duration (auto, register) or with the extern storage-class-specifier.

7 The decl-specifier-seq is omitted in constructor, destructor, and conversion function declarations only. The member-declarator-list can be omitted only after a class-specifier or an enum-specifier or in a friend declaration (11.4). A pure-specifier shall be used only in the declaration of a virtual function (10.3).

8 Non-static (9.4) data members shall not have incomplete types. In particular, a class C shall not contain a non-static member of class C, but it can contain a pointer or reference to an object of class C.

9 Each occurrence in an expression of the name of a non-static data member or non-static member function of a class shall be expressed as a class member access (5.2.5), except when it appears in the formation of a pointer to member (5.3.1), when it appears in the body of a non-static member function of its class or of a class derived from its class (9.3.1), or when it appears in a mem-initializer for a constructor for its class or for a class derived from its class (12.6.2).

10 [Note: the type of a non-static member function is an ordinary function type, and the type of a non-static data member is an ordinary object type. There are no special member function types or data member types. —end note]

11 [Example: A simple example of a class definition is

```c
struct tnode {
    char tword[20];
    int count;
    tnode *left;
    tnode *right;
};
```

which contains an array of twenty characters, an integer, and two pointers to similar structures. Once this definition has been given, the declaration

```c
tnode s, *sp;
```

declares s to be a tnode and sp to be a pointer to a tnode. With these declarations, sp->count refers to the count member of the structure to which sp points; s.left refers to the left subtree pointer of the structure s; and s.right->tword[0] refers to the initial character of the tword member of the right subtree of s. —end example]

12 Nonstatic data members of a (non-union) class declared without an intervening access-specifier are allocated so that later members have higher addresses within a class object. The order of allocation of non-static data members separated by an access-specifier is unspecified (11.1). Implementation alignment requirements might cause two adjacent members
not to be allocated immediately after each other; so might requirements for space for managing virtual functions (10.3) and virtual base classes (10.1).

13 If \( T \) is the name of a class, then each of the following shall have a name different from \( T \):
   - every static data member of class \( T \);
   - every member function of class \( T \) [\textit{Note:} this restriction does not apply to constructors, which do not have names (12.1) — \textit{end note}];
   - every member of class \( T \) that is itself a type;
   - every enumerator of every member of class \( T \) that is an enumerated type; and
   - every member of every anonymous union that is a member of class \( T \).

14 In addition, if class \( T \) has a user-declared constructor (12.1), every non-static data member of class \( T \) shall have a name different from \( T \).

15 Two POD-struct (clause 9) types are layout-compatible if they have the same number of non-static data members, and corresponding non-static data members (in order) have layout-compatible types (3.9).

16 Two POD-union (clause 9) types are layout-compatible if they have the same number of non-static data members, and corresponding non-static data members (in any order) have layout-compatible types (3.9).

17 If a POD-union contains two or more POD-structs that share a common initial sequence, and if the POD-union object currently contains one of these POD-structs, it is permitted to inspect the common initial part of any of them. Two POD-structs share a common initial sequence if corresponding members have layout-compatible types (and, for bit-fields, the same widths) for a sequence of one or more initial members.

18 A pointer to a POD-struct object, suitably converted using a \texttt{reinterpret_cast}, points to its initial member (or if that member is a bit-field, then to the unit in which it resides) and vice versa. [\textit{Note:} There might therefore be unnamed padding within a POD-struct object, but not at its beginning, as necessary to achieve appropriate alignment. — \textit{end note}]

9.3 Member functions

1 Functions declared in the definition of a class, excluding those declared with a \texttt{friend} specifier (11.4), are called member functions of that class. A member function may be declared \texttt{static} in which case it is a \texttt{static} member function of its class (9.4); otherwise it is a \texttt{non-static} member function of its class (9.3.1, 9.3.2).

2 A member function may be defined (8.4) in its class definition, in which case it is an \texttt{inline} member function (7.1.2), or it may be defined outside of its class definition if it has already been declared but not defined in its class definition. A member function definition that appears outside of the class definition shall appear in a namespace scope enclosing the class definition. Except for member function definitions that appear outside of a class definition, and except for explicit specializations of member functions of class templates and member function templates (14.7) appearing outside of the class definition, a member function shall not be redeclared.

3 An \texttt{inline} member function (whether static or non-static) may also be defined outside of its class definition provided either its declaration in the class definition or its definition outside of the class definition declares the function as \texttt{inline}. [\textit{Note:} member functions of a class in namespace scope have external linkage. Member functions of a local class (9.8) have no linkage. See 3.5. — \textit{end note}]

Draft
9.3 Member functions

There shall be at most one definition of a non-inline member function in a program; no diagnostic is required. There may be more than one inline member function definition in a program. See 3.2 and 7.1.2.

If the definition of a member function is lexically outside its class definition, the member function name shall be qualified by its class name using the :: operator. [Note: a name used in a member function definition (that is, in the parameter-declaration-clause including the default arguments (8.3.6), or in the member function body, or, for a constructor function (12.1), in a mem-initializer expression (12.6.2)) is looked up as described in 3.4. —end note] [Example:

```c
struct X {
    typedef int T;
    static T count;
    void f(T);
};
void X::f(T t = count) {} 
```
The member function f of class X is defined in global scope; the notation X::f specifies that the function f is a member of class X and in the scope of class X. In the function definition, the parameter type T refers to the typedef member T declared in class X and the default argument count refers to the static data member count declared in class X. —end example]

A static local variable in a member function always refers to the same object, whether or not the member function is inline.

Member functions may be mentioned in friend declarations after their class has been defined.

Member functions of a local class shall be defined inline in their class definition, if they are defined at all.

[Note: a member function can be declared (but not defined) using a typedef for a function type. The resulting member function has exactly the same type as it would have if the function declarator were provided explicitly, see 8.3.5. For example,

```c
typedef void fv(void);
typedef void fvc(void) const;
struct S {
    fv memfunc1; // equivalent to: void memfunc1(void);
    void memfunc2();
    fvc memfunc3; // equivalent to: void memfunc3(void) const;
};
fv S::* pmfv1 = &S::memfunc1;
fv S::* pmfv2 = &S::memfunc2;
fvc S::* pmfv3 = &S::memfunc3;
```
Also see 14.3. —end note]

9.3.1 Nonstatic member functions

A non-static member function may be called for an object of its class type, or for an object of a class derived (clause 10) from its class type, using the class member access syntax (5.2.5, 13.3.1.1). A non-static member function may also be called directly using the function call syntax (5.2.2, 13.3.1.1)

— from within the body of a member function of its class or of a class derived from its class, or
— from a mem-initializer (12.6.2) for a constructor for its class or for a class derived from its class.
If a non-static member function of a class \( X \) is called for an object that is not of type \( X \), or of a type derived from \( X \), the behavior is undefined.

When an \textit{id-expression} (5.1) that is not part of a class member access syntax (5.2.5) and not used to form a pointer to member (5.3.1) is used in the body of a non-static member function of class \( X \) or used in the \textit{mem-initializer} for a constructor of class \( X \), if name lookup (3.4.1) resolves the name in the \textit{id-expression} to a non-static non-type member of class \( X \) or of a base class of \( X \), the \textit{id-expression} is transformed into a class member access expression (5.2.5) using (*this) (9.3.2) as the \textit{postfix-expression} to the left of the . operator. The member name then refers to the member of the object for which the function is called. Similarly during name lookup, when an \textit{unqualified-id} (5.1) used in the definition of a member function for class \( X \) resolves to a \textit{static} member, an enumerator or a nested type of class \( X \) or of a base class of \( X \), the \textit{unqualified-id} is transformed into a \textit{qualified-id} (5.1) in which the \textit{nested-name-specifier} names the class of the member function. [Example:

\begin{verbatim}
struct tnode {
    char tword[20];
    int count;
    tnode *left;
    tnode *right;
    void set(char*, tnode* l, tnode* r);
};

void tnode::set(char* w, tnode* l, tnode* r)
{
    count = strlen(w)+1;
    if (sizeof(tword)<=count)
        perror("tnode string too long");
    strcpy(tword,w);
    left = l;
    right = r;
}

void f(tnode n1, tnode n2)
{
    n1.set("abc", &n2, 0);
    n2.set("def", 0, 0);
}
\end{verbatim}

In the body of the member function tnode::set, the member names tword, count, left, and right refer to members of the object for which the function is called. Thus, in the call n1.set("abc", &n2, 0), tword refers to n1.tword, and in the call n2.set("def", 0, 0), it refers to n2.tword. The functions strlen, perror, and strcpy are not members of the class tnode and should be declared elsewhere. — end example]

A non-static member function may be declared \textit{const}, \textit{volatile}, or \textit{const volatile}. These \textit{cv-qualifiers} affect the type of the this pointer (9.3.2). They also affect the function type (8.3.5) of the member function; a member function declared \textit{const} is a \textit{const} member function, a member function declared \textit{volatile} is a \textit{volatile} member function and a member function declared \textit{const volatile} is a \textit{const volatile} member function. [Example:

\begin{verbatim}
struct X {
\end{verbatim}

\footnote{See, for example, \texttt{<cstring>} (21.4).}
void g() const;
void h() const volatile;
};

X::g is a const member function and X::h is a const volatile member function. — end example ]

5 A non-static member function may be declared virtual (10.3) or pure virtual (10.4).

9.3.2 The this pointer

1 In the body of a non-static (9.3) member function, the keyword this is a non-lvalue expression whose value is the address of the object for which the function is called. The type of this in a member function of a class X is X*. If the member function is declared const, the type of this is const X*, if the member function is declared volatile, the type of this is volatile X*, and if the member function is declared const volatile, the type of this is const volatile X*.

2 In a const member function, the object for which the function is called is accessed through a const access path; therefore, a const member function shall not modify the object and its non-static data members. [ Example:

```c
struct s {
    int a;
    int f() const;
    int g() { return a++; }
    int h() const { return a++; } // error
};

int s::f() const { return a; }
```

The a++ in the body of s::h is ill-formed because it tries to modify (a part of) the object for which s::h() is called. This is not allowed in a const member function because this is a pointer to const; that is, *this has const type. — end example ]

3 Similarly, volatile semantics (7.1.5.1) apply in volatile member functions when accessing the object and its non-static data members.

4 A cv-qualified member function can be called on an object-expression (5.2.5) only if the object-expression is as cv-qualified or less-cv-qualified than the member function. [ Example:

```c
void k(s& x, const s& y)
{
    x.f();
    x.g();
    y.f();
    y.g(); // error
}
```

The call y.g() is ill-formed because y is const and s::g() is a non-const member function, that is, s::g() is less-qualified than the object-expression y. — end example ]
9.4 Static members

1 A data or function member of a class may be declared static in a class definition, in which case it is a static member of the class.

2 A static member \texttt{s} of class \texttt{X} may be referred to using the qualified-id expression \texttt{X::s}; it is not necessary to use the class member access syntax (5.2.5) to refer to a static member. A static member may be referred to using the class member access syntax, in which case the object-expression is evaluated. [Example:

```cpp
class process {
   public:
      static void reschedule();
   }

   process& g();

   void f()
   {
      process::reschedule();   // OK: no object necessary
      g().reschedule();        // \texttt{g()} is called
   }
```

— end example ]

3 A static member may be referred to directly in the scope of its class or in the scope of a class derived (clause 10) from its class; in this case, the static member is referred to as if a qualified-id expression was used, with the nested-name-specifier of the qualified-id naming the class scope from which the static member is referenced. [Example:

```cpp
int g();
struct X {
   static int g();
};
struct Y : X {
   static int i;
};
int Y::i = g();         // equivalent to \texttt{Y::g()};
```

— end example ]

4 If an unqualified-id (5.1) is used in the definition of a static member following the member’s declarator-id, and name lookup (3.4.1) finds that the unqualified-id refers to a static member, enumerator, or nested type of the member’s class (or of a base class of the member’s class), the unqualified-id is transformed into a qualified-id expression in which the nested-name-specifier names the class scope from which the member is referenced. The definition of a static member shall not use directly the names of the non-static members of its class or of a base class of its class (including as operands of the sizeof operator). The definition of a static member may only refer to these members to form pointer to members (5.3.1) or with the class member access syntax (5.2.5).
Static members obey the usual class member access rules (clause 11). When used in the declaration of a class member, the static specifier shall only be used in the member declarations that appear within the member-specification of the class definition. [Note: it cannot be specified in member declarations that appear in namespace scope. —end note]

9.4.1 Static member functions

[Note: the rules described in 9.3 apply to static member functions. —end note]

A static member function does not have a this pointer (9.3.2). —end note] A static member function shall not be virtual. There shall not be a static and a non-static member function with the same name and the same parameter types (13.1). A static member function shall not be declared const, volatile, or const volatile.

9.4.2 Static data members

A static data member is not part of the subobjects of a class. There is only one copy of a static data member shared by all the objects of the class.

The declaration of a static data member in its class definition is not a definition and may be of an incomplete type other than cv-qualified void. The definition for a static data member shall appear in a namespace scope enclosing the member’s class definition. In the definition at namespace scope, the name of the static data member shall be qualified by its class name using the :: operator. The initializer expression in the definition of a static data member is in the scope of its class (3.3.6).

```cpp
class process {
    static process* run_chain;
    static process* running;
};
```

```cpp```
```
```cpp
process* process::running = get_main();
process* process::run_chain = running;
```

The static data member run_chain of class process is defined in global scope; the notation process::run_chain specifies that the member run_chain is a member of class process and in the scope of class process. In the static data member definition, the initializer expression refers to the static data member running of class process. —end example]

[Note: once the static data member has been defined, it exists even if no objects of its class have been created. [Example: in the example above, run_chain and running exist even if no objects of class process are created by the program. —end example ] —end note]

If a static data member is of const integral or const enumeration type, its declaration in the class definition can specify a constant-initializer which shall be an integral constant expression (5.19). In that case, the member can appear in integral constant expressions. The member shall still be defined in a namespace scope if it is used in the program and the namespace scope definition shall not contain an initializer.

There shall be exactly one definition of a static data member that is used in a program; no diagnostic is required; see 3.2. Unnamed classes and classes contained directly or indirectly within unnamed classes shall not contain static data members.

Static data members of a class in namespace scope have external linkage (3.5). A local class shall not have static data members.
Static data members are initialized and destroyed exactly like non-local objects (3.6.2, 3.6.3).

A static data member shall not be mutable (7.1.1).

### 9.5 Unions

In a union, at most one of the data members can be active at any time, that is, the value of at most one of the data members can be stored in a union at any time. [Note: one special guarantee is made in order to simplify the use of unions: If a POD-union contains several POD-structs that share a common initial sequence (9.2), and if an object of this POD-union type contains one of the POD-structs, it is permitted to inspect the common initial sequence of any of POD-struct members; see 9.2. — end note] The size of a union is sufficient to contain the largest of its data members. Each data member is allocated as if it were the sole member of a struct. A union can have member functions (including constructors and destructors), but not virtual (10.3) functions. A union shall not have base classes. A union shall not be used as a base class. An object of a class with a non-trivial default constructor (12.1), a non-trivial destructor (12.4), or a non-trivial copy assignment operator (13.5.3, 12.8) cannot be a member of a union, nor can an array of such objects. If a union contains a static data member, or a member of reference type, the program is ill-formed.

A union of the form

```c
union { member-specification }
```

is called an anonymous union; it defines an unnamed object of unnamed type. The member-specification of an anonymous union shall only define non-static data members. [Note: nested types and functions cannot be declared within an anonymous union. — end note] The names of the members of an anonymous union shall be distinct from the names of any other entity in the scope in which the anonymous union is declared. For the purpose of name lookup, after the anonymous union definition, the members of the anonymous union are considered to have been defined in the scope in which the anonymous union is declared. [Example:

```c
void f()
{
    union { int a; char* p; }
    a = 1;
    // ... 
    p = "Jennifer";
    // ...
}
```

Here a and p are used like ordinary (nonmember) variables, but since they are union members they have the same address. — end example]

Anonymous unions declared in a named namespace or in the global namespace shall be declared static. Anonymous unions declared at block scope shall be declared with any storage class allowed for a block-scope variable, or with no storage class. A storage class is not allowed in a declaration of an anonymous union in a class scope. An anonymous union shall not have private or protected members (clause 11). An anonymous union shall not have function members.

A union for which objects or pointers are declared is not an anonymous union. [Example:

```c
union { int aa; char* p; } obj, *ptr = &obj;
aa = 1;
    // error
ptr->aa = 1;
    // OK
```

Draft
The assignment to plain \texttt{aa} is ill-formed since the member name is not visible outside the union, and even if it were visible, it is not associated with any particular object. — end example] [Note: Initialization of unions with no user-declared constructors is described in (8.5.1). — end note]

9.6 Bit-fields [class.bit]

A \textit{member-declarator} of the form

\begin{verbatim}
identifier_opt : constant-expression
\end{verbatim}

specifies a bit-field; its length is set off from the bit-field name by a colon. The bit-field attribute is not part of the type of the class member. The \textit{constant-expression} shall be an integral constant-expression with a value greater than or equal to zero. The constant-expression may be larger than the number of bits in the object representation (3.9) of the bit-field’s type; in such cases the extra bits are used as padding bits and do not participate in the value representation (3.9) of the bit-field. Allocation of bit-fields within a class object is implementation-defined. Alignment of bit-fields is implementation-defined. Bit-fields are packed into some addressable allocation unit. [Note: bit-fields straddle allocation units on some machines and not on others. Bit-fields are assigned right-to-left on some machines, left-to-right on others. — end note]

A declaration for a bit-field that omits the \textit{identifier} declares an \textit{unnamed} bit-field. Unnamed bit-fields are not members and cannot be initialized. [Note: an unnamed bit-field is useful for padding to conform to externally-imposed layouts. — end note] As a special case, an unnamed bit-field with a width of zero specifies alignment of the next bit-field at an allocation unit boundary. Only when declaring an unnamed bit-field may the \textit{constant-expression} be a value equal to zero.

A bit-field shall not be a static member. A bit-field shall have integral or enumeration type (3.9.1). It is implementation-defined whether a plain (neither explicitly signed nor unsigned) \texttt{char}, \texttt{short}, \texttt{int} or \texttt{long} bit-field is signed or unsigned. A \texttt{bool} value can successfully be stored in a bit-field of any nonzero size. The address-of operator & shall not be applied to a bit-field, so there are no pointers to bit-fields. A non-const reference shall not be bound to a bit-field (8.5.3). [Note: if the initializer for a reference of type const T& is an lvalue that refers to a bit-field, the reference is bound to a temporary initialized to hold the value of the bit-field; the reference is not bound to the bit-field directly. See 8.5.3. — end note]

If the value \texttt{true} or \texttt{false} is stored into a bit-field of type \texttt{bool} of any size (including a one bit bit-field), the original \texttt{bool} value and the value of the bit-field shall compare equal. If the value of an enumerator is stored into a bit-field of the same enumeration type and the number of bits in the bit-field is large enough to hold all the values of that enumeration type, the original enumerator value and the value of the bit-field shall compare equal. [Example:

\begin{verbatim}
enum BOOL { FALSE=0, TRUE=1 };  
struct A {  
    BOOL b:1;  
};  
A a;  
void f() {  
    a.b = TRUE;  
    if (a.b == TRUE)  
        { /* ... */ }  
    }  
\end{verbatim}

Draft
A class can be declared within another class. A class declared within another is called a nested class. The name of a nested class is local to its enclosing class. The nested class is in the scope of its enclosing class. [Note: In accordance with 9.2, except by using explicit pointers, references, and object names, declarations in a nested class shall not use non-static data members or non-static member functions from the enclosing class. This restriction applies in all constructs including the operands of the sizeof operator. — end note]

[Example:

```cpp
int x;
int y;

class enclose {
public:
    int x;
    static int s;

    class inner {

        void f(int i)
        {
            int a = sizeof(x);  // error: direct use of enclose::x even in sizeof
            x = i;              // error: assign to enclose::x
            s = i;              // OK: assign to enclose::s
            ::x = i;            // OK: assign to global x
            y = i;              // OK: assign to global y
        }

        void g(enclose* p, int i)
        {
            p->x = i;           // OK: assign to enclose::x
        }
    }

    inner* p = 0;        // error: inner not in scope
};
```

— end example ]

Member functions and static data members of a nested class can be defined in a namespace scope enclosing the definition of their class. [Example:

```cpp
class enclose {
public:
    class inner {
        static int x;
        void f(int i);
    }
};

inner* p = 0;        // error: inner not in scope
```
1 A class can be declared within a function definition; such a class is called a local class. The name of a local class is local to its enclosing scope. The local class is in the scope of the enclosing scope, and has the same access to names outside the function as does the enclosing function. Declarations in a local class can use only type names, static variables, extern variables and functions, and enumerators from the enclosing scope. [Example:

```c
int x;
void f()
{
    static int s;
    int x;
    extern int g();

    struct local {
        int g() { return x; } // error: x is auto
        int h() { return s; } // OK
        int k() { return ::x; } // OK
        int l() { return g(); } // OK
    };
    // ...
}

local* p = 0; // error: local not in scope

— end example ]
```
9.9 Nested type names

An enclosing function has no special access to members of the local class; it obeys the usual access rules (clause 11). Member functions of a local class shall be defined within their class definition, if they are defined at all.

If class X is a local class a nested class Y may be declared in class X and later defined in the definition of class X or be later defined in the same scope as the definition of class X. A class nested within a local class is a local class.

A local class shall not have static data members.

9.9 Nested type names

Type names obey exactly the same scope rules as other names. In particular, type names defined within a class definition cannot be used outside their class without qualification. [Example:

```cpp
class X {
    public:
        typedef int I;
        class Y { /* ... */ };  // error
        I a;
    }

    I b;  // error
    Y c;  // error
    X::Y d;  // OK
    X::I e;  // OK

    — end example ]
```
Chapter 10  Derived classes  

1 A list of base classes can be specified in a class definition using the notation:

\[
\text{base-clause:} \\
\quad : \text{base-specifier-list}
\]

\[
\text{base-specifier-list:} \\
\quad \text{base-specifier} \\
\quad \text{base-specifier-list} \ , \ \text{base-specifier}
\]

\[
\text{base-specifier:} \\
\quad \cdot \text{opt} \text{nested-name-specifier} \text{opt} \text{class-name} \\
\quad \text{virtual access-specifier} \text{opt} \cdot \text{opt} \text{nested-name-specifier} \text{opt} \text{class-name} \\
\quad \text{access-specifier} \text{virtual} \text{opt} \cdot \text{opt} \text{nested-name-specifier} \text{opt} \text{class-name}
\]

\[
\text{access-specifier:} \\
\quad \text{private} \\
\quad \text{protected} \\
\quad \text{public}
\]

2 The \text{class-name} in a \text{base-specifier} shall not be an incompletely defined class (clause 9); this class is called a \text{direct base class} for the class being defined. During the lookup for a base class name, non-type names are ignored (3.3.7). If the name found is not a \text{class-name}, the program is ill-formed. A class \(B\) is a base class of a class \(D\) if it is a direct base class of \(D\) or a direct base class of one of \(D\)'s base classes. A class is an \text{indirect} base class of another if it is a base class but not a direct base class. A class is said to be (directly or indirectly) \text{derived} from its (direct or indirect) base classes. [\text{Note: See clause 11 for the meaning of access-specifier. — end note} ] Unless redeclared in the derived class, members of a base class are also considered to be members of the derived class. The base class members are said to be \text{inherited} by the derived class. Inherited members can be referred to in expressions in the same manner as other members of the derived class, unless their names are hidden or ambiguous (10.2). [\text{Note: the scope resolution operator \(::\) (5.1) can be used to refer to a direct or indirect base member explicitly. This allows access to a name that has been redeclared in the derived class. A derived class can itself serve as a base class subject to access control; see 11.2. A pointer to a derived class can be implicitly converted to a pointer to an accessible unambiguous base class (4.10). An lvalue of a derived class type can be bound to a reference to an accessible unambiguous base class (8.5.3). — end note} ]

3 The \text{base-specifier-list} specifies the type of the \text{base class subobjects} contained in an object of the derived class type. [\text{Example:}]

```cpp
class Base {
    public:
        int a, b, c;
};
```
10.1 Multiple base classes

A class can be derived from any number of base classes. [Note: the use of more than one direct base class is often called multiple inheritance. — end note] [Example:

```cpp
class A { /* ... */};
class B { /* ... */};
class C { /* ... */};
class D : public A, public B, public C { /* ... */};
```

— end example]

[Note: the order of derivation is not significant except as specified by the semantics of initialization by constructor (12.6.2), cleanup (12.4), and storage layout (9.2, 11.1). — end note]

Draft
A class shall not be specified as a direct base class of a derived class more than once. [Note: a class can be an indirect base class more than once and can be a direct and an indirect base class. There are limited things that can be done with such a class. The non-static data members and member functions of the direct base class cannot be referred to in the scope of the derived class. However, the static members, enumerations and types can be unambiguously referred to. — end note] [Example:

class X { /* ... */ };
class Y : public X, public X { /* ... */ };  // ill-formed

class L { public: int next; /* ... */ };
class A : public L { /* ... */ };
class B : public L { /* ... */ };
class C : public A, public B { void f(); /* ... */ };  // well-formed
nclass D : public A, public L { void f(); /* ... */ };  // well-formed

— end example ]

A base class specifier that does not contain the keyword virtual, specifies a non-virtual base class. A base class specifier that contains the keyword virtual, specifies a virtual base class. For each distinct occurrence of a non-virtual base class in the class lattice of the most derived class, the most derived object (1.8) shall contain a corresponding distinct base class subobject of that type. For each distinct base class that is specified virtual, the most derived object shall contain a single base class subobject of that type. [Example: for an object of class type C, each distinct occurrence of a (non-virtual) base class L in the class lattice of C corresponds one-to-one with a distinct L subobject within the object of type C. Given the class C defined above, an object of class C will have two subobjects of class L as shown below.

```
   L
   |
   A
   |
   C
   |
   B
   |
  L
```

In such lattices, explicit qualification can be used to specify which subobject is meant. The body of function C::f could refer to the member next of each L subobject:

```cpp
void C::f() { A::next = B::next; }  // well-formed
```

Without the A:: or B:: qualifiers, the definition of C::f above would be ill-formed because of ambiguity (10.2).

For another example,

```cpp
class V { /* ... */ };
class A : virtual public V { /* ... */ };
class B : virtual public V { /* ... */ };
class C : public A, public B { /* ... */ };
```

for an object c of class type C, a single subobject of type V is shared by every base subobject of c that has a virtual base class of type V. Given the class C defined above, an object of class C will have one subobject of class V, as shown below.

Draft
A class can have both virtual and non-virtual base classes of a given type.

class B { /* ... */ };
class X : virtual public B { /* ... */ };
class Y : virtual public B { /* ... */ };
class Z : public B { /* ... */ };
class AA : public X, public Y, public Z { /* ... */ };

For an object of class AA, all virtual occurrences of base class B in the class lattice of AA correspond to a single B subobject within the object of type AA, and every other occurrence of a (non-virtual) base class B in the class lattice of AA corresponds one-to-one with a distinct B subobject within the object of type AA. Given the class AA defined above, class AA has two subobjects of class B: Z’s B and the virtual B shared by X and Y, as shown below.

--- end example ---

10.2 Member name lookup

Member name lookup determines the meaning of a name (id-expression) in a class scope (3.3.6). Name lookup can result in an ambiguity, in which case the program is ill-formed. For an id-expression, name lookup begins in the class scope of this; for a qualified-id, name lookup begins in the scope of the nested-name-specifier. Name lookup takes place before access control (3.4, clause 11).

The following steps define the result of name lookup for a member name f in a class scope C.

1. The lookup set for f in C, called $S(f, C)$, consists of two component sets: the declaration set, a set of members named f; and the subobject set, a set of subobjects where declarations of these members (possibly including using-declarations) were found. In the declaration set, using-declarations are replaced by the members they designate, and type declarations (including injected-class-names) are replaced by the types they designate. $S(f, C)$ is calculated as follows:

2. If C contains a declaration of the name f, the declaration set contains every declaration of f declared in C that satisfies the requirements of the language construct in which the lookup occurs. [Note: Looking up a name in an elaborated-type-specifier (3.4.4) or base-specifier (clause 10), for instance, ignores all non-type declarations, while looking up a name in
a nested-name-specifier (3.4.3) ignores function, object, and enumerator declarations. As another example, looking up a name in a using-declaration (7.3.3) includes the declaration of a class or enumeration that would ordinarily be hidden by another declaration of that name in the same scope. — end note] If the resulting declaration set is not empty, the subobject set contains C itself, and calculation is complete.

Otherwise (i.e., C does not contain a declaration of f or the resulting declaration set is empty), S(f, C) is initially empty. If C has base classes, calculate the lookup set for f in each direct base class subobject Bi, and merge each such lookup set S(f, Bi) in turn into S(f, C).

The following steps define the result of merging lookup set S(f, Bi) into the intermediate S(f, C):

— If each of the subobject members of S(f, Bi) is a base class subobject of at least one of the subobject members of S(f, C), or if S(f, Bi) is empty, S(f, C) is unchanged and the merge is complete. Conversely, if each of the subobject members of S(f, C) is a base class subobject of at least one of the subobject members of S(f, Bi), or if S(f, C) is empty, the new S(f, C) is a copy of S(f, Bi).

— Otherwise, if the declaration sets of S(f, Bi) and S(f, C) differ, the merge is ambiguous: the new S(f, C) is a lookup set with an invalid declaration set and the union of the subobject sets. In subsequent merges, an invalid declaration set is considered different from any other.

— Otherwise, the new S(f, C) is a lookup set with the shared set of declarations and the union of the subobject sets.

The result of name lookup for f in C is the declaration set of S(f, C). If it is an invalid set, the program is ill-formed. [ Example:

```cpp
struct A { int x; }; // S(x,A) = { { A::x }, { A } }
struct B { float x; }; // S(x,B) = { { B::x }, { B } }
struct C: public A, public B { }; // S(x,C) = { invalid, { A in C, B in C } }
struct D: public virtual C { }; // S(x,D) = S(x,C)
struct E: public virtual C { char x; }; // S(x,E) = { { E::x }, { E } }
struct F: public D, public E { }; // S(x,F) = S(x,E)
int main() {
    F f;
    f.x = 0; // OK, lookup finds E::x
}
```

S(x, F) is unambiguous because the A and B base subobjects of D are also base subobjects of E, so S(x, D) is discarded in the first merge step. — end example ]

If the name of an overloaded function is unambiguously found, overloading resolution (13.3) also takes place before access control. Ambiguities can often be resolved by qualifying a name with its class name. [ Example:

```cpp
class A {
    public:
    int f();
};

class B {
    public:
    int f();
};
```
class C : public A, public B {
    int f() { return A::f() + B::f(); }
};

— end example ]

[ Note: A static member, a nested type or an enumerator defined in a base class \( T \) can unambiguously be found even if an object has more than one base class subobject of type \( T \). Two base class subobjects share the non-static member subobjects of their common virtual base classes. — end note ]

Example:

class V { public: int v; }
class A {
    public:
        int a;
        static int s;
        enum { e };
    }
class B : public A, public virtual V {};
class C : public A, public virtual V {};
class D : public B, public C {};

void f(D* pd)
{
    pd->v++; // OK: only one v (virtual)
    pd->s++; // OK: only one s (static)
    int i = pd->e; // OK: only one e (enumerator)
    pd->a++; // error, ambiguous: two as in D
}

— end example ]

[ Note: When virtual base classes are used, a hidden declaration can be reached along a path through the subobject lattice that does not pass through the hiding declaration. This is not an ambiguity. The identical use with non-virtual base classes is an ambiguity; in that case there is no unique instance of the name that hides all the others. — end note ]

Example:

class V { public: int f(); int x; }
class W { public: int g(); int y; }
class B : public virtual V, public W {
    public:
        int f(); int x;
        int g(); int y;
    }
class C : public virtual V, public W {}
class D : public B, public C { void glorp(); }

— end example ]
11 [Note: The names declared in V and the left-hand instance of W are hidden by those in B, but the names declared in the right-hand instance of W are not hidden at all. —end note]

```cpp
void D::glorp()
{
    x++;     // OK: B::x hides V::x
    f();     // OK: B::f() hides V::f()
    y++;     // error: B::y and C's W::y
    g();     // error: B::g() and C's W::g()
}
```

—end example]

12 An explicit or implicit conversion from a pointer to or an lvalue of a derived class to a pointer or reference to one of its base classes shall unambiguously refer to a unique object representing the base class. [Example:

```cpp
class V { };
class A { };
class B : public A, public virtual V { };
class C : public A, public virtual V { };
class D : public B, public C { };

void g()
{
    D d;
    B* pb = &d;       // error, ambiguous: C's A or B's A?
    A* pa = &d;
    V* pv = &d;       // OK: only one V subobject
}
```

—end example]

13 [Note: Even if the result of name lookup is unambiguous, use of a name found in multiple subobjects might still be ambiguous (4.11, 5.2.5, 11.2). —end note] Example:

```cpp
struct B1 {
    void f();
    static void f(int);
    int i;
};
struct B2 {
    void f(double);
}
```
10.3 Virtual functions

Virtual functions support dynamic binding and object-oriented programming. A class that declares or inherits a virtual function is called a polymorphic class.

If a virtual member function vf is declared in a class Base and in a class Derived, derived directly or indirectly from Base, a member function vf with the same name, parameter-type-list (8.3.5), and cv-qualification as Base::vf is declared, then Derived::vf is also virtual (whether or not it is so declared) and it overrides Base::vf. For convenience we say that any virtual function overrides itself. Then in any well-formed class, for each virtual function declared in that class or any of its direct or indirect base classes there is a unique final overrider that overrides that function and every other overrider of that function. The rules for member lookup (10.2) are used to determine the final overrider for a virtual function in the scope of a derived class but ignoring names introduced by using-declarations.

Example:

```cpp
struct A {
    virtual void f();
};
struct B : virtual A {
    virtual void f();
};
struct C : B, virtual A {
    using A::f;
};
void foo() {
    C c;
    c.f(); // calls B::f, the final overrider
    c.C::f(); // calls A::f because of the using-declaration
}
```

A function with the same name but a different parameter list (clause 13) as a virtual function is not necessarily virtual and does not override. The use of the virtual specifier in the declaration of an overriding function is legal but redundant (has empty semantics). Access control (clause 11) is not considered in determining overriding.
3 [Note: a virtual member function does not have to be visible to be overridden, for example,

```c
struct B {
    virtual void f();
};
struct D : B {
    void f(int);
};
struct D2 : D {
    void f();
};
```

the function `f(int)` in class `D` hides the virtual function `f()` in its base class `B`; `D::f(int)` is not a virtual function. However, `f()` declared in class `D2` has the same name and the same parameter list as `B::f()`, and therefore is a virtual function that overrides the function `B::f()` even though `B::f()` is not visible in class `D2`. — end note]

4 Even though destructors are not inherited, a destructor in a derived class overrides a base class destructor declared virtual; see 12.4 and 12.5.

5 The return type of an overriding function shall be either identical to the return type of the overridden function or covariant with the classes of the functions. If a function `D::f` overrides a function `B::f`, the return types of the functions are covariant if they satisfy the following criteria:

- both are pointers to classes or references to classes\(^{(104)}\)
- the class in the return type of `B::f` is the same class as the class in the return type of `D::f`, or is an unambiguous and accessible direct or indirect base class of the class in the return type of `D::f`
- both pointers or references have the same cv-qualification and the class type in the return type of `D::f` has the same cv-qualification as or less cv-qualification than the class type in the return type of `B::f`.

6 If the return type of `D::f` differs from the return type of `B::f`, the class type in the return type of `D::f` shall be complete at the point of declaration of `D::f` or shall be the class type `D`. When the overriding function is called as the final overrider of the overridden function, its result is converted to the type returned by the (statically chosen) overridden function (5.2.2). [Example:

```c
class B {
};
class D : private B { friend class Derived; }
struct Base {
    virtual void vf1();
    virtual void vf2();
    virtual void vf3();
    virtual B* vf4();
    virtual B* vf5();
    void f();
};
```

\(^{(104)}\) Multi-level pointers to classes or references to multi-level pointers to classes are not allowed.
10.3 Virtual functions

struct No_good : public Base {
    D* vf4(); // error: B (base class of D) inaccessible
};

class A;
struct Derived : public Base {
    void vf1(); // virtual and overrides Base::vf1()
    void vf2(int); // not virtual, hides Base::vf2()
    char vf3(); // error: invalid difference in return type only
    D* vf4(); // OK: returns pointer to derived class
    A* vf5(); // error: returns pointer to incomplete class
    void f();
};

void g() {
    Derived d;
    Base* bp = &d; // standard conversion:
        // Derived* to Base*
    bp->vf1(); // calls Derived::vf1()
    bp->vf2(); // calls Base::vf2()
    bp->f(); // calls Base::f() (not virtual)
    B* p = bp->vf4(); // calls Derived::pf() and converts the
        // result to B*
    Derived* dp = &d;
    D* q = dp->vf4(); // calls Derived::pf() and does not
        // convert the result to B*
    dp->vf2(); // ill-formed: argument mismatch
}

— end example ]

7 [ Note: the interpretation of the call of a virtual function depends on the type of the object for which it is called (the dynamic type), whereas the interpretation of a call of a non-virtual member function depends only on the type of the pointer or reference denoting that object (the static type) (5.2.2). — end note ]

8 [ Note: the virtual specifier implies membership, so a virtual function cannot be a nonmember (7.1.2) function. Nor can a virtual function be a static member, since a virtual function call relies on a specific object for determining which function to invoke. A virtual function declared in one class can be declared a friend in another class. — end note ]

9 A virtual function declared in a class shall be defined, or declared pure (10.4) in that class, or both; but no diagnostic is required (3.2).

10 [ Example: here are some uses of virtual functions with multiple base classes: ]

    struct A {
        virtual void f();
    };

    struct B1 : A { // note non-virtual derivation
        void f();
    };

Draft
struct B2 : A {
    void f();
};

struct D : B1, B2 { // D has two separate A subobjects
};

void foo() {
    D d;
    // A* ap = &d; // would be ill-formed: ambiguous
    B1* b1p = &d;
    A* ap = b1p;
    D* dp = &d;
    ap->f(); // calls D::B1::f
    dp->f(); // ill-formed: ambiguous
}

In class D above there are two occurrences of class A and hence two occurrences of the virtual member function A::f. The final overrider of B1::A::f is B1::f and the final overrider of B2::A::f is B2::f.

11 The following example shows a function that does not have a unique final overrider:

struct A {
    virtual void f();
};

struct VB1 : virtual A { // note virtual derivation
    void f();
};

struct VB2 : virtual A {
    void f();
};

struct Error : VB1, VB2 { // ill-formed
};

struct Okay : VB1, VB2 {
    void f();
};

Both VB1::f and VB2::f override A::f but there is no overrider of both of them in class Error. This example is therefore ill-formed. Class Okay is well formed, however, because Okay::f is a final overrider.

12 The following example uses the well-formed classes from above.

struct VB1a : virtual A { // does not declare f
};
10.4 Abstract classes

The abstract class mechanism supports the notion of a general concept, such as a shape, of which only more concrete variants, such as circle and square, can actually be used. An abstract class can also be used to define an interface for which derived classes provide a variety of implementations.

An abstract class is a class that can be used only as a base class of some other class; no objects of an abstract class can be created except as subobjects of a class derived from it. A class is abstract if it has at least one pure virtual function. [Note: such a function might be inherited: see below. — end note] A virtual function is specified pure by using a pure-specifier (9.2) in the function declaration in the class definition. A pure virtual function need be defined only if called with, or as if with (12.4), the qualified-id syntax (5.1). [Example:

class point { /* ... */ };  
class shape {  // abstract class
    point center;          // ...
    public:
    
    point where() { return center; }
    void move(point p) { center=p; draw(); }
    virtual void rotate(int) = 0;  // pure virtual
    virtual void draw() = 0;      // pure virtual
  }
};

— end example] [Note: a function declaration cannot provide both a pure-specifier and a definition — end note] [Example:

struct C {
    virtual void f() = 0 { };       // ill-formed
};

Explicit qualification with the scope operator (5.1) suppresses the virtual call mechanism. [Example:

class B { public: virtual void f(); };  
class D : public B { public: void f(); };  

void D::f() { /* ... */ B::f(); }

Here, the function call in D::f really does call B::f and not D::f. —end example]
An abstract class shall not be used as a parameter type, as a function return type, or as the type of an explicit conversion. Pointers and references to an abstract class can be declared. [Example:

```cpp
shape x;          // error: object of abstract class
shape* p;        // OK
shape f();        // error
void g(shape);    // error
shape& h(shape&); // OK
```

— end example ]

A class is abstract if it contains or inherits at least one pure virtual function for which the final overrider is pure virtual. [Example:

```cpp
class ab_circle : public shape {
  int radius;
public:
  void rotate(int) {} // ab_circle::draw() is a pure virtual
  // ab_circle::draw() is a pure virtual by default. The alternative declaration,
  class circle : public shape {
    int radius;
public:
    void rotate(int) {} // a definition is required somewhere
    void draw();       // a definition is required somewhere
  };

Since shape::draw() is a pure virtual function ab_circle::draw() is a pure virtual by default. The alternative declaration,

```cpp
class circle : public shape {
  int radius;
public:
  void rotate(int) {} // a definition is required somewhere
  void draw();       // a definition is required somewhere
};
```

would make class circle nonabstract and a definition of circle::draw() must be provided. — end example ]

[ Note: an abstract class can be derived from a class that is not abstract, and a pure virtual function may override a virtual function which is not pure. — end note ]

Member functions can be called from a constructor (or destructor) of an abstract class; the effect of making a virtual call (10.3) to a pure virtual function directly or indirectly for the object being created (or destroyed) from such a constructor (or destructor) is undefined.
10.4 Abstract classes

Draft
Chapter 11  Member access control  [class.access]

1  A member of a class can be
   — private; that is, its name can be used only by members and friends of the class in which it is declared.
   — protected; that is, its name can be used only by members and friends of the class in which it is declared, and by members and friends of classes derived from this class (see 11.5).
   — public; that is, its name can be used anywhere without access restriction.

2  A member of a class can also access all the names declared in the class of which it is a member. A local class of a member function may access the same names that the member function itself may access.105)

3  Members of a class defined with the keyword class are private by default. Members of a class defined with the keywords struct or union are public by default. [Example:
   
   ```cpp
   class X {
      int a;  // X::a is private by default
   };
   
   struct S {
      int a;  // S::a is public by default
   };
   ```
   
   — end example ]

4  Access control is applied uniformly to all names, whether the names are referred to from declarations or expressions. [ Note: access control applies to names nominated by friend declarations (11.4) and using-declarations (7.3.3). — end note ] In the case of overloaded function names, access control is applied to the function selected by overload resolution. [ Note: because access control applies to names, if access control is applied to a typedef name, only the accessibility of the typedef name itself is considered. The accessibility of the entity referred to by the typedef is not considered. For example,
   
   ```cpp
   class A {
      class B { };  // B::a is protected by default
      public:
         typedef B BB;
   };
   ```

105) Access permissions are thus transitive and cumulative to nested and local classes.
null
Member declarations can be labeled by an access-specifier (clause 10): 
\[\text{access-specifier} : \text{member-specification}^\text{opt}\]

An access-specifier specifies the access rules for members following it until the end of the class or until another access-specifier is encountered. [Example:
\begin{verbatim}
class X {
  int a; //X::a is private by default: class used
public:
  int b; //X::b is public
  int c; //X::c is public
};
\end{verbatim}
— end example ]

Any number of access specifiers is allowed and no particular order is required. [Example:
\begin{verbatim}
struct S {
  int a; //S::a is public by default: struct used
protected:
  int b; //S::b is protected
private:
  int c; //S::c is private
public:
  int d; //S::d is public
};
\end{verbatim}
— end example ]

The order of allocation of data members with separate access-specifier labels is unspecified (9.2).

When a member is redeclared within its class definition, the access specified at its redeclaration shall be the same as at its initial declaration. [Example:
\begin{verbatim}
struct S {
  class A;
private:
  class A { }; // error: cannot change access
};
\end{verbatim}
— end example ]

[Note: In a derived class, the lookup of a base class name will find the injected-class-name instead of the name of the base class in the scope in which it was declared. The injected-class-name might be less accessible than the name of the base class in the scope in which it was declared. — end note]
11.2 Accessibility of base classes and base class members

[ Example:

```cpp
class A {}
class B : private A {}
class C : public B {
    A *p;  // error: injected-class-name & is inaccessible
    ::A *q;  // OK
};
```

— end example ]

11.2 Accessibility of base classes and base class members

If a class is declared to be a base class (clause 10) for another class using the public access specifier, the public members of the base class are accessible as public members of the derived class and protected members of the base class are accessible as protected members of the derived class. If a class is declared to be a base class for another class using the protected access specifier, the public and protected members of the base class are accessible as protected members of the derived class. If a class is declared to be a base class for another class using the private access specifier, the public and protected members of the base class are accessible as private members of the derived class.\(^{106}\)

2 In the absence of an access-specifier for a base class, public is assumed when the derived class is declared struct and private is assumed when the class is declared class. [ Example:

```cpp
class B { /* ... */ }
class D1 : private B { /* ... */ }
class D2 : public B { /* ... */ }
class D3 : B { /* ... */ }  // B private by default
struct D4 : public B { /* ... */ }
struct D5 : private B { /* ... */ }
struct D6 : B { /* ... */ }  // B public by default
class D7 : protected B { /* ... */ }
struct D8 : protected B { /* ... */ }
```

Here B is a public base of D2, D4, and D6, a private base of D1, D3, and D5, and a protected base of D7 and D8. — end example ]

3 [ Note: A member of a private base class might be inaccessible as an inherited member name, but accessible directly. Because of the rules on pointer conversions (4.10) and explicit casts (5.4), a conversion from a pointer to a derived class to a pointer to an inaccessible base class might be ill-formed if an implicit conversion is used, but well-formed if an explicit cast is used. For example,

```cpp
class B {
public:
    int mi;  // non-static member
    static int si;  // static member
};
class D : private B {
};
```

\(^{106}\) As specified previously in clause 11, private members of a base class remain inaccessible even to derived classes unless friend declarations within the base class definition are used to grant access explicitly.

Draft
class DD : public D {
    void f();
};

void DD::f() {
    mi = 3;           // error: mi is private in D
    si = 3;           // error: si is private in D
    ::B b;
    b.mi = 3;         // OK (b.mi is different from this->mi)
    b.si = 3;         // OK (b.si is different from this->si)
    ::B::si = 3;      // OK
    ::B* bp1 = this;  // error: B is a private base class
    ::B* bp2 = (::B*)this;  // OK with cast
    bp2->mi = 3;      // OK: access through a pointer to B.
}

— end note ]

4 A base class B of N is accessible at R, if
— an invented public member of B would be a public member of N, or
— R occurs in a member or friend of class N, and an invented public member of B would be a private or protected member of N, or
— R occurs in a member or friend of a class P derived from N, and an invented public member of B would be a private or protected member of P, or
— there exists a class S such that B is a base class of S accessible at R and S is a base class of N accessible at R.

[ Example:

class B {
    public:
        int m;
    };

class S: private B {
    friend class N;
};

class N: private S {
    void f() {
        B* p = this;      // OK because class S satisfies the fourth condition
        // above: B is a base class of N accessible in f() because
        // B is an accessible base class of S and S is an accessible
        // base class of N.
    }
};

— end example ]

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If a base class is accessible, one can implicitly convert a pointer to a derived class to a pointer to that base class (4.10, 4.11). [Note: it follows that members and friends of a class \( X \) can implicitly convert an \( X^* \) to a pointer to a private or protected immediate base class of \( X \). —end note] The access to a member is affected by the class in which the member is named. This naming class is the class in which the member name was looked up and found. [Note: this class can be explicit, e.g., when a \textit{qualified-id} is used, or implicit, e.g., when a class member access operator (5.2.5) is used (including cases where an implicit “\texttt{this->}” is added). If both a class member access operator and a \textit{qualified-id} are used to name the member (as in \texttt{p->T::m}), the class naming the member is the class named by the \textit{nested-name-specifier} of the \textit{qualified-id} (that is, \texttt{T}). —end note] A member \( m \) is accessible at the point \( R \) when named in class \( N \) if

- \( m \) as a member of \( N \) is public, or
- \( m \) as a member of \( N \) is private, and \( R \) occurs in a member or friend of class \( N \), or
- \( m \) as a member of \( N \) is protected, and \( R \) occurs in a member or friend of class \( N \), or in a member or friend of a class \( P \) derived from \( N \), where \( m \) as a member of \( P \) is public, private, or protected, or
- there exists a base class \( B \) of \( N \) that is accessible at \( R \), and \( m \) is accessible at \( R \) when named in class \( B \). [Example:

```cpp
class B;
class A {
private:
  int i;
  friend void f(B*);
};
class B : public A {};
void f(B* p) {
  p->i = 1;
  // OK: B* can be implicitly cast to A*,
  // and i has access to i in A
}
```
—end example]

If a class member access operator, including an implicit “\texttt{this->},” is used to access a non-static data member or non-static member function, the reference is ill-formed if the left operand (considered as a pointer in the “.,” operator case) cannot be implicitly converted to a pointer to the naming class of the right operand. [Note: this requirement is in addition to the requirement that the member be accessible as named. —end note]

11.3 Access declarations

The access of a member of a base class can be changed in the derived class by mentioning its \textit{qualified-id} in the derived class definition. Such mention is called an \textit{access declaration}. The effect of an access declaration \textit{qualified-id} ; is defined to be equivalent to the declaration using \textit{qualified-id} ;.

[Example:

```cpp
class A {
public:
  int z;
```]

\footnote{Access declarations are deprecated; member \textit{using-declarations} (7.3.3) provide a better means of doing the same things. In earlier versions of the C++ language, access declarations were more limited; they were generalized and made equivalent to \textit{using-declarations} in the interest of simplicity. Programmers are encouraged to use \textit{using-declarations}, rather than the new capabilities of access declarations, in new code.}

Draft
```cpp
int z1;
}

class B : public A {
    int a;
public:
    int b, c;
    int bf();
protected:
    int x;
    int y;
};
class D : private B {
    int d;
public:
    B::c; // adjust access to B::c
    B::z; // adjust access to A::z
    A::z1; // adjust access to A::z1
    int e;
    int df();
protected:
    B::x; // adjust access to B::x
    int g;
};
class X : public D {
    int xf();
};
int ef(D&);
int ff(X&);
```

The external function ef can use only the names c, z, z1, e, and df. Being a member of D, the function df can use the names b, c, z, z1, bf, x, y, d, e, df, and g, but not a. Being a member of B, the function bf can use the members a, b, c, z, z1, bf, x, and y. The function xf can use the public and protected names from D, that is, c, z, z1, e, and df (public), and x, and g (protected). Thus the external function ff has access only to c, z, z1, e, and df. If D were a protected or private base class of X, xf would have the same privileges as before, but ff would have no access at all.

— end example

### 11.4 Friends

A friend of a class is a function or class that is given permission to use the private and protected member names from the class. A class specifies its friends, if any, by way of friend declarations. Such declarations give special access rights to the friends, but they do not make the nominated friends members of the befriending class. [Example: the following example illustrates the differences between members and friends:]

```cpp
class X {
    int a;
    friend void friend_set(X*, int);
};
```
11.4 Friends

```cpp
public:
    void member_set(int);
};

void friend_set(X* p, int i) { p->a = i; }
void X::member_set(int i) { a = i; }

void f()
{
    X obj;
    friend_set(&obj,10);
    obj.member_set(10);
}
```

— end example ]

2 Declaring a class to be a friend implies that the names of private and protected members from the class granting friendship can be accessed in declarations of members of the befriended class. [ Note: this means that access to private and protected names is also granted to member functions of the friend class (as if the functions were each friends) and to the static data member definitions of the friend class. This also means that private and protected type names from the class granting friendship can be used in the base-clause of a nested class of the friend class. However, the declarations of members of classes nested within the friend class cannot access the names of private and protected members from the class granting friendship. Also, because the base-clause of the friend class is not part of its member declarations, the base-clause of the friend class cannot access the names of the private and protected members from the class granting friendship. For example,

```cpp
class A {
    class B { }
    friend class X;
};
class X : A::B {
    A::B mx;  // ill-formed: A::B cannot be accessed
    // in the base-clause for X
    class Y : A::B {
        A::B my;  // ill-formed: A::B cannot be accessed
        // to declare members of nested class of X
    };
};
```

— end note ] 108) A class shall not be defined in a friend declaration. [ Example:

```cpp
class X {
    enum { a=100 };  
    friend class Y;
};

class Y {
    int v[X::a];  // OK, Y is a friend of X
```
class Z {
    int v[X::a]; // error: X::a is private
};

— end example ]

3 A friend declaration that does not declare a function shall have one of the following forms:

friend elaborated-type-specifier;
friend simple-type-specifier;
friend typename-specifier;

[ Note: a friend declaration may be the declaration in a template-declaration (clause 14, 14.5.3). — end note ] If the type specifier in a friend declaration designates a (possibly cv-qualified) class type, that class is declared as a friend; otherwise, the friend declaration is ignored. [ Example:

```
class C;
typedef C Ct;

class X1 {
    friend C; // OK: class C is a friend
};

class X2 {
    friend Ct; // OK: class C is a friend
    friend D; // error: no type-name D in scope
    friend class D; // OK: elaborated-type-specifier declares new class
};

template <typename T> class R {
    friend T;
};

R<C> rc; // class C is a friend of R<C>
R<int> Ri; // OK: "friend int;" is ignored
```
— end example ]

4 A function first declared in a friend declaration has external linkage (3.5). Otherwise, the function retains its previous linkage (7.1.1).

5 When a friend declaration refers to an overloaded name or operator, only the function specified by the parameter types becomes a friend. A member function of a class X can be a friend of a class Y. [ Example:

```
class Y {
    friend char* X::foo(int);
    friend X::X(void);
    // constructors can be friends
    friend X::~X(void);
    // destructors can be friends
    // ...
};
```

A function can be defined in a friend declaration of a class if and only if the class is a non-local class (9.8), the function name is unqualified, and the function has namespace scope. [Example:

```cpp
class M {
    friend void f() { }
    // definition of global f, a friend of M
    // not the definition of a member function

};
```
—end example]

Such a function is implicitly inline. A friend function defined in a class is in the (lexical) scope of the class in which it is defined. A friend function defined outside the class is not (3.4.1).

No storage-class-specifier shall appear in the decl-specifier-seq of a friend declaration.

A name nominated by a friend declaration shall be accessible in the scope of the class containing the friend declaration. The meaning of the friend declaration is the same whether the friend declaration appears in the private, protected or public (9.2) portion of the class member-specification.

Friendship is neither inherited nor transitive. [Example:

```cpp
class A {
    friend class B;
    int a;
};

class B {
    friend class C;
};

class C {
    void f(A* p) {
        p->a++;
        // error: C is not a friend of A
        // despite being a friend of a friend
    }
};

class D : public B { 
    void f(A* p) {
        p->a++;
        // error: D is not a friend of A
        // despite being derived from a friend
    }
};
```
—end example]

If a friend declaration appears in a local class (9.8) and the name specified is an unqualified name, a prior declaration is looked up without considering scopes that are outside the innermost enclosing non-class scope. For a friend function

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declaration, if there is no prior declaration, the program is ill-formed. For a friend class declaration, if there is no prior declaration, the class that is specified belongs to the innermost enclosing non-class scope, but if it is subsequently referenced, its name is not found by name lookup until a matching declaration is provided in the innermost enclosing nonclass scope. [Example:

```cpp
class X;
void a();
void f() {
    class Y;
    extern void b();
    class A {
        friend class X; // OK, but X is a local class, not ::X
        friend class Y; // OK
        friend class Z; // OK, introduces local class Z
        friend void a(); // error, ::a is not considered
        friend void b(); // OK
        friend void c(); // error
    };
    X *px; // OK, but ::X is found
    Z *pz; // error, no Z is found
}
```
— end example ]

### 11.5 Protected member access [class.protected]

An additional access check beyond those described earlier in clause 11 is applied when a non-static data member or non-static member function is a protected member of its naming class (11.2)\(^{(109)}\). As described earlier, access to a protected member is granted because the reference occurs in a friend or member of some class C. If the access is to form a pointer to member (5.3.1), the nested-name-specifier shall name C or a class derived from C. All other accesses involve a (possibly implicit) object expression (5.2.5). In this case, the class of the object expression shall be C or a class derived from C. [Example:

```cpp
class B {
    protected:
        int i;
        static int j;
};

class D1 : public B {
};

class D2 : public B {
    friend void fr(B*,D1*,D2*);
    void mem(B*,D1*);
};

void fr(B* pb, D1* p1, D2* p2)
{
```

\(^{(109)}\) This additional check does not apply to other members, e.g. static data members or enumerator member constants.
11.6 Access to virtual functions

The access rules (clause 11) for a virtual function are determined by its declaration and are not affected by the rules for a function that later overrides it. [Example:

```cpp
class B {
  public:
    virtual int f();
};

class D : public B {
  private:
    int f();
};

void f()
{
  D d;
  B* pb = &d;
  ...
D* pd = &d;

pb->f(); // OK: B::f() is public,
          // D::f() is invoked
pd->f(); // error: D::f() is private
}

— end example ]

2 Access is checked at the call point using the type of the expression used to denote the object for which the member function is called (B* in the example above). The access of the member function in the class in which it was defined (D in the example above) is in general not known.

11.7 Multiple access [class.paths]

If a name can be reached by several paths through a multiple inheritance graph, the access is that of the path that gives most access. [Example:

```cpp
class W { public: void f(); };  // OK
class A : private virtual W { };  // OK
class B : public virtual W { };  // OK
class C : public A, public B {
    void f() { W::f(); }          // OK
};
```

Since W::f() is available to C::f() along the public path through B, access is allowed. — end example]

11.8 Nested classes [class.access.nest]

A nested class is a member and as such has the same access rights as any other member. The members of an enclosing class have no special access to members of a nested class; the usual access rules (clause 11) shall be obeyed. [Example:

```cpp
class E {
    int x;
    class B { };
};

    class I {
        B b;  // OK: E::I can access E::B
        int y;
        void f(E* p, int i)
        {
            p->x = i;  // OK: E::I can access E::x
        }
    };
    int g(I* p)
    {
        return p->y;  // error: I::y is private
    }
};
```

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— end example ]
The default constructor (12.1), copy constructor and copy assignment operator (12.8), and destructor (12.4) are *special member functions*. The implementation will implicitly declare these member functions for a class type when the program does not explicitly declare them, except as noted in 12.1. The implementation will implicitly define them if they are used, as specified in 12.1, 12.4 and 12.8. Programs shall not define implicitly-declared special member functions. Programs may explicitly refer to implicitly declared special member functions. [Example: a program may explicitly call, take the address of or form a pointer to member to an implicitly declared special member function.

```cpp
struct A { }; // implicitly-declared A::operator=
struct B : A {
    B& operator=(const B &);
};
B& B::operator=(const B & s) {
    this->A::operator=(s); // well-formed
    return *this;
}
— end example ]
```

[Note: the special member functions affect the way objects of class type are created, copied, and destroyed, and how values can be converted to values of other types. Often such special member functions are called implicitly. — end note ]

Special member functions obey the usual access rules (clause 11). [Example: declaring a constructor protected ensures that only derived classes and friends can create objects using it. — end example ]

12.1 Constructors [class.ctor]

Constructors do not have names. A special declarator syntax using an optional sequence of function-specifiers (7.1.2) followed by the constructor’s class name followed by a parameter list is used to declare or define the constructor. In such a declaration, optional parentheses around the constructor class name are ignored. [Example:

```cpp
class C {
    public:
        C(); // declares the constructor
};

c::C() { } // defines the constructor
— end example ]
A constructor is used to initialize objects of its class type. Because constructors do not have names, they are never found during name lookup; however an explicit type conversion using the functional notation (5.2.3) will cause a constructor to be called to initialize an object. [Note: for initialization of objects of class type see 12.6. — end note ]

A typedef-name shall not be used as the class-name in the declarator-id for a constructor declaration.

A constructor shall not be virtual (10.3) or static (9.4). A constructor can be invoked for a const, volatile or const volatile object. A constructor shall not be declared const, volatile, or const volatile (9.3.2). const and volatile semantics (7.1.5.1) are not applied on an object under construction. They come into effect when the constructor for the most derived object (1.8) ends.

A default constructor for a class X is a constructor of class X that can be called without an argument. If there is no user-declared constructor for class X, a default constructor is implicitly declared. An implicitly-declared default constructor is an inline public member of its class. A default constructor is trivial if it is implicitly-declared and if:

- its class has no virtual functions (10.3) and no virtual base classes (10.1), and
- all the direct base classes of its class have trivial default constructors, and
- for all the non-static data members of its class that are of class type (or array thereof), each such class has a trivial default constructor.

Otherwise, the default constructor is non-trivial.

An implicitly-declared default constructor for a class is implicitly defined when it is used (3.2) to create an object of its class type (1.8). The implicitly-defined default constructor performs the set of initializations of the class that would be performed by a user-written default constructor for that class with an empty mem-initializer-list (12.6.2) and an empty function body. If that user-written default constructor would be ill-formed, the program is ill-formed. Before the implicitly-declared default constructor for a class is implicitly defined, all the implicitly-declared default constructors for its base classes and its non-static data members shall have been implicitly defined. [Note: an implicitly-declared default constructor has an exception-specification (15.4). — end note ]

Default constructors are called implicitly to create class objects of static or automatic storage duration (3.7.1, 3.7.2) defined without an initializer (8.5), are called to create class objects of dynamic storage duration (3.7.3) created by a new-expression in which the new-initializer is omitted (5.3.4), or are called when the explicit type conversion syntax (5.2.3) is used. A program is ill-formed if the default constructor for an object is implicitly used and the constructor is not accessible (clause 11).

[Note: 12.6.2 describes the order in which constructors for base classes and non-static data members are called and describes how arguments can be specified for the calls to these constructors. — end note ]

A copy constructor (12.8) is used to copy objects of class type.

A union member shall not be of a class type (or array thereof) that has a non-trivial constructor.

No return type (not even void) shall be specified for a constructor. A return statement in the body of a constructor shall not specify a return value. The address of a constructor shall not be taken.

A functional notation type conversion (5.2.3) can be used to create new objects of its type. [Note: The syntax looks like an explicit call of the constructor. — end note ] [Example:

```c
complex zz = complex(1,2.3);
cprint( complex(7.8,1.2) );
```

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An object created in this way is unnamed. [Note: 12.2 describes the lifetime of temporary objects. — end note] [Note: explicit constructor calls do not yield lvalues, see 3.10. — end note]

[Note: some language constructs have special semantics when used during construction; see 12.6.2 and 12.7. — end note]

During the construction of a const object, if the value of the object or any of its subobjects is accessed through an lvalue that is not obtained, directly or indirectly, from the constructor’s this pointer, the value of the object or subobject thus obtained is unspecified. [Example:

```cpp
struct C;
void no_opt(C*);

struct C {
    int c;
    C() : c(0) { no_opt(this); }
};

const C cobj;

void no_opt(C* cptr) {
    int i = cobj.c * 100;  // value of cobj.c is unspecified
    cptr->c = 1;
    cout << cobj.c * 100  // value of cobj.c is unspecified
         << '\n';
}

— end example ]

12.2 Temporary objects [class.temporary]

Temporaries of class type are created in various contexts: binding an rvalue to a reference (8.5.3), returning an rvalue (6.6.3), a conversion that creates an rvalue (4.1, 5.2.9, 5.2.11, 5.4), throwing an exception (15.1), entering a handler (15.3), and in some initializations (8.5). [Note: the lifetime of exception objects is described in 15.1. — end note] Even when the creation of the temporary object is avoided (12.8), all the semantic restrictions must be respected as if the temporary object was created. [Example: even if the copy constructor is not called, all the semantic restrictions, such as accessibility (clause 11), shall be satisfied. — end example ]

[Example:

class X {
    // ...
public:
    // ...
    X(int);
    X(const X&);
    ~X();
};

Draft
12.2 Temporary objects

Special member functions

X f(X);

void g()
{
    X a(1);
    X b = f(X(2));
    a = f(a);
}

Here, an implementation might use a temporary in which to construct X(2) before passing it to f() using X's copy-constructor; alternatively, X(2) might be constructed in the space used to hold the argument. Also, a temporary might be used to hold the result of f(X(2)) before copying it to b using X's copy-constructor; alternatively, f()’s result might be constructed in b. On the other hand, the expression a=f(a) requires a temporary for the result of f(a), which is then assigned to a. — end example

When an implementation introduces a temporary object of a class that has a non-trivial constructor (12.1, 12.8), it shall ensure that a constructor is called for the temporary object. Similarly, the destructor shall be called for a temporary with a non-trivial destructor (12.4). Temporary objects are destroyed as the last step in evaluating the full-expression (1.9) that (lexically) contains the point where they were created. This is true even if that evaluation ends in throwing an exception.

There are two contexts in which temporaries are destroyed at a different point than the end of the full-expression. The first context is when a default constructor is called to initialize an element of an array. If the constructor has one or more default arguments, any temporaries created in the default argument expressions are destroyed immediately after return from the constructor.

The second context is when a reference is bound to a temporary. The temporary to which the reference is bound or the temporary that is the complete object of a subobject to which the reference is bound persists for the lifetime of the reference except as specified below. A temporary bound to a reference member in a constructor’s ctor-initializer (12.6.2) persists until the constructor exits. A temporary bound to a reference parameter in a function call (5.2.2) persists until the completion of the full expression containing the call. A temporary bound to the returned value in a function return statement (6.6.3) persists until the function exits. In all these cases, the temporaries created during the evaluation of the expression initializing the reference, except the temporary to which the reference is bound, are destroyed at the end of the full-expression in which they are created and in the reverse order of the completion of their construction. If the lifetime of two or more temporaries to which references are bound ends at the same point, these temporaries are destroyed at that point in the reverse order of the completion of their construction. In addition, the destruction of temporaries bound to references shall take into account the ordering of destruction of objects with static or automatic storage duration (3.7.1, 3.7.2); that is, if obj1 is an object with static or automatic storage duration with the same storage duration as the temporary and created before the temporary is created the temporary shall be destroyed before obj1 is destroyed; if obj2 is an object with static or automatic storage duration with the same storage duration as the temporary and created after the temporary is created the temporary shall be destroyed after obj2 is destroyed. [Example:
the expression C(16)+C(23) creates three temporaries. A first temporary T1 to hold the result of the expression C(16), a second temporary T2 to hold the result of the expression C(23), and a third temporary T3 to hold the result of the addition of these two expressions. The temporary T3 is then bound to the reference cr. It is unspecified whether T1 or T2 is created first. On an implementation where T1 is created before T2, it is guaranteed that T2 is destroyed before T1. The temporaries T1 and T2 are bound to the reference parameters of operator+; these temporaries are destroyed at the end of the full expression containing the call to operator+. The temporary T3 bound to the reference cr is destroyed at the end of cr’s lifetime, that is, at the end of the program. In addition, the order in which T3 is destroyed takes into account the destruction order of other objects with static storage duration. That is, because obj1 is constructed before T3, and T3 is constructed before obj2, it is guaranteed that obj2 is destroyed before T3, and that T3 is destroyed before obj1. — end example }

12.3 Conversions [class.conv]

1 Type conversions of class objects can be specified by constructors and by conversion functions. These conversions are called user-defined conversions and are used for implicit type conversions (clause 4), for initialization (8.5), and for explicit type conversions (5.4, 5.2.9).

2 User-defined conversions are applied only where they are unambiguous (10.2, 12.3.2). Conversions obey the access control rules (clause 11). Access control is applied after ambiguity resolution (3.4).

[ Note: See 13.3 for a discussion of the use of conversions in function calls as well as examples below. — end note ]

4 At most one user-defined conversion (constructor or conversion function) is implicitly applied to a single value.

[Example:

class X {
   // ...
   public:
      operator int();
};

class Y {
   // ...
   public:
      operator X();
};

Y a;
int b = a;  // error
            // a.operator X().operator int() not tried
int c = X(a);  // OK: a.operator X().operator int()

— end example ]

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User-defined conversions are used implicitly only if they are unambiguous. A conversion function in a derived class does not hide a conversion function in a base class unless the two functions convert to the same type. Function overload resolution (13.3.3) selects the best conversion function to perform the conversion. [Example:

```c++
class X {
public:
    // ...
    operator int();
};

class Y : public X {
public:
    // ...
    operator char();
};

void f(Y& a)
{
    if (a) {
        // ill-formed:
        // X::operator int() or Y::operator char() // ...
    }
}
```

— end example ]

12.3.1 Conversion by constructor [class.convctor]

A constructor declared without the function-specifier explicit that can be called with a single parameter specifies a conversion from the type of its first parameter to the type of its class. Such a constructor is called a converting constructor. [Example:

```c++
class X {
    // ...
public:
    X(int);
    X(const char*, int =0);
};

void f(X arg)
{
    X a = 1; // a = X(1)
    X b = "Jessie"; // b = X("Jessie",0)
    a = 2; // a = X(2)
    f(3); // f(X(3))
}
```

— end example ]

An explicit constructor constructs objects just like non-explicit constructors, but does so only where the direct-initialization syntax (8.5) or where casts (5.2.9, 5.4) are explicitly used. A default constructor may be an explicit constructor; such a constructor will be used to perform default-initialization or value-initialization (8.5). [Example:
class Z {
public:
    explicit Z();
    explicit Z(int);
    // ...
};

Z a; // OK: default-initialization performed
Z a1 = 1; // error: no implicit conversion
Z a3 = Z(1); // OK: direct initialization syntax used
Z a2(1); // OK: direct initialization syntax used
Z* p = new Z(1); // OK: direct initialization syntax used
Z a4 = (Z)1; // OK: explicit cast used
Z a5 = static_cast<Z>(1); // OK: explicit cast used

— end example ]

A non-explicit copy-constructor (12.8) is a converting constructor. An implicitly-declared copy constructor is not an explicit constructor; it may be called for implicit type conversions.

### 12.3.2 Conversion functions

A member function of a class \(X\) with a name of the form

\[
\text{conversion-function-id:} \quad \text{operator} \ conversion-type-id
\]

\[
\text{conversion-type-id:} \quad \text{type-specifier-seq} \ conversion-declarator_{opt}
\]

\[
\text{conversion-declarator:} \quad \text{ptr-operator} \ conversion-declarator_{opt}
\]

specifies a conversion from \(X\) to the type specified by the \text{conversion-type-id}. Such member functions are called conversion functions. Classes, enumerations, and \text{typedef-names} shall not be declared in the \text{type-specifier-seq}. Neither parameter types nor return type can be specified. The type of a conversion function (8.3.5) is “function taking no parameter returning \text{conversion-type-id}.” A conversion function is never used to convert a (possibly cv-qualified) object to the (possibly cv-qualified) same object type (or a reference to it), to a (possibly cv-qualified) base class of that type (or a reference to it), or to (possibly cv-qualified) void.\(^{110}\)

[Example:

```cpp
class X {
    // ...
public:
    operator int();
};

void f(X a)
{
    int i = int(a);
}
```

\(^{110}\) Even though never directly called to perform a conversion, such conversion functions can be declared and can potentially be reached through a call to a virtual conversion function in a base class.
i = (int)a;
i = a;
}

In all three cases the value assigned will be converted by X::operator int(). — end example

2 User-defined conversions are not restricted to use in assignments and initializations. [ Example:

```c
void g(X a, X b)
{
    int i = (a) ? 1+a : 0;
    int j = (a&&b) ? a+b : i;
    if (a) { // ...
    }
}

— end example ]
```

3 The conversion-type-id shall not represent a function type nor an array type. The conversion-type-id in a conversion-function-id is the longest possible sequence of conversion-declarators. [ Note: this prevents ambiguities between the declarator operator * and its expression counterparts. [ Example:

```c
&ac.operator int*i;
 // syntax error:
 // parsed as: &(ac.operator int *)i
 // not as: &(ac.operator int)*i
```

The * is the pointer declarator and not the multiplication operator. — end example ] — end note

4 Conversion functions are inherited.

5 Conversion functions can be virtual.

6 Conversion functions cannot be declared static.

12.4 Destructors [class.dtor]

1 A special declarator syntax using an optional function-specifier (7.1.2) followed by ~ followed by the destructor’s class name followed by an empty parameter list is used to declare the destructor in a class definition. In such a declaration, the ~ followed by the destructor’s class name can be enclosed in optional parentheses; such parentheses are ignored. A typedef-name shall not be used as the class-name following the ~ in the declarator for a destructor declaration.

2 A destructor is used to destroy objects of its class type. A destructor takes no parameters, and no return type can be specified for it (not even void). The address of a destructor shall not be taken. A destructor shall not be static. A destructor can be invoked for a const, volatile or const volatile object. A destructor shall not be declared const, volatile or const volatile (9.3.2), const and volatile semantics (7.1.5.1) are not applied on an object under destruction. They stop being in effect when the destructor for the most derived object (1.8) starts.

3 If a class has no user-declared destructor, a destructor is declared implicitly. An implicitly-declared destructor is an inline public member of its class. A destructor is trivial if it is implicitly-declared and if:

— all of the direct base classes of its class have trivial destructors and
for all of the non-static data members of its class that are of class type (or array thereof), each such class has a trivial destructor.

Otherwise, the destructor is non-trivial.

An implicitly-declared destructor is implicitly defined when it is used to destroy an object of its class type (3.7). A program is ill-formed if the class for which a destructor is implicitly defined has:

- a non-static data member of class type (or array thereof) with an inaccessible destructor, or
- a base class with an inaccessible destructor.

Before the implicitly-declared destructor for a class is implicitly defined, all the implicitly-declared destructors for its base classes and its non-static data members shall have been implicitly defined. [Note: an implicitly-declared destructor has an exception-specification (15.4). — end note]

After executing the body of the destructor and destroying any automatic objects allocated within the body, a destructor for class X calls the destructors for X’s direct members, the destructors for X’s direct base classes and, if X is the type of the most derived class (12.6.2), its destructor calls the destructors for X’s virtual base classes. All destructors are called as if they were referenced with a qualified name, that is, ignoring any possible virtual overriding destructors in more derived classes. Bases and members are destroyed in the reverse order of the completion of their constructor (see 12.6.2). A return statement (6.6.3) in a destructor might not directly return to the caller; before transferring control to the caller, the destructors for the members and bases are called. Destructors for elements of an array are called in reverse order of their construction (see 12.6).

A destructor can be declared virtual (10.3) or pure virtual (10.4); if any objects of that class or any derived class are created in the program, the destructor shall be defined. If a class has a base class with a virtual destructor, its destructor (whether user- or implicitly-declared) is virtual.

[Note: some language constructs have special semantics when used during destruction; see 12.7. — end note]

A union member shall not be of a class type (or array thereof) that has a non-trivial destructor.

Destructors are invoked implicitly (1) for a constructed object with static storage duration (3.7.1) at program termination (3.6.3), (2) for a constructed object with automatic storage duration (3.7.2) when the block in which the object is created exits (6.7), (3) for a constructed temporary object when the lifetime of the temporary object ends (12.2), (4) for a constructed object allocated by a new-expression (5.3.4), through use of a delete-expression (5.3.5), (5) in several situations due to the handling of exceptions (15.3). A program is ill-formed if an object of class type or array thereof is declared and the destructor for the class is not accessible at the point of the declaration. Destructors can also be invoked explicitly.

At the point of definition of a virtual destructor (including an implicit definition (12.8)), the non-array deallocation function is looked up in the scope of the destructor’s class (10.2), and, if no declaration is found, the function is looked up in the global scope. If the result of this lookup is ambiguous or inaccessible, or if the lookup selects a placement deallocation function, the program is ill-formed. [Note: this assures that a deallocation function corresponding to the dynamic type of an object is available for the delete-expression (12.5). — end note]

In an explicit destructor call, the destructor name appears as a ~ followed by a type-name that names the destructor’s class type. The invocation of a destructor is subject to the usual rules for member functions (9.3), that is, if the object is not of the destructor’s class type and not of a class derived from the destructor’s class type, the program has undefined behavior (except that invoking delete on a null pointer has no effect). [Example:
12.4 Destructors

Special member functions

struct B {
    virtual ~B() { }
};

struct D : B {
    ~D() { }
};

D D_object;
typedef B B_alias;
B* B_ptr = &D_object;

void f() {
    D_object.B::~B();           // calls B's destructor
    B_ptr->~B();                // calls D's destructor
    B_ptr->~B_alias();          // calls D's destructor
    B_ptr->B_alias::~B();       // calls B's destructor
    B_ptr->B_alias::~B_alias();  // calls B's destructor
}

— end example ] [ Note: an explicit destructor call must always be written using a member access operator (5.2.5) or a qualified-id (5.1); in particular, the unary-expression "X() in a member function is not an explicit destructor call (5.3.1).
— end note ]

13 [ Note: explicit calls of destructors are rarely needed. One use of such calls is for objects placed at specific addresses using a new-expression with the placement option. Such use of explicit placement and destruction of objects can be necessary to cope with dedicated hardware resources and for writing memory management facilities. For example,

    void* operator new(std::size_t, void* p) { return p; }
    struct X {
        //...
        X(int);
        ~X();
    };
    void f(X* p);

    void g()    // rare, specialized use:
    {
        char* buf = new char[sizeof(X)];
        X* p = new(buf) X(222);            // use buf[] and initialize
        f(p);
        p->X::~X();                        // cleanup
    }

— end note ]

14 Once a destructor is invoked for an object, the object no longer exists; the behavior is undefined if the destructor is invoked for an object whose lifetime has ended (3.8). [ Example: if the destructor for an automatic object is explicitly invoked, and the block is subsequently left in a manner that would ordinarily invoke implicit destruction of the object, the behavior is undefined. — end example ]
15  [Note: the notation for explicit call of a destructor can be used for any scalar type name (5.2.4). Allowing this makes it possible to write code without having to know if a destructor exists for a given type. For example,

```c
typedef int I;
I* p;
// ...
p->I::~I();
```
— end note ]

12.5  Free store  [class.free]

1  Any allocation function for a class T is a static member (even if not explicitly declared static).

2  [Example:

```c
class Arena;
struct B {
  void* operator new(std::size_t, Arena*);
};
struct D1 : B {
};

Arena* ap;
void foo(int i)
{
  new (ap) D1;       // calls B::operator new(std::size_t, Arena*)
  new D1[i];         // calls ::operator new[] (std::size_t)
  new D1;            // ill-formed: ::operator new(std::size_t) hidden
}
```
— end example ]

3  When an object is deleted with a `delete-expression` (5.3.5), a deallocation function (operator `delete()` for non-array objects or `operator delete[]()` for arrays) is (implicitly) called to reclaim the storage occupied by the object (3.7.3.2).

4  If a `delete-expression` begins with a unary `::` operator, the deallocation function’s name is looked up in global scope. Otherwise, if the `delete-expression` is used to deallocate a class object whose static type has a virtual destructor, the deallocation function is the one selected at the point of definition of the dynamic type’s virtual destructor (12.4). Otherwise, if the `delete-expression` is used to deallocate an object of class T or array thereof, the static and dynamic types of the object shall be identical and the deallocation function’s name is looked up in the scope of T. If this lookup fails to find the name, the name is looked up in the global scope. If the result of the lookup is ambiguous or inaccessible, or if the lookup selects a placement deallocation function, the program is ill-formed.

5  When a `delete-expression` is executed, the selected deallocation function shall be called with the address of the block of storage to be reclaimed as its first argument and (if the two-parameter style is used) the size of the block as its second

\[111\] A similar provision is not needed for the array version of `operator delete` because 5.3.5 requires that in this situation, the static type of the `delete-expression`’s operand be the same as its dynamic type.
6 Any deallocation function for a class \(X\) is a static member (even if not explicitly declared \texttt{static}). [\textit{Example}:

```cpp
class X {
    // ...
    void operator delete(void*);
    void operator delete[](void*, std::size_t);
};

class Y {
    // ...
    void operator delete(void*, std::size_t);
    void operator delete[](void*);
};
```

— end example ]

7 Since member allocation and deallocation functions are \texttt{static} they cannot be virtual. [\textit{Note}: however, when the \textit{cast-expression} of a \textit{delete-expression} refers to an object of class type, because the deallocation function actually called is looked up in the scope of the class that is the dynamic type of the object, if the destructor is virtual, the effect is the same. For example,

```cpp
struct B {
    virtual ~B();
    void operator delete(void*, std::size_t);
};

struct D : B {
    void operator delete(void*);
};

void f()
{
    B* bp = new D;
    delete bp; // \textit{I: uses D::operator delete(void*)}
}
```

Here, storage for the non-array object of class \(D\) is deallocated by \texttt{D::operator delete()}, due to the virtual destructor. — end note ] [\textit{Note}: virtual destructors have no effect on the deallocation function actually called when the \textit{cast-expression} of a \textit{delete-expression} refers to an array of objects of class type. For example,

```cpp
struct B {
    virtual ~B();
    void operator delete[](void*, std::size_t);
};

struct D : B {
    void operator delete[](void*, std::size_t);
};
```

\footnote{If the static type in the \textit{delete-expression} is different from the dynamic type and the destructor is not virtual the size might be incorrect, but that case is already undefined; see \texttt{5.3.5}.}
void f(int i) {
    D* dp = new D[i];
    delete[] dp; // uses D::operator delete[](void*, std::size_t)
    B* bp = new D[i];
    delete[] bp; // undefined behavior
}

— end note ]

8 Access to the deallocation function is checked statically. Hence, even though a different one might actually be executed, the statically visible deallocation function is required to be accessible. [ Example: for the call on line //1 above, if B::operator delete() had been private, the delete expression would have been ill-formed. — end example ]

12.6 Initialization [class.init]

1 When no initializer is specified for an object of (possibly cv-qualified) class type (or array thereof), or the initializer has the form (), the object is initialized as specified in 8.5. The object is default-initialized if there is no initializer, or value-initialized if the initializer is ()..

2 An object of class type (or array thereof) can be explicitly initialized; see 12.6.1 and 12.6.2.

3 When an array of class objects is initialized (either explicitly or implicitly), the constructor shall be called for each element of the array, following the subscript order; see 8.3.4. [ Note: destructors for the array elements are called in reverse order of their construction. — end note ]

12.6.1 Explicit initialization [class.expl.init]

1 An object of class type can be initialized with a parenthesized expression-list, where the expression-list is construed as an argument list for a constructor that is called to initialize the object. Alternatively, a single assignment-expression can be specified as an initializer using the = form of initialization. Either direct-initialization semantics or copy-initialization semantics apply; see 8.5. [ Example:

    class complex {
        // ...
        public:
            complex();
            complex(double);
            complex(double,double);
            // ...
    };

    complex sqrt(complex,complex);

    complex a(1); // initialize by a call of
                   // complex(double)
    complex b = a; // initialize by a copy of a
    complex c = complex(1,2); // construct complex(1,2)
                             // using complex(double,double)
                             // copy it into c

    Draft
complex d = sqrt(b,c); // call sqrt(complex,complex)
// and copy the result into d
complex e; // initialize by a call of
    // complex()
complex f = 3; // construct complex(3) using
    // complex(double)
    // copy it into f
complex g = { 1, 2 }; // error: constructor is required

— end example ] [ Note: overloading of the assignment operator (13.5.3) has no effect on initialization. — end note ]

When an aggregate (whether class or array) contains members of class type and is initialized by a brace-enclosed initializer-list (8.5.1), each such member is copy-initialized (see 8.5) by the corresponding assignment-expression. If there are fewer initializers in the initializer-list than members of the aggregate, each member not explicitly initialized shall be value-initialized (8.5). [ Note: 8.5.1 describes how assignment-expressions in an initializer-list are paired with the aggregate members they initialize. — end note ]

Example:
complex v[6] = { 1, complex(1,2), complex(), 2 };

Here, complex::complex(double) is called for the initialization of v[0] and v[3], complex::complex(double, double) is called for the initialization of v[1], complex::complex() is called for the initialization v[2], v[4], and v[5]. For another example,

class X {
public:
    int i;
    float f;
    complex c;
} x = { 99, 88.8, 77.7 };

Here, x.i is initialized with 99, x.f is initialized with 88.8, and complex::complex(double) is called for the initialization of x.c. — end example ] [ Note: braces can be elided in the initializer-list for any aggregate, even if the aggregate has members of a class type with user-defined type conversions; see 8.5.1. — end note ]

[ Note: if T is a class type with no default constructor, any declaration of an object of type T (or array thereof) is ill-formed if no initializer is explicitly specified (see 12.6 and 8.5). — end note ]

[ Note: the order in which objects with static storage duration are initialized is described in 3.6.2 and 6.7. — end note ]

12.6.2 Initializing bases and members

In the definition of a constructor for a class, initializers for direct and virtual base subobjects and non-static data members can be specified by a ctor-initializer, which has the form

cTOR-initializer:
    : mem-initializer-list
mem-initializer-list:
    mem-initializer
    mem-initializer , mem-initializer-list
mem-initializer:
    mem-initializer-id ( expression-listopt )
mem-initializer-id:
   ::opt nested-name-specifier opt class-name
   identifier

Names in a mem-initializer-id are looked up in the scope of the constructor’s class and, if not found in that scope, are looked up in the scope containing the constructor’s definition. [Note: if the constructor’s class contains a member with the same name as a direct or virtual base class of the class, a mem-initializer-id naming the member or base class and composed of a single identifier refers to the class member. A mem-initializer-id for the hidden base class may be specified using a qualified name. —end note] Unless the mem-initializer-id names the constructor’s class, a non-static data member of the constructor’s class or a direct or virtual base of that class, the mem-initializer is ill-formed. A mem-initializer-list can initialize a base class using any name that denotes that base class type. [Example:

```
struct A { A();
    typedef A global_A;
    struct B { }
    struct C: public A, public B { C(); }
    C::C(): global_A() { }  // mem-initializer for base A
```
—end example]

A mem-initializer-list can delegate to another constructor of the constructor’s class using any name that denotes the constructor’s class itself. If a mem-initializer-id designates the constructor’s class, it shall be the only mem-initializer, the constructor is a delegating constructor, and the constructor selected by the mem-initializer is the target constructor. The principal constructor is the first constructor invoked in the construction of an object (that is, not a target constructor for that object’s construction). The target constructor is selected by overload resolution. Once the target constructor returns, the body of the delegating constructor is executed. If a constructor delegates to itself directly or indirectly, the program is ill-formed; no diagnostic is required. [Example:

```
struct C {
    C( int ) { }   // 1: non-delegating constructor
    C(): C(42) { }  // 2: delegates to 1
    C( char c ): C(42.0) { }  // 3: ill-formed due to recursion with 4
    C( double d ): C(‘a’) { }  // 4: ill-formed due to recursion with 3
};
```
—end example] If a mem-initializer-id is ambiguous because it designates both a direct non-virtual base class and an inherited virtual base class, the mem-initializer is ill-formed. [Example:

```
struct A { A();
    struct B: public virtual A { }
    struct C: public A, public B { C(); }
    C::C(): A() { }  // ill-formed: which A?
```
—end example] A ctor-initializer may initialize the member of an anonymous union that is a member of the constructor’s class. If a ctor-initializer specifies more than one mem-initializer for the same member, for the same base class or for multiple members of the same union (including members of anonymous unions), the ctor-initializer is ill-formed.

The expression-list in a mem-initializer is used to initialize the base class or non-static data member subobject denoted by the mem-initializer-id. The semantics of a mem-initializer are as follows:

— if the expression-list of the mem-initializer is omitted, the base class or member subobject is value-initialized (see 8.5);
— otherwise, the subobject indicated by `mem-initializer-id` is direct-initialized using `expression-list` as the `initializer` (see 8.5).

[Example:]  
```cpp
struct B1 { B1(int); /* ... */ };  
struct B2 { B2(int); /* ... */ };  
struct D : B1, B2 {  
  D(int);  
  B1 b;  
  const int c;  
};  
D::D(int a) : B2(a+1), B1(a+2), c(a+3), b(a+4)  
{ /* ... */ }  
D d(10);  
```

— end example] There is a sequence point (1.9) after the initialization of each base and member. The `expression-list` of a `mem-initializer` is evaluated as part of the initialization of the corresponding base or member.

4 If a given non-static data member or base class is not named by a `mem-initializer-id` (including the case where there is no `mem-initializer-list` because the constructor has no `ctor-initializer`), then

— If the entity is a non-static data member of (possibly cv-qualified) class type (or array thereof) or a base class, and the entity class is a non-POD class, the entity is default-initialized (8.5). If the entity is a non-static data member of a const-qualified type, the entity class shall have a user-declared default constructor.

— Otherwise, the entity is not initialized. If the entity is of const-qualified type or reference type, or of a (possibly cv-qualified) POD class type (or array thereof) containing (directly or indirectly) a member of a const-qualified type, the program is ill-formed.

After the call to a constructor for class X has completed, if a member of X is neither specified in the constructor’s `mem-initializers`, nor default-initialized, nor value-initialized, nor given a value during execution of the body of the constructor, the member has indeterminate value.

5 Initialization shall proceed in the following order:

— First, and only for the constructor of the most derived class as described below, virtual base classes shall be initialized in the order they appear on a depth-first left-to-right traversal of the directed acyclic graph of base classes, where “left-to-right” is the order of appearance of the base class names in the derived class `base-specifier-list`.

— Then, direct base classes shall be initialized in declaration order as they appear in the `base-specifier-list` (regardless of the order of the `mem-initializers`).

— Then, non-static data members shall be initialized in the order they were declared in the class definition (again regardless of the order of the `mem-initializers`).

— Finally, the body of the constructor is executed.

[Note: the declaration order is mandated to ensure that base and member subobjects are destroyed in the reverse order of initialization. — end note]
All subobjects representing virtual base classes are initialized by the constructor of the most derived class (1.8). If the constructor of the most derived class does not specify a mem-initializer for a virtual base class V, then V’s default constructor is called to initialize the virtual base class subobject. If V does not have an accessible default constructor, the initialization is ill-formed. A mem-initializer naming a virtual base class shall be ignored during execution of the constructor of any class that is not the most derived class. [Example:

```cpp
class V {
  public:
    V();
    V(int);
    // ...
};

class A : public virtual V {
  public:
    A();
    A(int);
    // ...
};

class B : public virtual V {
  public:
    B();
    B(int);
    // ...
};

class C : public A, public B, private virtual V {
  public:
    C();
    C(int);
    // ...
};

A::A(int i) : V(i) { /* */ ...
B::B(int i) { /* */ ...
C::C(int i) { /* */ ...

V v(1);          // use V(int)
A a(2);          // use V(int)
B b(3);          // use V()
C c(4);          // use V()

—end example]

7 Names in the expression-list of a mem-initializer are evaluated in the scope of the constructor for which the mem-initializer is specified. [Example:

```cpp
class X {
  int a;
  int b;

Draft
12.6 Initialization

```cpp
int i;
int j;
public:
    const int& r;
    X(int i): r(a), b(i), i(i), j(this->i) {}
};
```

initializes X::r to refer to X::a, initializes X::b with the value of the constructor parameter i, initializes X::i with the value of the constructor parameter i, and initializes X::j with the value of X::i; this takes place each time an object of class X is created. —end example [ Note: because the mem-initializer are evaluated in the scope of the constructor, the this pointer can be used in the expression-list of a mem-initializer to refer to the object being initialized. —end note ]

Member functions (including virtual member functions, 10.3) can be called for an object under construction. Similarly, an object under construction can be the operand of the typeid operator (5.2.8) or of a dynamic_cast (5.2.7). However, if these operations are performed in a ctor-initializer (or in a function called directly or indirectly from a ctor-initializer) before all the mem-initializers for base classes have completed, the result of the operation is undefined. [ Example:

```cpp
class A {
    public:
        A(int);
    }

class B : public A {
    int j;
    public:
        int f();
        B() : A(f()), j(f()) { } // well-defined: bases are all initialized
    }

class C {
    public:
        C(int);
    }

class D : public B, C {
    int i;
    public:
        D() : C(f()), i(f()) {} // well-defined: bases are all initialized
    }
}

—end example ]

[ Note: 12.7 describes the result of virtual function calls, typeid and dynamic_casts during construction for the well-defined cases; that is, describes the polymorphic behavior of an object under construction. —end note ]
12.7 Construction and destruction

1 For an object of non-POD class type (clause 9), before the constructor begins execution and after the destructor finishes execution, referring to any non-static member or base class of the object results in undefined behavior. [Example:

```c
struct X { int i; };  
struct Y : X { };  
struct A { int a; };  
struct B : public A { int j; Y y; };  

extern B bobj;  
B* pb = &bobj;  // OK  
int* p1 = bobj.a;  // undefined, refers to base class member  
int* p2 = &bobj.y.i;  // undefined, refers to member's member  

A* pa = &bobj;  // undefined, upcast to a base class type  
B bobj;  // definition of bobj  

extern X xobj;  
int* p3 = &xobj.i;  // OK, X is a POD class  
X xobj;  
```

— end example ]

2 For another example,

```c
struct W { int j; };  
struct X : public virtual W { };  
struct Y {  
    int *p;  
    X x;  
    Y() : p(&x.j)  // undefined, x is not yet constructed  
    {}  
};  
```

3 To explicitly or implicitly convert a pointer (an lvalue) referring to an object of class X to a pointer (reference) to a direct or indirect base class B of X, the construction of X and the construction of all of its direct or indirect bases that directly or indirectly derive from B shall have started and the destruction of these classes shall not have completed, otherwise the conversion results in undefined behavior. To form a pointer to (or access the value of) a direct non-static member of an object obj, the construction of obj shall have started and its destruction shall not have completed, otherwise the computation of the pointer value (or accessing the member value) results in undefined behavior. [Example:

```c
struct A { };  
struct B : virtual A { };  
struct C : B { };  
struct D : virtual A { D(A*); };  
struct X { X(A*); };  

struct E : C, D, X {  
    E() : D(this),  // undefined: upcast from E* to A*  
    // might use path E* → D* → A*  
};  
```

Draft
Member functions, including virtual functions (10.3), can be called during construction or destruction (12.6.2). When a virtual function is called directly or indirectly from a constructor (including from the mem-initializer for a data member) or from a destructor, and the object to which the call applies is the object under construction or destruction, the function called is the one defined in the constructor or destructor’s own class or in one of its bases, but not a function overriding it in a class derived from the constructor or destructor’s class, or overriding it in one of the other base classes of the most derived object (1.8). If the virtual function call uses an explicit class member access (5.2.5) and the object-expression refers to the object under construction or destruction but its type is neither the constructor or destructor’s own class or one of its bases, the result of the call is undefined. [Example:

```cpp
class V {
public:
    virtual void f();
    virtual void g();
};

class A : public virtual V {
public:
    virtual void f();
};

class B : public virtual V {
public:
    virtual void g();
    B(V*, A*);
};

class D : public A, B {
public:
    virtual void f();
    virtual void g();
    D() : B((A*)this, this) { }
};

B::B(V* v, A* a) {
    f(); // calls V::f, not A::f
    g(); // calls B::g, not D::g
    v->g(); // v is base of B, the call is well-defined, calls B::g
    a->f(); // undefined behavior, a's type not a base of B

    };

```
The `typeid` operator (5.2.8) can be used during construction or destruction (12.6.2). When `typeid` is used in a constructor (including from the `mem-initializer` for a data member) or in a destructor, or used in a function called (directly or indirectly) from a constructor or destructor, if the operand of `typeid` refers to the object under construction or destruction, `typeid` yields the `std::type_info` object representing the constructor or destructor’s class. If the operand of `typeid` refers to the object under construction or destruction and the static type of the operand is neither the constructor or destructor’s class nor one of its bases, the result of `typeid` is undefined.

Dynamic_casts (5.2.7) can be used during construction or destruction (12.6.2). When a `dynamic_cast` is used in a constructor (including from the `mem-initializer` for a data member) or in a destructor, or used in a function called (directly or indirectly) from a constructor or destructor, if the operand of the `dynamic_cast` refers to the object under construction or destruction, this object is considered to be a most derived object that has the type of the constructor or destructor’s class. If the operand of the `dynamic_cast` refers to the object under construction or destruction and the static type of the operand is not a pointer to or object of the constructor or destructor’s own class or one of its bases, the `dynamic_cast` results in undefined behavior.

```cpp
Example:

class V {
public:
    virtual void f();
};

class A : public virtual V { };

class B : public virtual V {
public:
    B(V*, A*);
};

class D : public A, B {
public:
    D() : B((A*)this, this) { }
};

B::B(V* v, A* a) {
    typeid(*this);            // type_info for B
    typeid(*v);               // well-defined; *v has type V, a base of B
    // yields type_info for B
    typeid(*a);               // undefined behavior: type A not a base of B
    dynamic_cast<B*>(v);     // well-defined; v of type V*, V base of B
    // results in B*
    dynamic_cast<B*>(a);     // undefined behavior;
    // a has type A*, A not a base of B
}
```
12.8 Copying class objects

A class object can be copied in two ways, by initialization (12.1, 8.5), including for function argument passing (5.2.2) and for function value return (6.6.3), and by assignment (5.17). Conceptually, these two operations are implemented by a copy constructor (12.1) and copy assignment operator (13.5.3).

A non-template constructor for class $X$ is a copy constructor if its first parameter is of type $X\&$, $\text{const } X\&$, volatile $X\&$, or $\text{const volatile } X\&$, and either there are no other parameters or else all other parameters have default arguments (8.3.6).\(^{113}\) [Example: $X::X(\text{const } X\&)$ and $X::X(X\&, \text{int}=1)$ are copy constructors.]

```cpp
class X {
public:
    X(int);
    X(const X&, int = 1);
};
X a(1); // calls X(int);
X b(a, 0); // calls X(const X&, int);
X c = b; // calls X(const X&, int);
```

— end example — Note: all forms of copy constructor may be declared for a class. [Example:]

```cpp
class X {
public:
    //...
    X(const X&);
    X(X&); // OK
};
```

— end example — end note — Note: if a class $X$ only has a copy constructor with a parameter of type $X\&$, an initializer of type $\text{const } X$ or volatile $X$ cannot initialize an object of type (possibly cv-qualified) $X$. [Example:]

```cpp
struct X {
    X(); // default constructor
    X(X&); // copy constructor with a nonconst parameter
};
const X cx;
X x = cx; // error — $X::X(X\&)$ cannot copy $cx$ into $x$
```

— end example — end note

3 A declaration of a constructor for a class $X$ is ill-formed if its first parameter is of type (optionally cv-qualified) $X$ and either there are no other parameters or else all other parameters have default arguments. A member function template is never instantiated to perform the copy of a class object to an object of its class type. [Example:

\(^{113}\) Because a template constructor is never a copy constructor, the presence of such a template does not suppress the implicit declaration of a copy constructor. Template constructors participate in overload resolution with other constructors, including copy constructors, and a template constructor may be used to copy an object if it provides a better match than other constructors.
struct S {
  template<typename T> S(T);
};

S f();

void g() {
  S a( f() ); // does not instantiate member template
}

— end example ]

If the class definition does not explicitly declare a copy constructor, one is declared implicitly. Thus, for the class definition

```cpp
struct X {
  X(const X&, int);
};
```
a copy constructor is implicitly-declared. If the user-declared constructor is later defined as

```cpp
X::X(const X& x, int i = 0) { /* ... */ }
```
then any use of X’s copy constructor is ill-formed because of the ambiguity; no diagnostic is required.

The implicitly-declared copy constructor for a class X will have the form

```cpp
X::X(X&)
```

if

---
1. each direct or virtual base class B of X has a copy constructor whose first parameter is of type `const B&` or `const volatile B&`, and
2. for all the non-static data members of X that are of a class type M (or array thereof), each such class type has a copy constructor whose first parameter is of type `const M&` or `const volatile M&`.\(^\text{114}\)
---

Otherwise, the implicitly declared copy constructor will have the form

```cpp
X::X(X&)
```

An implicitly-declared copy constructor is an inline public member of its class.

A copy constructor for class X is trivial if it is implicitly declared and if

---
1. class X has no virtual functions (10.3) and no virtual base classes (10.1), and
2. each direct base class of X has a trivial copy constructor, and
3. for all the non-static data members of X that are of class type (or array thereof), each such class type has a trivial copy constructor;
---

\(^\text{114}\) This implies that the reference parameter of the implicitly-declared copy constructor cannot bind to a volatile lvalue; see C.1.8.
otherwise the copy constructor is *non-trivial*.

7 An implicitly-declared copy constructor is *implicitly defined* if it is used to initialize an object of its class type from a copy of an object of its class type or of a class type derived from its class type\(^{15}\). [Note: the copy constructor is implicitly defined even if the implementation elided its use (12.2). — end note] A program is ill-formed if the class for which a copy constructor is implicitly defined has:

---

7.1 a non-static data member of class type (or array thereof) with an inaccessible or ambiguous copy constructor, or

7.2 a base class with an inaccessible or ambiguous copy constructor.

Before the implicitly-declared copy constructor for a class is implicitly defined, all implicitly-declared copy constructors for its direct and virtual base classes and its non-static data members shall have been implicitly defined. [Note: an implicitly-declared copy constructor has an *exception-specification* (15.4). — end note]

8 The implicitly-defined copy constructor for class \(X\) performs a memberwise copy of its subobjects. The order of copying is the same as the order of initialization of bases and members in a user-defined constructor (see 12.6.2). Each subobject is copied in the manner appropriate to its type:

---

8.1 if the subobject is of class type, the copy constructor for the class is used;

8.2 if the subobject is an array, each element is copied, in the manner appropriate to the element type;

8.3 if the subobject is of scalar type, the built-in assignment operator is used.

Virtual base class subobjects shall be copied only once by the implicitly-defined copy constructor (see 12.6.2).

9 A user-declared *copy* assignment operator \(X::\text{operator=}\) is a non-static non-template member function of class \(X\) with exactly one parameter of type \(X\), \(X\&\), \(\text{const }X\&\), \(\text{volatile }X\&\) or \(\text{const volatile }X\&\).\(^{16}\) [Note: an overloaded assignment operator must be declared to have only one parameter; see 13.5.3. — end note] [Note: more than one form of copy assignment operator may be declared for a class. — end note] [Note: if a class \(X\) only has a copy assignment operator with a parameter of type \(X\&\), an expression of type \(\text{const }X\) cannot be assigned to an object of type \(X\). [Example:

```c
struct X {
  X();
  X& operator=(X&); 
};
const X cx;
X x;
void f() {
  x = cx; // error:
  // X::operator=(X&) cannot assign cx into x
}
```

— end example] — end note]

10 If the class definition does not explicitly declare a copy assignment operator, one is declared *implicitly*. The implicitly-declared copy assignment operator for a class \(X\) will have the form

---

\(^{15}\) See 8.5 for more details on direct and copy initialization.

\(^{16}\) Because a template assignment operator is never a copy assignment operator, the presence of such a template does not suppress the implicit declaration of a copy assignment operator. Template assignment operators participate in overload resolution with other assignment operators, including copy assignment operators, and a template assignment operator may be used to assign an object if it provides a better match than other assignment operators.
X& X::operator=(const X&)

if

— each direct base class B of X has a copy assignment operator whose parameter is of type const B& or B, and

— for all the non-static data members of X that are of a class type M (or array thereof), each such class type has a copy assignment operator whose parameter is of type const M&, const volatile M& or M.\(^{(117)}\)

Otherwise, the implicitly declared copy assignment operator will have the form

X& X::operator=(X&)

The implicitly-declared copy assignment operator for class X has the return type X&; it returns the object for which the assignment operator is invoked, that is, the object assigned to. An implicitly-declared copy assignment operator is an inline public member of its class. Because a copy assignment operator is implicitly declared for a class if not declared by the user, a base class copy assignment operator is always hidden by the copy assignment operator of a derived class (13.5.3). A using-declaration (7.3.3) that brings in from a base class an assignment operator with a parameter type that could be that of a copy-assignment operator for the derived class is not considered an explicit declaration of a copy-assignment operator and does not suppress the implicit declaration of the derived class copy-assignment operator; the operator introduced by the using-declaration is hidden by the implicitly-declared copy-assignment operator in the derived class.

11 A copy assignment operator for class X is trivial if it is implicitly declared and if

— class X has no virtual functions (10.3) and no virtual base classes (10.1), and

— each direct base class of X has a trivial copy assignment operator, and

— for all the non-static data members of X that are of class type (or array thereof), each such class type has a trivial copy assignment operator;

otherwise the copy assignment operator is non-trivial.

12 An implicitly-declared copy assignment operator is implicitly defined when an object of its class type is assigned a value of its class type or a value of a class type derived from its class type. A program is ill-formed if the class for which a copy assignment operator is implicitly defined has:

— a non-static data member of const type, or

— a non-static data member of reference type, or

— a non-static data member of class type (or array thereof) with an inaccessible copy assignment operator, or

— a base class with an inaccessible copy assignment operator.

Before the implicitly-declared copy assignment operator for a class is implicitly defined, all implicitly-declared copy assignment operators for its direct base classes and its non-static data members shall have been implicitly defined. [Note: an implicitly-declared copy assignment operator has an exception-specification (15.4). — end note]

\(^{(117)}\) This implies that the reference parameter of the implicitly-declared copy assignment operator cannot bind to a volatile lvalue; see C.1.8.
The implicitly-defined copy assignment operator for class \( X \) performs memberwise assignment of its subobjects. The direct base classes of \( X \) are assigned first, in the order of their declaration in the base-specifier-list, and then the immediate non-static data members of \( X \) are assigned, in the order in which they were declared in the class definition. Each subobject is assigned in the manner appropriate to its type:

- if the subobject is of class type, the copy assignment operator for the class is used (as if by explicit qualification; that is, ignoring any possible virtual overriding functions in more derived classes);
- if the subobject is an array, each element is assigned, in the manner appropriate to the element type;
- if the subobject is of scalar type, the built-in assignment operator is used.

It is unspecified whether subobjects representing virtual base classes are assigned more than once by the implicitly-defined copy assignment operator. [Example:

```cpp
struct V { }
struct A : virtual V { }
struct B : virtual V { }
struct C : B, A { }
```

it is unspecified whether the virtual base class subobject \( V \) is assigned twice by the implicitly-defined copy assignment operator for \( C \). — end example ]

14 A program is ill-formed if the copy constructor or the copy assignment operator for an object is implicitly used and the special member function is not accessible (clause 11). [Note: Copying one object into another using the copy constructor or the copy assignment operator does not change the layout or size of either object. — end note ]

15 When certain criteria are met, an implementation is allowed to omit the copy construction of a class object, even if the copy constructor and/or destructor for the object have side effects. In such cases, the implementation treats the source and target of the omitted copy operation as simply two different ways of referring to the same object, and the destruction of that object occurs at the later of the times when the two objects would have been destroyed without the optimization.\(^{118}\) This elision of copy operations is permitted in the following circumstances (which may be combined to eliminate multiple copies):

- in a return statement in a function with a class return type, when the expression is the name of a non-volatile automatic object with the same cv-unqualified type as the function return type, the copy operation can be omitted by constructing the automatic object directly into the function’s return value

- in a throw-expression, when the operand is the name of a non-volatile automatic object, the copy operation from the operand to the exception object (15.1) can be omitted by constructing the automatic object directly into the exception object

- when a temporary class object that has not been bound to a reference (12.2) would be copied to a class object with the same cv-unqualified type, the copy operation can be omitted by constructing the temporary object directly into the target of the omitted copy

- when the exception-declaration of an exception handler (clause 15) declares an object of the same type (except for cv-qualification) as the exception object (15.1), the copy operation can be omitted by treating the exception-declaration

\(^{118}\) Because only one object is destroyed instead of two, and one copy constructor is not executed, there is still one object destroyed for each one constructed.

Draft
as an alias for the exception object if the meaning of the program will be unchanged except for the execution of
constructors and destructors for the object declared by the exception-declaration.

[Example:

class Thing {
public:
    Thing();
    ~Thing();
    Thing(const Thing&);
};

Thing f() {  
    Thing t;
    return t;
}

Thing t2 = f();

Here the criteria for elision can be combined to eliminate two calls to the copy constructor of class Thing: the copying
of the local automatic object t into the temporary object for the return value of function f() and the copying of that
temporary object into object t2. Effectively, the construction of the local object t can be viewed as directly initializing
the global object t2, and that object’s destruction will occur at program exit. — end example]
Chapter 13  Overloading

1  When two or more different declarations are specified for a single name in the same scope, that name is said to be overloaded. By extension, two declarations in the same scope that declare the same name but with different types are called overloaded declarations. Only function declarations can be overloaded; object and type declarations cannot be overloaded.

2  When an overloaded function name is used in a call, which overloaded function declaration is being referenced is determined by comparing the types of the arguments at the point of use with the types of the parameters in the overloaded declarations that are visible at the point of use. This function selection process is called overload resolution and is defined in 13.3. [Example:
\[
\text{double abs(double);} \\
\text{int abs(int);} \\
\text{abs(1);}  \\
\text{// call abs(int);} \\
\text{abs(1.0);}  \\
\text{// call abs(double);} \\
\]
— end example ]

13.1 Overloadable declarations

1  Not all function declarations can be overloaded. Those that cannot be overloaded are specified here. A program is ill-formed if it contains two such non-overloadable declarations in the same scope. [Note: this restriction applies to explicit declarations in a scope, and between such declarations and declarations made through a using-declaration (7.3.3). It does not apply to sets of functions fabricated as a result of name lookup (e.g., because of using-directives) or overload resolution (e.g., for operator functions). — end note ]

2  Certain function declarations cannot be overloaded:

—  Function declarations that differ only in the return type cannot be overloaded.

—  Member function declarations with the same name and the same parameter-type-list cannot be overloaded if any of them is a static member function declaration (9.4). Likewise, member function template declarations with the same name, the same parameter-type-list, and the same template parameter lists cannot be overloaded if any of them is a static member function template declaration. The types of the implicit object parameters constructed for the member functions for the purpose of overload resolution (13.3.1) are not considered when comparing parameter-type-lists for enforcement of this rule. In contrast, if there is no static member function declaration among a set of member function declarations with the same name and the same parameter-type-list, then these member function declarations can be overloaded if they differ in the type of their implicit object parameter. [Example: the following illustrates this distinction:
class X {
    static void f();
    void f(); // ill-formed
    void f() const; // ill-formed
    void f() const volatile; // ill-formed
    void g();
    void g() const; // OK: no static g
    void g() const volatile; // OK: no static g
};

— end example

[Note: as specified in 8.3.5, function declarations that have equivalent parameter declarations declare the same function and therefore cannot be overloaded:

— Parameter declarations that differ only in the use of equivalent typedef “types” are equivalent. A typedef is not a separate type, but only a synonym for another type (7.1.3). [Example:

typedef int Int;

    void f(int i);
    void f(Int i); // OK: redeclaration of f(int)
    void f(int i) { /* ... */ }
    void f(Int i) { /* ... */ } // error: redefinition of f(int)

— end example]

Enumerations, on the other hand, are distinct types and can be used to distinguish overloaded function declarations. [Example:

    enum E { a };

    void f(int i) { /* ... */ }
    void f(E i) { /* ... */ }

— end example]

— Parameter declarations that differ only in a pointer * versus an array [] are equivalent. That is, the array declaration is adjusted to become a pointer declaration (8.3.5). Only the second and subsequent array dimensions are significant in parameter types (8.3.4). [Example:

    int f(char*);
    int f(char[]); // same as f(char*);
    int f(char[7]); // same as f(char*);
    int f(char[9]); // same as f(char*);
    int g(char[*][10]);
    int g(char[5][10]); // same as g(char[*][10]);
    int g(char[7][10]); // same as g(char[*][10]);
    int g(char[*][20]); // different from g(char[*][10]);

— end example]
Parameter declarations that differ only in that one is a function type and the other is a pointer to the same function type are equivalent. That is, the function type is adjusted to become a pointer to function type (8.3.5). [Example:

```c
void h(int());
void h(int (*)(())); // redeclaration of h(int())
void h(int x()); // definition of h(int())
void h(int (*)(x)()); // ill-formed: redefinition of h(int())
```
—end example]

Parameter declarations that differ only in the presence or absence of `const` and/or `volatile` are equivalent. That is, the `const` and `volatile` type-specifiers for each parameter type are ignored when determining which function is being declared, defined, or called. [Example:

```c
typedef const int cInt;

int f (int);
int f (const int); // redeclaration of f(int)
int f (int) { ... } // definition of f(int)
int f (cInt) { ... } // error: redefinition of f(int)
```
—end example]

Only the `const` and `volatile` type-specifiers at the outermost level of the parameter type specification are ignored in this fashion; `const` and `volatile` type-specifiers buried within a parameter type specification are significant and can be used to distinguish overloaded function declarations.119 In particular, for any type `T`, “pointer to `T`,” “pointer to `const T`,” and “pointer to `volatile T`” are considered distinct parameter types, as are “reference to `T`,” “reference to `const T`,” and “reference to `volatile T`.”

Two parameter declarations that differ only in their default arguments are equivalent. [Example: consider the following:

```c
void f (int i, int j);
void f (int i, int j = 99); // OK: redeclaration of f(int, int)
void f (int i = 88, int j); // OK: redeclaration of f(int, int)
void f (); // OK: overloaded declaration of f

void prog ()
{
    f (1, 2); // OK: call f(int, int)
    f (1); // OK: call f(int, int)
    f (); // Error: f(int, int) or f()? 
}
```
—end example] —end note]

119) When a parameter type includes a function type, such as in the case of a parameter type that is a pointer to function, the `const` and `volatile` type-specifiers at the outermost level of the parameter type specifications for the inner function type are also ignored.
13.2 Declaration matching

Two function declarations of the same name refer to the same function if they are in the same scope and have equivalent parameter declarations (13.1). A function member of a derived class is not in the same scope as a function member of the same name in a base class. [Example:

```cpp
class B {
    public:
        int f(int);
};

class D : public B {
    public:
        int f(char*);
};
```

Here D::f(char*) hides B::f(int) rather than overloading it.

```cpp
void h(D* pd)
{
    pd->f(1);  // error:
               // D::f(char*) hides B::f(int)
    pd->B::f(1);  // OK
    pd->f("Ben");  // OK, calls D::f
}
```

—end example]

2 A locally declared function is not in the same scope as a function in a containing scope. [Example:

```cpp
int f(char*);
void g()
{
    extern f(int);
    f("asdf");  // error: f(int) hides f(char*)
               // so there is no f(char*) in this scope
}

void caller()
{
    extern void callee(int, int);
    {
        extern void callee(int); // hides callee(int, int)
        callee(88, 99);  // error: only callee(int) in scope
    }
}
```

—end example]

3 Different versions of an overloaded member function can be given different access rules. [Example:

```cpp
Draft
```
Overloading

13.3 Overload resolution

Overload resolution is a mechanism for selecting the best function to call given a list of expressions that are to be the arguments of the call and a set of candidate functions that can be called based on the context of the call. The selection criteria for the best function are the number of arguments, how well the arguments match the parameter-type-list of the candidate function, how well (for non-static member functions) the object matches the implied object parameter, and certain other properties of the candidate function. [Note: the function selected by overload resolution is not guaranteed to be appropriate for the context. Other restrictions, such as the accessibility of the function, can make its use in the calling context ill-formed. — end note]

Overload resolution selects the function to call in seven distinct contexts within the language:

1. invocation of a function named in the function call syntax (13.3.1.1.1);
2. invocation of a function call operator, a pointer-to-function conversion function, a reference-to-pointer-to-function conversion function, or a reference-to-function conversion function on a class object named in the function call syntax (13.3.1.1.2);
3. invocation of the operator referenced in an expression (13.3.1.2);
4. invocation of a constructor for direct-initialization (8.5) of a class object (13.3.1.3);
5. invocation of a user-defined conversion for copy-initialization (8.5) of a class object (13.3.1.4);
6. invocation of a conversion function for initialization of an object of a nonclass type from an expression of class type (13.3.1.5); and
7. invocation of a conversion function for conversion to an lvalue to which a reference (8.5.3) will be directly bound (13.3.1.6).

Each of these contexts defines the set of candidate functions and the list of arguments in its own unique way. But, once the candidate functions and argument lists have been identified, the selection of the best function is the same in all cases:

1. First, a subset of the candidate functions (those that have the proper number of arguments and meet certain other conditions) is selected to form a set of viable functions (13.3.2).

Draft
13.3 Overload resolution

— Then the best viable function is selected based on the implicit conversion sequences (13.3.3.1) needed to match each argument to the corresponding parameter of each viable function.

3 If a best viable function exists and is unique, overload resolution succeeds and produces it as the result. Otherwise overload resolution fails and the invocation is ill-formed. When overload resolution succeeds, and the best viable function is not accessible (clause 11) in the context in which it is used, the program is ill-formed.

13.3.1 Candidate functions and argument lists

The subclauses of 13.3.1 describe the set of candidate functions and the argument list submitted to overload resolution in each of the seven contexts in which overload resolution is used. The source transformations and constructions defined in these subclauses are only for the purpose of describing the overload resolution process. An implementation is not required to use such transformations and constructions.

2 The set of candidate functions can contain both member and non-member functions to be resolved against the same argument list. So that argument and parameter lists are comparable within this heterogeneous set, a member function is considered to have an extra parameter, called the implicit object parameter, which represents the object for which the member function has been called. For the purposes of overload resolution, both static and non-static member functions have an implicit object parameter, but constructors do not.

3 Similarly, when appropriate, the context can construct an argument list that contains an implied object argument to denote the object to be operated on. Since arguments and parameters are associated by position within their respective lists, the convention is that the implicit object parameter, if present, is always the first parameter and the implied object argument, if present, is always the first argument.

4 For non-static member functions, the type of the implicit object parameter is “reference to cv X” where X is the class of which the function is a member and cv is the cv-qualification on the member function declaration. [Example: for a const member function of class X, the extra parameter is assumed to have type “reference to const X”. — end example] For conversion functions, the function is considered to be a member of the class of the implicit object argument for the purpose of defining the type of the implicit object parameter. For non-conversion functions introduced by a using-declaration into a derived class, the function is considered to be a member of the derived class for the purpose of defining the type of the implicit object parameter. For static member functions, the implicit object parameter is considered to match any object (since if the function is selected, the object is discarded). [Note: no actual type is established for the implicit object parameter of a static member function, and no attempt will be made to determine a conversion sequence for that parameter (13.3.3). — end note]

5 During overload resolution, the implied object argument is indistinguishable from other arguments. The implicit object parameter, however, retains its identity since conversions on the corresponding argument shall obey these additional rules:

— no temporary object can be introduced to hold the argument for the implicit object parameter;
— no user-defined conversions can be applied to achieve a type match with it; and
— even if the implicit object parameter is not const-qualified, an rvalue temporary can be bound to the parameter as long as in all other respects the temporary can be converted to the type of the implicit object parameter.

6 Because only one user-defined conversion is allowed in an implicit conversion sequence, special rules apply when selecting the best user-defined conversion (13.3.3, 13.3.3.1). [Example:
class T {
    public:
        T();
        // ...
    }

class C : T {
    public:
        C(int);
        // ...
    }

T a = 1; // ill-formed: T(C(1)) not tried

In each case where a candidate is a function template, candidate function template specializations are generated using template argument deduction (14.8.3, 14.8.2). Those candidates are then handled as candidate functions in the usual way. A given name can refer to one or more function templates and also to a set of overloaded non-template functions. In such a case, the candidate functions generated from each function template are combined with the set of non-template candidate functions.

13.3.1.1 Function call syntax

Recall from 5.2.2, that a function call is a postfix-expression, possibly nested arbitrarily deep in parentheses, followed by an optional expression-list enclosed in parentheses: 

\[
( \ldots \text{opt } \text{postfix-expression} \ldots \text{opt } \text{expression-listopt} )
\]

Overload resolution is required if the postfix-expression is the name of a function, a function template (14.5.5), an object of class type, or a set of pointers-to-function.

1 The fourth case arises from a postfix-expression of the form \&F, where F names a set of overloaded functions. In the context of a function call, \&F is treated the same as the name F by itself. Thus, \((\&F) (\text{expression-list}_{\text{opt}})\) is simply \((F) (\text{expression-list}_{\text{opt}})\), which is discussed in 13.3.1.1.1. If the function selected by overload resolution according to 13.3.1.1 is a non-static member function, the program is ill-formed. (13.4.) (The resolution of \&F in other contexts is described in 13.4.)

13.3.1.1.1 Call to named function

Of interest in 13.3.1.1.1 are only those function calls in which the postfix-expression ultimately contains a name that denotes one or more functions that might be called. Such a postfix-expression, perhaps nested arbitrarily deep in parentheses, has one of the following forms:

\[1^{20}\] The process of argument deduction fully determines the parameter types of the function template specializations, i.e., the parameters of function template specializations contain no template parameter types. Therefore the function template specializations can be treated as normal (non-template) functions for the remainder of overload resolution.

\[1^{21}\] When F is a non-static member function, a reference of the form \&A::f is a pointer-to-member, which cannot be used with the function-call syntax, and a reference of the form \&F is an invalid use of the “\&” operator on a non-static member function.
These represent two syntactic subcategories of function calls: qualified function calls and unqualified function calls.

2 In qualified function calls, the name to be resolved is an id-expression and is preceded by an -> or . operator. Since the construct A->B is generally equivalent to (*A).B, the rest of clause 13 assumes, without loss of generality, that all member function calls have been normalized to the form that uses an object and the . operator. Furthermore, clause 13 assumes that the postfix-expression that is the left operand of the . operator has type “cv T” where T denotes a class. Under this assumption, the id-expression in the call is looked up as a member function of T following the rules for looking up names in classes (10.2). The function declarations found by that lookup constitute the set of candidate functions. The argument list is the expression-list in the call augmented by the addition of the left operand of the . operator in the normalized member function call as the implied object argument (13.3.1).

3 In unqualified function calls, the name is not qualified by an -> or . operator and has the more general form of a primary-expression. The name is looked up in the context of the function call following the normal rules for name lookup in function calls (3.4). The function declarations found by that lookup constitute the set of candidate functions. Because of the rules for name lookup, the set of candidate functions consists (1) entirely of non-member functions or (2) entirely of member functions of some class T. In case (1), the argument list is the same as the expression-list in the call. In case (2), the argument list is the expression-list in the call augmented by the addition of an implied object argument as in a qualified function call. If the keyword this (9.3.2) is in scope and refers to class T, or a derived class of T, then the implied object argument is (*this). If the keyword this is not in scope or refers to another class, then a contrived object of type T becomes the implied object argument. If the argument list is augmented by a contrived object and overload resolution selects one of the non-static member functions of T, the call is ill-formed.

13.3.1.1.2 Call to object of class type

1 If the primary-expression E in the function call syntax evaluates to a class object of type “cv T”, then the set of candidate functions includes at least the function call operators of T. The function call operators of T are obtained by ordinary lookup of the name operator() in the context of (E).operator().

2 In addition, for each conversion function declared in T of the form

```
operator conversion-type-id () cv-qualifier
```

where cv-qualifier is the same cv-qualification as, or a greater cv-qualification than, cv, and where conversion-type-id denotes the type “pointer to function of (P1,...,Pn) returning R”, or the type “reference to pointer to function of (P1,...,Pn) returning R”, or the type “reference to function of (P1,...,Pn) returning R”, a surrogate call function with the unique name call-function and having the form

```
R call-function ( conversion-type-id F, P1 a1, ... ,Pn an) { return F (a1,... ,an); }
```

is also considered as a candidate function. Similarly, surrogate call functions are added to the set of candidate functions for each conversion function declared in a base class of T provided the function is not hidden within T by another intervening declaration.

---

(122) Note that cv-qualifiers on the type of objects are significant in overload resolution for both lvalue and class rvalue objects.

(123) An implied object argument must be contrived to correspond to the implicit object parameter attributed to member functions during overload resolution. It is not used in the call to the selected function. Since the member functions all have the same implicit object parameter, the contrived object will not be the cause to select or reject a function.

(124) Note that this construction can yield candidate call functions that cannot be differentiated one from the other by overload resolution because they have identical declarations or differ only in their return type. The call will be ambiguous if overload resolution cannot select a match to the call that is uniquely better than such undifferentiable functions.
If such a surrogate call function is selected by overload resolution, the corresponding conversion function will be called to convert \( E \) to the appropriate function pointer or reference, and the function will then be invoked with the arguments of the call. If the conversion function cannot be called (e.g., because of an ambiguity), the program is ill-formed.

The argument list submitted to overload resolution consists of the argument expressions present in the function call syntax preceded by the implied object argument \((E)\). [Note: when comparing the call against the function call operators, the implied object argument is compared against the implicit object parameter of the function call operator. When comparing the call against a surrogate call function, the implied object argument is compared against the first parameter of the surrogate call function. The conversion function from which the surrogate call function was derived will be used in the conversion sequence for that parameter since it converts the implied object argument to the appropriate function pointer or reference required by that first parameter. — end note] [Example:

```c
int f1(int);
int f2(float);
typedef int (*fp1)(int);
typedef int (*fp2)(float);
struct A {
    operator fp1() { return f1; }
    operator fp2() { return f2; }
} a;
int i = a(1); // Calls f1 via pointer returned from
              // conversion function
```

— end example]

### 13.3.1.2 Operators in expressions

If no operand of an operator in an expression has a type that is a class or an enumeration, the operator is assumed to be a built-in operator and interpreted according to clause 5. [Note: because ., .*, and :: cannot be overloaded, these operators are always built-in operators interpreted according to clause 5. ?: cannot be overloaded, but the rules in this subclause are used to determine the conversions to be applied to the second and third operands when they have class or enumeration type (5.16). — end note] [Example:

```c
class String {
public:
    String (const String&);
    String (char*);
    operator char* () ;
};
String operator + (const String&, const String&);

void f(void)
{
    char* p= "one" + "two"; // ill-formed because neither
    // operand has user-defined type
    int I = 1 + 1; // Always evaluates to 2 even if
    // user-defined types exist which
    // would perform the operation.
}
```

— end example]
2 If either operand has a type that is a class or an enumeration, a user-defined operator function might be declared that implements this operator or a user-defined conversion can be necessary to convert the operand to a type that is appropriate for a built-in operator. In this case, overload resolution is used to determine which operator function or built-in operator is to be invoked to implement the operator. Therefore, the operator notation is first transformed to the equivalent function-call notation as summarized in Table 9 (where @ denotes one of the operators covered in the specified subclause).

Table 9: relationship between operator and function call notation

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Expression</th>
<th>As member function</th>
<th>As non-member function</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5.1</td>
<td>@a</td>
<td>(a).operator@ ()</td>
<td>operator@ (a)</td>
</tr>
<tr>
<td>13.5.2</td>
<td>a@b</td>
<td>(a).operator@ (b)</td>
<td>operator@ (a, b)</td>
</tr>
<tr>
<td>13.5.3</td>
<td>a=b</td>
<td>(a).operator= (b)</td>
<td></td>
</tr>
<tr>
<td>13.5.5</td>
<td>a[b]</td>
<td>(a).operator[] (b)</td>
<td></td>
</tr>
<tr>
<td>13.5.6</td>
<td>a-&gt;</td>
<td>(a).operator-&gt; ()</td>
<td></td>
</tr>
<tr>
<td>13.5.7</td>
<td>a</td>
<td>(a).operator@ (0)</td>
<td>operator@ (a, 0)</td>
</tr>
</tbody>
</table>

3 For a unary operator @ with an operand of a type whose cv-unqualified version is T1, and for a binary operator @ with a left operand of a type whose cv-unqualified version is T1 and a right operand of a type whose cv-unqualified version is T2, three sets of candidate functions, designated member candidates, non-member candidates and built-in candidates, are constructed as follows:

- If T1 is a complete class type, the set of member candidates is the result of the qualified lookup of T1::operator@ (13.3.1.1.1); otherwise, the set of member candidates is empty.
- The set of non-member candidates is the result of the unqualified lookup of operator@ in the context of the expression according to the usual rules for name lookup in unqualified function calls (3.4.2) except that all member functions are ignored. However, if no operand has a class type, only those non-member functions in the lookup set that have a first parameter of type T1 or “reference to (possibly cv-qualified) T1”, when T1 is an enumeration type, or (if there is a right operand) a second parameter of type T2 or “reference to (possibly cv-qualified) T2”, when T2 is an enumeration type, are candidate functions.
- For the operator ,, the unary operator &, or the operator ->, the built-in candidates set is empty. For all other operators, the built-in candidates include all of the candidate operator functions defined in 13.6 that, compared to the given operator,
  - have the same operator name, and
  - accept the same number of operands, and
  - accept operand types to which the given operand or operands can be converted according to 13.3.3.1, and
  - do not have the same parameter-type-list as any non-template non-member candidate.

4 For the built-in assignment operators, conversions of the left operand are restricted as follows:

- no temporaries are introduced to hold the left operand, and
- no user-defined conversions are applied to the left operand to achieve a type match with the left-most parameter of a built-in candidate.

5 For all other operators, no such restrictions apply.
The set of candidate functions for overload resolution is the union of the member candidates, the non-member candidates, and the built-in candidates. The argument list contains all of the operands of the operator. The best function from the set of candidate functions is selected according to 13.3.2 and 13.3.3. [Example:

```cpp
struct A {
    operator int();
};
A operator+(const A&, const A&);
void m() {
    A a, b;
    a + b; // operator+(a,b) chosen over int(a) + int(b)
}
```
— end example ]

If a built-in candidate is selected by overload resolution, the operands are converted to the types of the corresponding parameters of the selected operation function. Then the operator is treated as the corresponding built-in operator and interpreted according to clause 5.

The second operand of operator `->` is ignored in selecting an `operator->` function, and is not an argument when the `operator->` function is called. When `operator->` returns, the operator `->` is applied to the value returned, with the original second operand. [126]

If the operator is the operator `,`, the unary operator `&`, or the operator `->`, and there are no viable functions, then the operator is assumed to be the built-in operator and interpreted according to clause 5.

[Note: the lookup rules for operators in expressions are different than the lookup rules for operator function names in a function call, as shown in the following example:

```cpp
struct A { };  // ERROR — global operator hidden by member
void operator + (A, A);

struct B {
    void operator + (B);
    void f () {
    }
};
A a;
void B::f() {
    operator+ (a,a); // ERROR — global operator hidden by member
    a + a; // OK — calls global operator+
}
```
— end note ]

\[125\] If the set of candidate functions is empty, overload resolution is unsuccessful.

\[126\] If the value returned by the `operator->` function has class type, this may result in selecting and calling another `operator->` function. The process repeats until an `operator->` function returns a value of non-class type.
13.3 Overload resolution

13.3.1.3 Initialization by constructor

When objects of class type are direct-initialized (8.5), or copy-initialized from an expression of the same or a derived class type (8.5), overload resolution selects the constructor. For direct-initialization, the candidate functions are all the constructors of the class of the object being initialized. For copy-initialization, the candidate functions are all the converting constructors (12.3.1) of that class. The argument list is the expression-list within the parentheses of the initializer.

13.3.1.4 Copy-initialization of class by user-defined conversion

Under the conditions specified in 8.5, as part of a copy-initialization of an object of class type, a user-defined conversion can be invoked to convert an initializer expression to the type of the object being initialized. Overload resolution is used to select the user-defined conversion to be invoked. Assuming that “cv1 T” is the type of the object being initialized, with T a class type, the candidate functions are selected as follows:

— The converting constructors (12.3.1) of T are candidate functions.

— When the type of the initializer expression is a class type “cv S”, the conversion functions of S and its base classes are considered. Those that are not hidden within S and yield a type whose cv-unqualified version is the same type as T or is a derived class thereof are candidate functions. Conversion functions that return “reference to X” return lvalues of type X and are therefore considered to yield X for this process of selecting candidate functions.

In both cases, the argument list has one argument, which is the initializer expression. [Note: this argument will be compared against the first parameter of the constructors and against the implicit object parameter of the conversion functions. — end note]

13.3.1.5 Initialization by conversion function

Under the conditions specified in 8.5, as part of an initialization of an object of nonclass type, a conversion function can be invoked to convert an initializer expression of class type to the type of the object being initialized. Overload resolution is used to select the conversion function to be invoked. Assuming that “cv1 T” is the type of the object being initialized, and “cv S” is the type of the initializer expression, with S a class type, the candidate functions are selected as follows:

— The conversion functions of S and its base classes are considered. Those that are not hidden within S and yield type T or a type that can be converted to type T via a standard conversion sequence (13.3.3.1.1) are candidate functions. Conversion functions that return a cv-qualified type are considered to yield the cv-unqualified version of that type for this process of selecting candidate functions. Conversion functions that return “reference to cv2 X” return lvalues of type cv2 X and are therefore considered to yield X for this process of selecting candidate functions.

The argument list has one argument, which is the initializer expression. [Note: this argument will be compared against the implicit object parameter of the conversion functions. — end note]

13.3.1.6 Initialization by conversion function for direct reference binding

Under the conditions specified in 8.5.3, a reference can be bound directly to an lvalue that is the result of applying a conversion function to an initializer expression. Overload resolution is used to select the conversion function to be
invoked. Assuming that “cv1 T” is the underlying type of the reference being initialized, and “cv S” is the type of the initializer expression, with S a class type, the candidate functions are selected as follows:

— The conversion functions of S and its base classes are considered. Those that are not hidden within S and yield type “reference to cv2 T2”, where “cv1 T” is reference-compatible (8.5.3) with “cv2 T2”, are candidate functions.

2 The argument list has one argument, which is the initializer expression. \[\text{[Note: this argument will be compared against the implicit object parameter of the conversion functions. — end note]}\]

### 13.3.2 Viable functions

1 From the set of candidate functions constructed for a given context (13.3.1), a set of viable functions is chosen, from which the best function will be selected by comparing argument conversion sequences for the best fit (13.3.3). The selection of viable functions considers relationships between arguments and function parameters other than the ranking of conversion sequences.

2 First, to be a viable function, a candidate function shall have enough parameters to agree in number with the arguments in the list.

— If there are m arguments in the list, all candidate functions having exactly m parameters are viable.

— A candidate function having fewer than m parameters is viable only if it has an ellipsis in its parameter list (8.3.5). For the purposes of overload resolution, any argument for which there is no corresponding parameter is considered to “match the ellipsis” (13.3.3.1.3).

— A candidate function having more than m parameters is viable only if the (m+1)-st parameter has a default argument (8.3.6). For the purposes of overload resolution, the parameter list is truncated on the right, so that there are exactly m parameters.

3 Second, for F to be a viable function, there shall exist for each argument an implicit conversion sequence (13.3.3.1) that converts that argument to the type of the i-th parameter of viable function F. If the parameter has reference type, the implicit conversion sequence includes the operation of binding the reference, and the fact that a reference to non-\texttt{const} cannot be bound to an rvalue can affect the viability of the function (see 13.3.3.1.4).

### 13.3.3 Best Viable Function

1 Define ICS(F) as follows:

— if F is a static member function, ICS(F) is defined such that ICS(F) is neither better nor worse than ICS(G) for any function G, and, symmetrically, ICS(G) is neither better nor worse than ICS(F)\(^{128}\); otherwise,

— let ICS(F) denote the implicit conversion sequence that converts the i-th argument in the list to the type of the i-th parameter of viable function F. 13.3.3.1 defines the implicit conversion sequences and 13.3.3.2 defines what it means for one implicit conversion sequence to be a better conversion sequence or worse conversion sequence than another.

\(^{127}\) According to 8.3.6, parameters following the (m+1)-st parameter must also have default arguments.

\(^{128}\) If a function is a static member function, this definition means that the first argument, the implied object parameter, has no effect in the determination of whether the function is better or worse than any other function.
Given these definitions, a viable function \( F_1 \) is defined to be a \textit{better} function than another viable function \( F_2 \) if for all arguments \( i \), ICS\(_i\)(\( F_1 \)) is not a worse conversion sequence than ICS\(_i\)(\( F_2 \)), and then

- for some argument \( j \), ICS\(_j\)(\( F_1 \)) is a better conversion sequence than ICS\(_j\)(\( F_2 \)), or, if not that,
- \( F_1 \) is a non-template function and \( F_2 \) is a function template specialization, or, if not that,
- \( F_1 \) and \( F_2 \) are function template specializations, and the function template for \( F_1 \) is more specialized than the template for \( F_2 \) according to the partial ordering rules described in 14.5.5.2, or, if not that,
- the context is an initialization by user-defined conversion (see 8.5, 13.3.1.5, and 13.3.1.6) and the standard conversion sequence from the return type of \( F_1 \) to the destination type (i.e., the type of the entity being initialized) is a better conversion sequence than the standard conversion sequence from the return type of \( F_2 \) to the destination type. \[ \text{Example:} \]

```c
struct A {
    A();
    operator int();
    operator double();
} a;
int i = a;  // a.operator int() followed by no conversion
           // is better than a.operator double() followed by
           // a conversion to int
float x = a;  // ambiguous: both possibilities require conversions,
             // and neither is better than the other
```

\[ \text{— end example} \]

2 If there is exactly one viable function that is a better function than all other viable functions, then it is the one selected by overload resolution; otherwise the call is ill-formed\(^{129}\).

\[ \text{Example:} \]

```c
void Fcn(const int*, short);
void Fcn(int*, int);

int i;
short s = 0;

void f() {
    Fcn(&i, s);  // is ambiguous because
                // &i \rightarrow \text{int*} is better than &i \rightarrow \text{const int*}
                // but s \rightarrow \text{short} is also better than s \rightarrow \text{int}
    Fcn(&i, 1L);  // calls Fcn(int*, int), because
                   // &i \rightarrow \text{int*} is better than &i \rightarrow \text{const int*}
                   // and 1L \rightarrow \text{short} and 1L \rightarrow \text{int} are indistinguishable
```

\(^{129}\) The algorithm for selecting the best viable function is linear in the number of viable functions. Run a simple tournament to find a function \( W \) that is not worse than any opponent it faced. Although another function \( F \) that \( W \) did not face might be at least as good as \( W \), \( F \) cannot be the best function because at some point in the tournament \( F \) encountered another function \( G \) such that \( F \) was not better than \( G \). Hence, \( W \) is either the best function or there is no best function. So, make a second pass over the viable functions to verify that \( W \) is better than all other functions.
Overloading

```c
Fcn(&i,'c'); // calls Fcn(int*, int), because
// &i -> int* is better than &i -> const int*
// and c -> int is better than c -> short
```

— end example]

If the best viable function resolves to a function for which multiple declarations were found, and if at least two of these declarations — or the declarations they refer to in the case of using-declarations — specify a default argument that made the function viable, the program is ill-formed. [Example:

```c
namespace A {
extern "C" void f(int = 5);
}
namespace B {
extern "C" void f(int = 5);
}
using A::f;
using B::f;

void use() {
    f(3); // OK, default argument was not used for viability
    f(); // Error: found default argument twice
}
```

— end example]

### 13.3.3.1 Implicit conversion sequences

An **implicit conversion sequence** is a sequence of conversions used to convert an argument in a function call to the type of the corresponding parameter of the function being called. The sequence of conversions is an implicit conversion as defined in clause 4, which means it is governed by the rules for initialization of an object or reference by a single expression (8.5, 8.5.3).

Implicit conversion sequences are concerned only with the type, cv-qualification, and lvalue-ness of the argument and how these are converted to match the corresponding properties of the parameter. Other properties, such as the lifetime, storage class, alignment, or accessibility of the argument and whether or not the argument is a bit-field are ignored. So, although an implicit conversion sequence can be defined for a given argument-parameter pair, the conversion from the argument to the parameter might still be ill-formed in the final analysis.

A well-formed implicit conversion sequence is one of the following forms:

- a **standard conversion sequence** (13.3.3.1.1),
- a **user-defined conversion sequence** (13.3.3.1.2), or
- an **ellipsis conversion sequence** (13.3.3.1.3).
However, when considering the argument of a user-defined conversion function that is a candidate by 13.3.1.3 when invoked for the copying of the temporary in the second step of a class copy-initialization, or by 13.3.1.4, 13.3.1.5, or 13.3.1.6 in all cases, only standard conversion sequences and ellipsis conversion sequences are allowed.

For the case where the parameter type is a reference, see 13.3.3.1.4.

When the parameter type is not a reference, the implicit conversion sequence models a copy-initialization of the parameter from the argument expression. The implicit conversion sequence is the one required to convert the argument expression to an rvalue of the type of the parameter. [Note: when the parameter has a class type, this is a conceptual conversion defined for the purposes of clause 13; the actual initialization is defined in terms of constructors and is not a conversion. — end note] Any difference in top-level cv-qualification is subsumed by the initialization itself and does not constitute a conversion. [Example: a parameter of type A can be initialized from an argument of type const A. The implicit conversion sequence for that case is the identity sequence; it contains no “conversion” from const A to A. — end example] When the parameter has a class type and the argument expression has the same type, the implicit conversion sequence is an identity conversion. When the parameter has a class type and the argument expression has a derived class type, the implicit conversion sequence is a derived-to-base Conversion from the derived class to the base class. [Note: there is no such standard conversion; this derived-to-base Conversion exists only in the description of implicit conversion sequences. — end note] A derived-to-base Conversion has Conversion rank (13.3.3.1.1).

In all contexts, when converting to the implicit object parameter or when converting to the left operand of an assignment operation only standard conversion sequences that create no temporary object for the result are allowed.

If no conversions are required to match an argument to a parameter type, the implicit conversion sequence is the standard conversion sequence consisting of the identity conversion (13.3.3.1.1).

If no sequence of conversions can be found to convert an argument to a parameter type or the conversion is otherwise ill-formed, an implicit conversion sequence cannot be formed.

If several different sequences of conversions exist that each convert the argument to the parameter type, the implicit conversion sequence associated with the parameter is defined to be the unique conversion sequence designated the ambiguous conversion sequence. For the purpose of ranking implicit conversion sequences as described in 13.3.3.2, the ambiguous conversion sequence is treated as a user-defined sequence that is indistinguishable from any other user-defined conversion sequence. If a function that uses the ambiguous conversion sequence is selected as the best viable function, the call will be ill-formed because the conversion of one of the arguments in the call is ambiguous.

130) The ambiguous conversion sequence is ranked with user-defined conversion sequences because multiple conversion sequences for an argument can exist only if they involve different user-defined conversions. The ambiguous conversion sequence is indistinguishable from any other user-defined conversion sequence because it represents at least two user-defined conversion sequences, each with a different user-defined conversion, and any other user-defined conversion sequence must be indistinguishable from at least one of them.

This rule prevents a function from becoming non-viable because of an ambiguous conversion sequence for one of its parameters. Consider this example.

```c
class B;
class A { A (B&); }
class B { operator A (); }
class C { C (B&); }
void f(A) {}
void f(C) {}
B b;
if (A) { }
if (C) { }
// ambiguous because b -> C via constructor and
// b -> A via constructor or conversion function.
```

If it were not for this rule, f(A) would be eliminated as a viable function for the call f(b) causing overload resolution to select f(C) as the function to call even though it is not clearly the best choice. On the other hand, if an f(B) were to be declared then f(b) would resolve to that f(B) because the exact match with f(B) is better than any of the sequences required to match f(A).
The three forms of implicit conversion sequences mentioned above are defined in the following subclauses.

13.3.3.1 Standard conversion sequences

Table 10 summarizes the conversions defined in clause 4 and partitions them into four disjoint categories: Lvalue Transformation, Qualification Adjustment, Promotion, and Conversion. [Note: these categories are orthogonal with respect to lvalue-ness, cv-qualification, and data representation: the Lvalue Transformations do not change the cv-qualification or data representation of the type; the Qualification Adjustments do not change the lvalue-ness or data representation of the type; and the Promotions and Conversions do not change the lvalue-ness or cv-qualification of the type. — end note]

[Note: As described in clause 4, a standard conversion sequence is either the Identity conversion by itself (that is, no conversion) or consists of one to three conversions from the other four categories. At most one conversion from each category is allowed in a single standard conversion sequence. If there are two or more conversions in the sequence, the conversions are applied in the canonical order: Lvalue Transformation, Promotion or Conversion, Qualification Adjustment. — end note]

Each conversion in Table 10 also has an associated rank (Exact Match, Promotion, or Conversion). These are used to rank standard conversion sequences (13.3.3.2). The rank of a conversion sequence is determined by considering the rank of each conversion in the sequence and the rank of any reference binding (13.3.3.1.4). If any of those has Conversion rank, the sequence has Conversion rank; otherwise, if any of those has Promotion rank, the sequence has Promotion rank; otherwise, the sequence has Exact Match rank.

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Category</th>
<th>Rank</th>
<th>Subclause</th>
</tr>
</thead>
<tbody>
<tr>
<td>No conversions required</td>
<td>Identity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lvalue-to-rvalue conversion</td>
<td>Lvalue Transformation</td>
<td>Exact Match</td>
<td>4.1</td>
</tr>
<tr>
<td>Array-to-pointer conversion</td>
<td>Lvalue Transformation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Function-to-pointer conversion</td>
<td>Lvalue Transformation</td>
<td></td>
<td>4.3</td>
</tr>
<tr>
<td>Qualification conversions</td>
<td>Qualification Adjustment</td>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td>Integral promotions</td>
<td>Promotion</td>
<td>Promotion</td>
<td>4.5</td>
</tr>
<tr>
<td>Floating point promotion</td>
<td>Promotion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integral conversions</td>
<td>Conversion</td>
<td>Conversion</td>
<td>4.7</td>
</tr>
<tr>
<td>Floating point conversions</td>
<td>Conversion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floating-integral conversions</td>
<td>Conversion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pointer conversions</td>
<td>Conversion</td>
<td></td>
<td>4.10</td>
</tr>
<tr>
<td>Pointer to member conversions</td>
<td></td>
<td></td>
<td>4.11</td>
</tr>
<tr>
<td>Boolean conversions</td>
<td></td>
<td></td>
<td>4.12</td>
</tr>
</tbody>
</table>

13.3.3.1.2 User-defined conversion sequences

A user-defined conversion sequence consists of an initial standard conversion sequence followed by a user-defined conversion (12.3) followed by a second standard conversion sequence. If the user-defined conversion is specified by a constructor (12.3.1), the initial standard conversion sequence converts the source type to the type required by the constructor.
argument of the constructor. If the user-defined conversion is specified by a conversion function (12.3.2), the initial standard conversion sequence converts the source type to the implicit object parameter of the conversion function.

2 The second standard conversion sequence converts the result of the user-defined conversion to the target type for the sequence. Since an implicit conversion sequence is an initialization, the special rules for initialization by user-defined conversion apply when selecting the best user-defined conversion for a user-defined conversion sequence (see 13.3.3 and 13.3.3.1).

3 If the user-defined conversion is specified by a template conversion function, the second standard conversion sequence must have exact match rank.

4 A conversion of an expression of class type to the same class type is given Exact Match rank, and a conversion of an expression of class type to a base class of that type is given Conversion rank, in spite of the fact that a copy constructor (i.e., a user-defined conversion function) is called for those cases.

13.3.3.1.3 Ellipsis conversion sequences

An ellipsis conversion sequence occurs when an argument in a function call is matched with the ellipsis parameter specification of the function called.

13.3.3.1.4 Reference binding

When a parameter of reference type binds directly (8.5.3) to an argument expression, the implicit conversion sequence is the identity conversion, unless the argument expression has a type that is a derived class of the parameter type, in which case the implicit conversion sequence is a derived-to-base Conversion (13.3.3.1). [Example:

```c
struct A {};
struct B : public A {} b;
int f(A&);
int f(B&);
int i = f(b); // Calls f(B&), an exact match, rather than
              // f(A&), a conversion
```

— end example] If the parameter binds directly to the result of applying a conversion function to the argument expression, the implicit conversion sequence is a user-defined conversion sequence (13.3.3.1.2), with the second standard conversion sequence either an identity conversion or, if the conversion function returns an entity of a type that is a derived class of the parameter type, a derived-to-base Conversion.

2 When a parameter of reference type is not bound directly to an argument expression, the conversion sequence is the one required to convert the argument expression to the underlying type of the reference according to 13.3.3.1. Conceptually, this conversion sequence corresponds to copy-initializing a temporary of the underlying type with the argument expression. Any difference in top-level cv-qualification is subsumed by the initialization itself and does not constitute a conversion.

3 A standard conversion sequence cannot be formed if it requires binding a reference to non-const to an rvalue (except when binding an implicit object parameter; see the special rules for that case in 13.3.1). [Note: this means, for example, that a candidate function cannot be a viable function if it has a non-const reference parameter (other than the implicit object parameter) and the corresponding argument is a temporary or would require one to be created to initialize the reference (see 8.5.3). — end note]

4 Other restrictions on binding a reference to a particular argument that are not based on the types of the reference and the argument do not affect the formation of a standard conversion sequence, however. [Example: a function with a
“reference to int” parameter can be a viable candidate even if the corresponding argument is an int bit-field. The formation of implicit conversion sequences treats the int bit-field as an int lvalue and finds an exact match with the parameter. If the function is selected by overload resolution, the call will nonetheless be ill-formed because of the prohibition on binding a non-const reference to a bit-field (8.5.3). — end example ]

5 The binding of a reference to an expression that is reference-compatible with added qualification influences the rank of a standard conversion; see 13.3.3.2 and 8.5.3.

13.3.3.2 Ranking implicit conversion sequences [over.ics.rank]

1 13.3.3.2 defines a partial ordering of implicit conversion sequences based on the relationships better conversion sequence and better conversion. If an implicit conversion sequence S1 is defined by these rules to be a better conversion sequence than S2, then it is also the case that S2 is a worse conversion sequence than S1. If conversion sequence S1 is neither better than nor worse than conversion sequence S2, S1 and S2 are said to be indistinguishable conversion sequences.

2 When comparing the basic forms of implicit conversion sequences (as defined in 13.3.3.1)

— a standard conversion sequence (13.3.3.1.1) is a better conversion sequence than a user-defined conversion sequence or an ellipsis conversion sequence, and

— a user-defined conversion sequence (13.3.3.1.2) is a better conversion sequence than an ellipsis conversion sequence (13.3.3.1.3).

3 Two implicit conversion sequences of the same form are indistinguishable conversion sequences unless one of the following rules apply:

— Standard conversion sequence S1 is a better conversion sequence than standard conversion sequence S2 if

— S1 is a proper subsequence of S2 (comparing the conversion sequences in the canonical form defined by 13.3.3.1.1, excluding any Lvalue Transformation; the identity conversion sequence is considered to be a subsequence of any non-identity conversion sequence) or, if not that,

— the rank of S1 is better than the rank of S2, or S1 and S2 have the same rank and are distinguishable by the rules in the paragraph below, or, if not that,

— S1 and S2 differ only in their qualification conversion and yield similar types T1 and T2 (4.4), respectively, and the cv-qualification signature of type T1 is a proper subset of the cv-qualification signature of type T2, and S1 is not the deprecated string literal array-to-pointer conversion (4.2). [ Example:

```c
int f(const int *);
int f(int *);
int i;
int j = f(&i);  // Calls f(int*)
```

— end example ] or, if not that,

— S1 and S2 are reference bindings (8.5.3), and the types to which the references refer are the same type except for top-level cv-qualifiers, and the type to which the reference initialized by S2 refers is more cv-qualified than the type to which the reference initialized by S1 refers. [ Example:

```c
int f(const int &);
int f(int &);
int g(const int &);
```
int g(int);
int i;
int j = f(i);  // Calls f(int &)
int k = g(i);  // ambiguous

class X {
public:
    void f() const;
    void f();
};
void g(const X& a, X b)
{
    a.f();     // Calls X::f() const
    b.f();     // Calls X::f()
}
— end example }

— User-defined conversion sequence U1 is a better conversion sequence than another user-defined conversion sequence U2 if they contain the same user-defined conversion function or constructor and if the second standard conversion sequence of U1 is better than the second standard conversion sequence of U2. [Example:

    struct A {
        operator short();
    } a;
    int f(int);
    int f(float);
    int i = f(a);  // Calls f(int), because short → int is
                   // better than short → float.

— end example ]

4 Standard conversion sequences are ordered by their ranks: an Exact Match is a better conversion than a Promotion, which is a better conversion than a Conversion. Two conversion sequences with the same rank are indistinguishable unless one of the following rules applies:

— A conversion that is not a conversion of a pointer, or pointer to member, to bool is better than another conversion that is such a conversion.

— If class B is derived directly or indirectly from class A, conversion of B* to A* is better than conversion of B* to void*, and conversion of A* to void* is better than conversion of B* to void*.

— If class B is derived directly or indirectly from class A and class C is derived directly or indirectly from B,

— conversion of C* to B* is better than conversion of C* to A*, [Example:

    struct A {};
    struct B : public A {};
    struct C : public B {};
    C *pc;
    int f(A *);
int f(B *);
int i = f(pc); // Calls f(B*)

— end example ]

— binding of an expression of type C to a reference of type B& is better than binding an expression of type C to a reference of type A&,
— conversion of A::* to B::* is better than conversion of A::* to C::*,
— conversion of C to B is better than conversion of C to A,
— conversion of B* to A* is better than conversion of C* to A*,
— binding of an expression of type B to a reference of type A& is better than binding an expression of type C to a reference of type A&,
— conversion of B::* to C::* is better than conversion of A::* to C::*, and
— conversion of B to A is better than conversion of C to A.

[ Note: compared conversion sequences will have different source types only in the context of comparing the second standard conversion sequence of an initialization by user-defined conversion (see 13.3.3); in all other contexts, the source types will be the same and the target types will be different. — end note ]

13.4 Address of overloaded function [over.over]

A use of an overloaded function name without arguments is resolved in certain contexts to a function, a pointer to function or a pointer to member function for a specific function from the overload set. A function template name is considered to name a set of overloaded functions in such contexts. The function selected is the one whose type matches the target type required in the context. The target can be

— an object or reference being initialized (8.5, 8.5.3),
— the left side of an assignment (5.17),
— a parameter of a function (5.2.2),
— a parameter of a user-defined operator (13.5),
— the return value of a function, operator function, or conversion (6.6.3),
— an explicit type conversion (5.2.3, 5.2.9, 5.4), or
— a non-type template-parameter (14.3.2).

The overloaded function name can be preceded by the & operator. An overloaded function name shall not be used without arguments in contexts other than those listed. [ Note: any redundant set of parentheses surrounding the overloaded function name is ignored (5.1). — end note ]

2 If the name is a function template, template argument deduction is done (14.8.2.2), and if the argument deduction succeeds, the resulting template argument list is used to generate a single function template specialization, which is added to the set of overloaded functions considered. [ Note: As described in 14.8.1, if deduction fails and the function template name is followed by an explicit template argument list, the template-id is then examined to see whether it
13.4 Address of overloaded function

identifies a single function template specialization. If it does, the template-id is considered to be an lvalue for that function template specialization. The target type is not used in that determination. —end note

3 Non-member functions and static member functions match targets of type “pointer-to-function” or “reference-to-function.” Nonstatic member functions match targets of type “pointer-to-member-function;” the function type of the pointer to member is used to select the member function from the set of overloaded member functions. If a non-static member function is selected, the reference to the overloaded function name is required to have the form of a pointer to member as described in 5.3.1.

4 If more than one function is selected, any function template specializations in the set are eliminated if the set also contains a non-template function, and any given function template specialization F1 is eliminated if the set contains a second function template specialization whose function template is more specialized than the function template of F1 according to the partial ordering rules of 14.5.5.2. After such eliminations, if any, there shall remain exactly one selected function.

[Example:

```c
int f(double);
int f(int);
int (*pfd)(double) = &f; // selects f(double)
int (*pfi)(int) = &f; // selects f(int)
int (*pfe)(...) = &f; // error: type mismatch
int (&rfi)(int) = f; // selects f(int)
int (&rfd)(double) = f; // selects f(double)
void g() {
    (int (*)(int))&f; // cast expression as selector
}
```

The initialization of pfe is ill-formed because no f() with type int(...) has been declared, and not because of any ambiguity. For another example,

```c
struct X {
    int f(int);
    static int f(long);
};

int (X::*p1)(int) = &X::f; // OK
int (p2)(int) = &X::f; // error: mismatch
int (p3)(long) = &X::f; // OK
int (X::*p4)(long) = &X::f; // error: mismatch
int (X::*p5)(int) = &X::f; // error: wrong syntax for
// pointer to member
int (p6)(long) = &X::f; // OK
```

—end example]

6 [Note: if f() and g() are both overloaded functions, the cross product of possibilities must be considered to resolve f(&g), or the equivalent expression f(g). —end note]

7 [Note: there are no standard conversions (clause 4) of one pointer-to-function type into another. In particular, even if B is a public base of D, we have]
13.5 Overloaded operators

A function declaration having one of the following operator-function-ids as its name declares an operator function. An operator function is said to implement the operator named in its operator-function-id.

operator-function-id:
  operator operator < template-argument-list_opt >

operator: one of
  new delete new[] delete[]
  + - * / % ~ & |
  ! = < > += -= *= /= %=
  ^= &= |= << >> >>= <<= == !=
  <= >= && || ++ -- , ->* ->
  () []

[Note: the last two operators are function call (5.2.2) and subscripting (5.2.1). The operators new[], delete[], (), and [] are formed from more than one token. —end note]

2 Both the unary and binary forms of

  + - * &

can be overloaded.

3 The following operators cannot be overloaded:

  . . * :: ?:

  nor can the preprocessing symbols # and ## (clause 16).

4 Operator functions are usually not called directly; instead they are invoked to evaluate the operators they implement (13.5.1 - 13.5.7). They can be explicitly called, however, using the operator-function-id as the name of the function in the function call syntax (5.2.2). [Example:

  complex z = a.operator+(b); // complex z = a+b;
  void* p = operator new(sizeof(int)*n);

  —end example]

5 The allocation and deallocation functions, operator new, operator new[], operator delete and operator delete[], are described completely in 3.7.3. The attributes and restrictions found in the rest of this subclause do not apply to them unless explicitly stated in 3.7.3.
An operator function shall either be a non-static member function or be a non-member function and have at least one parameter whose type is a class, a reference to a class, an enumeration, or a reference to an enumeration. It is not possible to change the precedence, grouping, or number of operands of operators. The meaning of the operators =, (unary) &, and , (comma), predefined for each type, can be changed for specific class and enumeration types by defining operator functions that implement these operators. Operator functions are inherited in the same manner as other base class functions.

The identities among certain predefined operators applied to basic types (for example, ++a ≡ a+=1) need not hold for operator functions. Some predefined operators, such as +=, require an operand to be an lvalue when applied to basic types; this is not required by operator functions.

An operator function cannot have default arguments (8.3.6), except where explicitly stated below. Operator functions cannot have more or fewer parameters than the number required for the corresponding operator, as described in the rest of this subclause.

Operators not mentioned explicitly in subclauses 13.5.3 through 13.5.7 act as ordinary unary and binary operators obeying the rules of 13.5.1 or 13.5.2.

### 13.5.1 Unary operators

A prefix unary operator shall be implemented by a non-static member function (9.3) with no parameters or a non-member function with one parameter. Thus, for any prefix unary operator @, @x can be interpreted as either x.operator@() or operator@(x). If both forms of the operator function have been declared, the rules in 13.3.1.2 determine which, if any, interpretation is used. See 13.5.7 for an explanation of the postfix unary operators ++ and --.

The unary and binary forms of the same operator are considered to have the same name. [Note: consequently, a unary operator can hide a binary operator from an enclosing scope, and vice versa. —end note]

### 13.5.2 Binary operators

A binary operator shall be implemented either by a non-static member function (9.3) with one parameter or by a non-member function with two parameters. Thus, for any binary operator @, x@y can be interpreted as either x.operator=-(y) or operator@(x,y). If both forms of the operator function have been declared, the rules in 13.3.1.2 determine which, if any, interpretation is used.

### 13.5.3 Assignment

An assignment operator shall be implemented by a non-static member function with exactly one parameter. Because a copy assignment operator operator= is implicitly declared for a class if not declared by the user (12.8), a base class assignment operator is always hidden by the copy assignment operator of the derived class.

Any assignment operator, even the copy assignment operator, can be virtual. [Note: for a derived class D with a base class B for which a virtual copy assignment has been declared, the copy assignment operator in D does not override B’s virtual copy assignment operator. [Example:

```cpp
struct B {
    virtual int operator= (int);
    virtual B& operator= (const B&);
};
struct D : B {
    virtual int operator= (int);
    virtual D& operator= (const B&);
}
```

Draft
D dobj1;
D dobj2;
B* bptr = &dobj1;

void f() {
    bptr->operator=(99); // calls D::operator=(int)
    *bptr = 99;          // ditto
    bptr->operator=(dobj2); // calls D::operator=(const B&)
    *bptr = dobj2;      // ditto
    dobj1 = dobj2;      // calls implicitly-declared
                        // D::operator=(const D&)
}

— end example ] — end note ]

13.5.4 Function call [over.call]

operator() shall be a non-static member function with an arbitrary number of parameters. It implements the function call syntax

```
postfix-expression ( expression-list opt )
```

where the postfix-expression evaluates to a class object and the possibly empty expression-list matches the parameter list of an operator() member function of the class. Thus, a call \( x(\text{arg}_1, \ldots) \) is interpreted as \( x.\text{operator}()(\text{arg}_1, \ldots) \) for a class object \( x \) of type \( T \) if \( T::\text{operator}()(T_1, T_2, T_3) \) exists and if the operator is selected as the best match function by the overload resolution mechanism (13.3.3).

13.5.5 Subscripting [over.sub]

operator[] shall be a non-static member function with exactly one parameter. It implements the subscripting syntax

```
postfix-expression [ expression ]
```

Thus, a subscripting expression \( x[y] \) is interpreted as \( x.\text{operator}[](y) \) for a class object \( x \) of type \( T \) if \( T::\text{operator}[](T_1) \) exists and if the operator is selected as the best match function by the overload resolution mechanism (13.3.3).

13.5.6 Class member access [over.ref]

operator-> shall be a non-static member function taking no parameters. It implements the class member access syntax

```
postfix-expression -> template opt id-expression
postfix-expression -> pseudo-destructor-name
```

An expression \( x->m \) is interpreted as \( (x.\text{operator} ()->())->m \) for a class object \( x \) of type \( T \) if \( T::\text{operator}()->() \) exists and if the operator is selected as the best match function by the overload resolution mechanism (13.3).

13.5.7 Increment and decrement [over.inc]

The user-defined function called operator++ implements the prefix and postfix ++ operator. If this function is a member function with no parameters, or a non-member function with one parameter of class or enumeration type, it defines the
prefix increment operator ++ for objects of that type. If the function is a member function with one parameter (which shall be of type int) or a non-member function with two parameters (the second of which shall be of type int), it defines the postfix increment operator ++ for objects of that type. When the postfix increment is called as a result of using the ++ operator, the int argument will have value zero. [Example:

```cpp
class X {
public:
    X& operator++(); // prefix ++a
    X operator++(int); // postfix a++
};

class Y { 
};
Y& operator++(Y&); // prefix ++b
Y operator++(Y&, int); // postfix b++

void f(X a, Y b) {
    ++a; // a.operator++();
    a++; // a.operator++(0);
    ++b; // operator++(b);
    b++; // operator++(b, 0);

    a.operator++(); // explicit call: like ++a;
    a.operator++(0); // explicit call: like a++;
    operator++(b); // explicit call: like ++b;
    operator++(b, 0); // explicit call: like b++;
}
```
—end example]

The prefix and postfix decrement operators ~ are handled analogously.

13.6 Built-in operators [over.built]

1 The candidate operator functions that represent the built-in operators defined in clause 5 are specified in this subclause. These candidate functions participate in the operator overload resolution process as described in 13.3.1.2 and are used for no other purpose. [Note: because built-in operators take only operands with non-class type, and operator overload resolution occurs only when an operand expression originally has class or enumeration type, operator overload resolution can resolve to a built-in operator only when an operand has a class type that has a user-defined conversion to a non-class type appropriate for the operator, or when an operand has an enumeration type that can be converted to a type appropriate for the operator. Also note that some of the candidate operator functions given in this subclause are more permissive than the built-in operators themselves. As described in 13.3.1.2, after a built-in operator is selected by overload resolution the expression is subject to the requirements for the built-in operator given in clause 5, and therefore to any additional semantic constraints given there. If there is a user-written candidate with the same name and parameter types as a built-in candidate operator function, the built-in operator function is hidden and is not included in the set of candidate functions. —end note]

2 In this subclause, the term promoted integral type is used to refer to those integral types which are preserved by integral promotion (including e.g. int and long but excluding e.g. char). Similarly, the term promoted arithmetic type refers

131) Calling operator++ explicitly, as in expressions like a.operator++(2), has no special properties: The argument to operator++ is 2.
to floating types plus promoted integral types. [Note: in all cases where a promoted integral type or promoted arithmetic type is required, an operand of enumeration type will be acceptable by way of the integral promotions. — end note]

3 For every pair \((T, VQ)\), where \(T\) is an arithmetic type, and \(VQ\) is either volatile or empty, there exist candidate operator functions of the form
   \[
   VQ T* \text{operator}++(VQ T*);
   T \text{operator}++(VQ T*, \text{int});
   \]

4 For every pair \((T, VQ)\), where \(T\) is an arithmetic type other than bool, and \(VQ\) is either volatile or empty, there exist candidate operator functions of the form
   \[
   VQ T* \text{operator}--(VQ T*);
   T \text{operator}--(VQ T*, \text{int});
   \]

5 For every pair \((T, VQ)\), where \(T\) is a cv-qualified or cv-unqualified object type, and \(VQ\) is either volatile or empty, there exist candidate operator functions of the form
   \[
   T*VQk \text{operator}++(T*VQk);
   T*VQk \text{operator}--(T*VQk);
   T* \text{operator}++(T*VQk, \text{int});
   T* \text{operator}--(T*VQk, \text{int});
   \]

6 For every cv-qualified or cv-unqualified object type \(T\), there exist candidate operator functions of the form
   \[
   Tk \quad \text{operator}*(T*);
   \]

7 For every function type \(T\), there exist candidate operator functions of the form
   \[
   Tk \quad \text{operator}*(T*);
   \]

8 For every type \(T\), there exist candidate operator functions of the form
   \[
   T* \quad \text{operator}++(T*);
   \]

9 For every promoted arithmetic type \(T\), there exist candidate operator functions of the form
   \[
   T \text{operator}+(T);
   T \text{operator}-(T);
   \]

10 For every promoted integral type \(T\), there exist candidate operator functions of the form
    \[
    T \text{operator}~(T);
    \]

11 For every quintuple \((C1, C2, T, CV1, CV2)\), where \(C2\) is a class type, \(C1\) is the same type as \(C2\) or is a derived class of \(C2\), \(T\) is an object type or a function type, and \(CV1\) and \(CV2\) are cv-qualifier-seqs, there exist candidate operator functions of the form
    \[
    CV12 Tk \text{operator}->*(CV1 C1*, CV2 T C2::*);
    \]
    where \(CV12\) is the union of \(CV1\) and \(CV2\).

12 For every pair of promoted arithmetic types \(L\) and \(R\), there exist candidate operator functions of the form

Draft
13.6 Built-in operators

Overloading

\[ LR \] operator\*(L, R);
\[ LR \] operator/(L, R);
\[ LR \] operator+(L, R);
\[ LR \] operator-(L, R);

bool operator<\( L, R \);
bool operator>\( L, R \);
bool operator<=\( L, R \);
bool operator>=\( L, R \);
bool operator==\( L, R \);
bool operator!=\( L, R \);

where \( LR \) is the result of the usual arithmetic conversions between types \( L \) and \( R \).

13. For every cv-qualified or cv-unqualified object type \( T \) there exist candidate operator functions of the form

\[ T \] operator\*(T\*, std::ptrdiff_t);
\[ T\& \] operator[]\( T\*, std::ptrdiff_t \);
\[ T \] operator-(T\*, std::ptrdiff_t);
\[ T \] operator\*(std::ptrdiff_t, T\*);
\[ T\& \] operator[]\( std::ptrdiff_t, T\* \);

14. For every \( T \), where \( T \) is a pointer to object type, there exist candidate operator functions of the form

\[ std::ptrdiff_t \] operator-(T, T);

15. For every pointer or enumeration type \( T \), there exist candidate operator functions of the form

bool operator<\( T, T \);
bool operator>\( T, T \);
bool operator<=\( T, T \);
bool operator>=\( T, T \);
bool operator==\( T, T \);
bool operator!=\( T, T \);

16. For every pointer to member type \( T \), there exist candidate operator functions of the form

bool operator==\( T, T \);
bool operator!=\( T, T \);

17. For every pair of promoted integral types \( L \) and \( R \), there exist candidate operator functions of the form

\[ LR \] operator\%(L, R);
\[ LR \] operator&\( L, R \);
\[ LR \] operator\^\( L, R \);
\[ LR \] operator|\( L, R \);
\[ L \] operator<<\( L, R \);
\[ L \] operator>>\( L, R \);

where \( LR \) is the result of the usual arithmetic conversions between types \( L \) and \( R \).

18. For every triple \( (L, VQ, R) \), where \( L \) is an arithmetic type, \( VQ \) is either volatile or empty, and \( R \) is a promoted arithmetic type, there exist candidate operator functions of the form

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For every pair \((T, VQ)\), where \(T\) is any type and \(VQ\) is either volatile or empty, there exist candidate operator functions of the form

\[
T\ast VQ \& \text{ operator=} (T\ast VQ \&, T\*);
\]

For every pair \((T, VQ)\), where \(T\) is an enumeration or pointer to member type and \(VQ\) is either volatile or empty, there exist candidate operator functions of the form

\[
VQ T \& \text{ operator=} (VQ T\&, T);
\]

For every pair \((T, VQ)\), where \(T\) is a cv-qualified or cv-unqualified object type and \(VQ\) is either volatile or empty, there exist candidate operator functions of the form

\[
T\ast VQ \& \text{ operator=} (T\ast VQ \&, std::ptrdiff_t);
\]

\[
T\ast VQ \& \text{ operator=} (T\ast VQ \&, std::ptrdiff_t);
\]

For every triple \((L, VQ, R)\), where \(L\) is an integral type, \(VQ\) is either volatile or empty, and \(R\) is a promoted integral type, there exist candidate operator functions of the form

\[
VQ L \& \text{ operator=} (VQ L\&, R);
\]

\[
VQ L \& \text{ operator=} (VQ L\&, R);
\]

\[
VQ L \& \text{ operator=} (VQ L\&, R);
\]

\[
VQ L \& \text{ operator=} (VQ L\&, R);
\]

\[
VQ L \& \text{ operator=} (VQ L\&, R);
\]

\[
VQ L \& \text{ operator=} (VQ L\&, R);
\]

There also exist candidate operator functions of the form

\[
\text{bool} \ \text{ operator!} (\text{bool});
\]

\[
\text{bool} \ \text{ operator&&} (\text{bool}, \text{bool});
\]

\[
\text{bool} \ \text{ operator||} (\text{bool}, \text{bool});
\]

For every pair of promoted arithmetic types \(L\) and \(R\), there exist candidate operator functions of the form

\[
LR \text{ operator?} (\text{bool}, L, R);
\]

where \(LR\) is the result of the usual arithmetic conversions between types \(L\) and \(R\). [\textit{Note:} as with all these descriptions of candidate functions, this declaration serves only to describe the built-in operator for purposes of overload resolution. The operator “?” cannot be overloaded. —\textit{end note}]

For every type \(T\), where \(T\) is a pointer or pointer-to-member type, there exist candidate operator functions of the form

\[
T \text{ operator?} (\text{bool}, T, T);
\]
13.6 Built-in operators

Overloading

Draft
A template defines a family of classes or functions.

```
 template-declaration:
   export_opt template < template-parameter-list > declaration

 template-parameter-list:
   template-parameter
   template-parameter-list , template-parameter
```

[Note: The > token following the template-parameter-list of a template-declaration may be the product of replacing a >> token by two consecutive > tokens (14.2). — end note]

The declaration in a template-declaration shall

— declare or define a function or a class, or

— define a member function, a member class or a static data member of a class template or of a class nested within a class template, or

— define a member template of a class or class template.

A template-declaration is a declaration. A template-declaration is also a definition if its declaration defines a function, a class, or a static data member.

2 A template-declaration can appear only as a namespace scope or class scope declaration. In a function template declaration, the declarator-id shall be a template-name (i.e., not a template-id). [Note: in a class template declaration, if the class name is a template-id, the declaration declares a class template partial specialization (14.5.4). — end note]

3 In a template-declaration, explicit specialization, or explicit instantiation the init-declarator-list in the declaration shall contain at most one declarator. When such a declaration is used to declare a class template, no declarator is permitted.

4 A template name has linkage (3.5). A non-member function template can have internal linkage; any other template name shall have external linkage. Entities generated from a template with internal linkage are distinct from all entities generated in other translation units. A template, a template explicit specialization (14.7.3), and a class template partial specialization shall not have C linkage. Use of a linkage specification other than C or C++ with any of these constructs is conditionally-supported, with implementation-defined semantics. Template definitions shall obey the one definition rule (3.2). [Note: default arguments for function templates and for member functions of class templates are considered definitions for the purpose of template instantiation (14.5) and must also obey the one definition rule. — end note]

5 A class template shall not have the same name as any other template, class, function, object, enumeration, enumerator, namespace, or type in the same scope (3.3), except as specified in (14.5.4). Except that a function template can be
overloaded either by (non-template) functions with the same name or by other function templates with the same name (14.8.3), a template name declared in namespace scope or in class scope shall be unique in that scope.

6 A template-declaration may be preceded by the export keyword. Such a template is said to be exported. Declaring exported a class template is equivalent to declaring exported all of its non-inline member functions, static data members, member classes, member class templates, and non-inline member function templates.

7 If a template is exported in one translation unit, it shall be exported in all translation units in which it appears; no diagnostic is required. A declaration of an exported template shall appear with the export keyword before any point of instantiation (14.6.4.1) of that template in that translation unit. In addition, the first declaration of an exported template containing the export keyword must not follow the definition of that template. The export keyword shall not be used in a friend declaration.

8 Templates defined in an unnamed namespace, inline functions, and inline function templates shall not be exported. An exported non-class template shall be defined only once in a program; no diagnostic is required. An exported non-class template need only be declared (and not necessarily defined) in a translation unit in which it is instantiated.

9 A non-exported non-class template must be defined in every translation unit in which it is implicitly instantiated (14.7.1), unless the corresponding specialization is explicitly instantiated (14.7.2) in some translation unit; no diagnostic is required.

[Note: an implementation may require that a translation unit containing the definition of an exported template be compiled before any translation unit containing an instantiation of that template. — end note]

14.1 Template parameters

1 The syntax for template-parameters is:

   template-parameter:
     type-parameter
     parameter-declaration

type-parameter:
  class identifier_opt
class identifier_opt = type-id
typename identifier_opt
typename identifier_opt = type-id
template <template-parameter-list> class identifier_opt
template <template-parameter-list> class identifier_opt = id-expression

[Note: The > token following the template-parameter-list of a type-parameter may be the product of replacing a >> token by two consecutive > tokens (14.2). — end note]

2 There is no semantic difference between class and typename in a template-parameter. typename followed by an unqualified-id names a template type parameter. typename followed by a qualified-id denotes the type in a non-type parameter-declaration. A storage class shall not be specified in a template-parameter declaration. [Note: a template parameter may be a class template. For example,

   template<class T> class myarray { /*...*/ };]

132 Since template template-parameters and template template-arguments are treated as types for descriptive purposes, the terms non-type parameter and non-type argument are used to refer to non-type, non-template parameters and arguments.
template<class K, class V, template<class T> class C = myarray>
class Map {
    C<K> key;
    C<V> value;
    // ...
};

/* end note */

A type-parameter defines its identifier to be a typedef-name (if declared with class or typename) or template-name (if declared with template) in the scope of the template declaration. [Note: because of the name lookup rules, a template-parameter that could be interpreted as either a non-type template-parameter or a type-parameter (because its identifier is the name of an already existing class) is taken as a type-parameter. For example,

class T { /* ... */};
int i;

template<class T, T i> void f(T t)
{
    T t1 = i;                        // template-parameters T and i
    ::T t2 = ::i;                   // global namespace members T and i
}

Here, the template f has a type-parameter called T, rather than an unnamed non-type template-parameter of class T.  
/* end note */

A non-type template-parameter shall have one of the following (optionally cv-qualified) types:

— integral or enumeration type,
— pointer to object or pointer to function,
— reference to object or reference to function,
— pointer to member.

[Note: other types are disallowed either explicitly below or implicitly by the rules governing the form of template-arguments (14.3).  
/* end note */ The top-level cv-qualifiers on the template-parameter are ignored when determining its type.

A non-type non-reference template-parameter is not an lvalue. It shall not be assigned to or in any other way have its value changed. A non-type non-reference template-parameter cannot have its address taken. When a non-type non-reference template-parameter is used as an initializer for a reference, a temporary is always used.  [Example:

template<const X& x, int i> void f()
{
    i++;                       // error: change of template-parameter value
    &x;                        // OK
    &i;                        // error: address of non-reference template-parameter
    int& ri = i;               // error: non-const reference bound to temporary
    const int& cri = i;        // OK: const reference bound to temporary

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A non-type template-parameter shall not be declared to have floating point, class, or void type. [Example:

```cpp
template<double d> class X;  // error
template<double* pd> class Y; // OK
template<double& rd> class Z;  // OK
```
— end example ]

A non-type template-parameter of type “array of T” or “function returning T” is adjusted to be of type “pointer to T” or “pointer to function returning T”, respectively. [Example:

```cpp
template<int *a> struct R { /* ... */};
template<int b[5]> struct S { /* ... */};
int p;
R<&p> w; // OK
S<&p> x; // OK due to parameter adjustment
int v[5];
R<v> y; // OK due to implicit argument conversion
S<v> z; // OK due to both adjustment and conversion
```
— end example ]

A default template-argument is a template-argument (14.3) specified after = in a template-parameter. A default template-argument may be specified for any kind of template-parameter (type, non-type, template). A default template-argument may be specified in a template declaration. A default template-argument shall not be specified in the template-parameter-lists of the definition of a member of a class template that appears outside of the member’s class. A default template-argument shall not be specified in a friend class template declaration. If a friend function template declaration specifies a default template-argument, that declaration shall be a definition and shall be the only declaration of the function template in the translation unit.

The set of default template-arguments available for use with a template declaration or definition is obtained by merging the default arguments from the definition (if in scope) and all declarations in scope in the same way default function arguments are (8.3.6). [Example:

```cpp
template<class T1, class T2 = int> class A;
template<class T1 = int, class T2> class A;
```
is equivalent to

```cpp
template<class T1 = int, class T2 = int> class A;
```
— end example ]

If a template-parameter of a class template has a default template-argument, all subsequent template-parameters shall have a default template-argument supplied. [Note: This is not a requirement for function templates because template arguments might be deduced (14.8.2). [Example:

```cpp
template<class T1 = int, class T2> class B;  // error
```

Draft
14.2 Names of template specializations

A template specialization (14.7) can be referred to by a template-id:
14.2 Names of template specializations

```
template-id:
  template-name < template-argument-list_opt >

template-name:
  identifier

template-argument-list:
  template-argument
  template-argument-list , template-argument

template-argument:
  assignment-expression
  type-id
  id-expression

[ Note: the name lookup rules (3.4) are used to associate the use of a name with a template declaration; that is, to identify a name as a template-name. — end note ]

2 For a template-name to be explicitly qualified by the template arguments, the name must be known to refer to a template.

3 After name lookup (3.4) finds that a name is a template-name, if this name is followed by a <, the < is always taken as the beginning of a template-argument-list and never as a name followed by the less-than operator. When parsing a template-id, the first non-nested > is always taken as the beginning of a template-argument-list and never as a name followed by the greater-than operator. Similarly, the first non-nested >> is treated as two consecutive but distinct > tokens, the first of which is taken as the end of the template-argument-list and completes the template-id. [ Note: The second > token produced by this replacement rule may terminate an enclosing template-id construct or it may be part of a different construct (e.g. a cast). — end note ]

[ Example:

```
example changed to:

    template<int i> class X { /* ... */ };

    X< 1>2 > x1; // syntax error
    X<(1>2)> x2; // OK

    template<class T> class Y { /* ... */ };
    Y<X<1>> x3; // OK, same as Y<X<1> > x3;
    Y<X<6>>1>> x4; // syntax error
    Y<X<(6>>1)>> x5; // OK

    — end example ]
```

4 When the name of a member template specialization appears after . or -> in a postfix-expression, or after a nested-name-specifier in a qualified-id, and the postfix-expression or qualified-id explicitly depends on a template-parameter (14.6.2) but does not refer to a member of the current instantiation (14.6.2.1), the member template name must be prefixed by the keyword template. Otherwise the name is assumed to name a non-template. [ Example:

```
class X {
  public:
    template<std::size_t> X* alloc();
    template<std::size_t> static X* adjust();
```

[133] A > that encloses the type-id of a dynamic_cast, static_cast, reinterpret_cast or const_cast, or which encloses the template-arguments of a subsequent template-id, is considered nested for the purpose of this description.
template<class T> void f(T* p)
{
    T* p1 = p->alloc<200>();
    // ill-formed: < means less than
    T* p2 = p->template alloc<200>();
    // OK: < starts template argument list
    T::adjust<100>();
    // ill-formed: < means less than
    T::template adjust<100>();
    // OK: < starts template argument list
}

— end example ]

5 If a name prefixed by the keyword template is not the name of a template, the program is ill-formed. [ Note: the keyword template may not be applied to non-template members of class templates. — end note ] Furthermore, names of member templates shall not be prefixed by the keyword template if the postfix-expression or qualified-id does not appear in the scope of a template. [ Note: just as is the case with the typename prefix, the template prefix is allowed in cases where it is not strictly necessary; i.e., when the expression on the left of the -> or ., or the nested-name-specifier is not dependent on a template-parameter. — end note ]

6 A template-id that names a class template specialization is a class-name (clause 9).

14.3 Template arguments

There are three forms of template-argument, corresponding to the three forms of template-parameter: type, non-type and template. The type and form of each template-argument specified in a template-id shall match the type and form specified for the corresponding parameter declared by the template in its template-parameter-list. [ Example:
In a template-argument, an ambiguity between a type-id and an expression is resolved to a type-id, regardless of the form of the corresponding template-parameter.\[^{\text{134}}\] [Example:

```
 template<class T> void f();
 template<int I> void f();

 void g()
 {
  f<int>(); // int() is a type-id: call the first f()
 }
```
— end example ]

The name of a template-argument shall be accessible at the point where it is used as a template-argument. [Note: if the name of the template-argument is accessible at the point where it is used as a template-argument, there is no further access restriction in the resulting instantiation where the corresponding template-parameter name is used. — end note] [Example:

```
 template<class T> class X {
  static T t;
};

class Y {
 private:
  struct S { /* ... */ }; // OK: S is accessible
  X<S> x; // X<Y::S> has a static member of type Y::S
  // OK: even though Y::S is private
};

 X<Y::S> y; // error: S not accessible
```
— end example ] For a template-argument of class type, the template definition has no special access rights to the inaccessible members of the template argument type.

When default template-arguments are used, a template-argument list can be empty. In that case the empty <> brackets shall still be used as the template-argument-list. [Example:

```
 template<class T = char> class String;
 String<>* p; // OK: String<char>
 String* q; // syntax error
```
— end example ]

\[^{\text{134}}\] There is no such ambiguity in a default template-argument because the form of the template-parameter determines the allowable forms of the template-argument.
5 An explicit destructor call (12.4) for an object that has a type that is a class template specialization may explicitly specify the template-arguments. [Example:
```
template<class T> struct A {
    ~A();
};
void f(A<int>* p, A<int>* q) {
    p->A<int>::~A(); // OK: destructor call
    q->A<int>::~A<int>(); // OK: destructor call
}
```
— end example ]

6 If the use of a template-argument gives rise to an ill-formed construct in the instantiation of a template specialization, the program is ill-formed.

7 When the template in a template-id is an overloaded function template, both non-template functions in the overload set and function templates in the overload set for which the template-arguments do not match the template-parameters are ignored. If none of the function templates have matching template-parameters, the program is ill-formed.

14.3.1 Template type arguments

1 A template-argument for a template-parameter which is a type shall be a type-id.

2 A type without linkage (3.5) shall not be used as a template-argument for a template type-parameter.

[ Example:
```
template <class T> class X { /* ... */ };
void f()
{
    struct S { /* ... */ };
    X<S> x3; // error: local type used as template-argument
    X<S*> x4; // error: pointer to local type used as template-argument
}
```
— end example ] [ Note: a template type argument may be an incomplete type (3.9). — end note ]

3 If a declaration acquires a function type through a type dependent on a template-parameter and this causes a declaration that does not use the syntactic form of a function declarator to have function type, the program is ill-formed. [ Example:
```
template<class T> struct A {
    static T t;
};
typedef int function();
A<function> a; // ill-formed: would declare A<function>::t
```
— end example ]

4 If a template-argument for a template-parameter T names a type “reference to cv1 S”, an attempt to create the type “reference to cv2 T” creates the type “reference to cv12 S”, where cv12 is the union of the cv-qualifiers cv1 and cv2. Redundant cv-qualifiers are ignored. [ Example:
14.3 Template arguments

template <class T> class X {
    void f(const T&);
    // ... */
};
X<int&> x; // X<int&>::f has the parameter type const int&

— end example []

14.3.2 Template non-type arguments

A template-argument for a non-type, non-template template-parameter shall be one of:

— an integral constant-expression of integral or enumeration type; or
— the name of a non-type template-parameter; or
— the address of an object or function with external linkage, including function templates and function template-ids but excluding non-static class members, expressed as & id-expression where the & is optional if the name refers to a function or array, or if the corresponding template-parameter is a reference; or
— a constant expression that evaluates to a null pointer value (4.10); or
— a constant expression that evaluates to a null member pointer value (4.11); or
— a pointer to member expressed as described in 5.3.1.

[Note: A string literal (2.13.4) does not satisfy the requirements of any of these categories and thus is not an acceptable template-argument. [Example:

template<class T, char* p> class X {
    // ...
    X();
    X(const char* q) { /* ... */ }
};
X<int,"Studebaker"> x1; // error: string literal as template-argument
char p[] = "Vivisectionist";
X<int,p> x2; // OK

— end example ] — end note ]

[Note: Addresses of array elements and names or addresses of non-static class members are not acceptable template-arguments. [Example:

template<int* p> class X { }

int a[10];
struct S { int m; static int s; } s;
X<&a[2]> x3; // error: address of array element
X<&s.m> x4; // error: address of non-static member
X<&s.s> x5; // error: &S::s must be used
X<&S::s> x6; // OK: address of static member

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4 [ Note: Temporaries, unnamed lvalues, and named lvalues that do not have external linkage are not acceptable template-arguments when the corresponding template-parameter has reference type. ]

```cpp
template<const int& CRI> struct B {
    /* */ ...
};

B<1> b2;        // error: temporary would be required for template argument

int c = 1;
B<c> b1;        // OK
```

— end example ] — end note ]

5 The following conversions are performed on each expression used as a non-type template-argument. If a non-type template-argument cannot be converted to the type of the corresponding template-parameter then the program is ill-formed.

— for a non-type template-parameter of integral or enumeration type, integral promotions (4.5) and integral conversions (4.7) are applied.

— for a non-type template-parameter of type pointer to object, qualification conversions (4.4) and the array-to-pointer conversion (4.2) are applied. [ Note: In particular, neither the null pointer conversion (4.10) nor the derived-to-base conversion (4.10) are applied. Although 0 is a valid template-argument for a non-type template-parameter of integral type, it is not a valid template-argument for a non-type template-parameter of pointer type. However, (int*)0 is a valid template-argument for a non-type template-parameter of type “pointer to int.” — end note ]

— For a non-type template-parameter of type reference to object, no conversions apply. The type referred to by the reference may be more cv-qualified than the (otherwise identical) type of the template-argument. The template-parameter is bound directly to the template-argument, which must be an lvalue.

— For a non-type template-parameter of type pointer to function, only the function-to-pointer conversion (4.3) is applied. If the template-argument represents a set of overloaded functions (or a pointer to such), the matching function is selected from the set (13.4).

— For a non-type template-parameter of type reference to function, no conversions apply. If the template-argument represents a set of overloaded functions, the matching function is selected from the set (13.4).

— For a non-type template-parameter of type pointer to member function, no conversions apply. If the template-argument represents a set of overloaded member functions, the matching member function is selected from the set (13.4).

— For a non-type template-parameter of type pointer to data member, qualification conversions (4.4) are applied.

```cpp
[ Example:

template<const int* pci> struct X { /* */ ...
};
int ai[10];
X<ai> xi;        // array to pointer and qualification conversions

struct Y { /* */ ...
};
template<const Y& b> struct Z { /* */ ...
};
```

Draft
14.4 Type equivalence

Y y;
Z<y> z;  // no conversion, but note extra cv-qualification

template<int (&pa)[5]> struct W { /* ... */ };  
int b[5];
W<b> w;  // no conversion

void f(char);
void f(int);

template<void (*pf)(int)> struct A { /* ... */ };  
A<&f> a;  // selects f(int)

— end example ]

14.3.3 Template template arguments [temp.arg.template]

1 A template-argument for a template template-parameter shall be the name of a class template, expressed as id-expression. Only primary class templates are considered when matching the template template argument with the corresponding parameter; partial specializations are not considered even if their parameter lists match that of the template template parameter.

2 Any partial specializations (14.5.4) associated with the primary class template are considered when a specialization based on the template template-parameter is instantiated. If a specialization is not visible at the point of instantiation, and it would have been selected had it been visible, the program is ill-formed; no diagnostic is required. [ Example:

```cpp
template<class T> class A {       // primary template
   int x;
};
template<class T> class A<T*> {   // partial specialization
   long x;
};
template<template<class U> class V> class C { 
   V<int> y;
   V<int*> z;
};
C<A> c;                      // V<int> within C<A> uses the primary template,
                             // so c.y.x has type int
                             // V<int*> within C<A> uses the partial specialization,
                             // so c.z.x has type long

— end example ]

14.4 Type equivalence [temp.type]

1 Two template-ids refer to the same class or function if
   — their template-names refer to the same template, and
   — their corresponding type template-arguments are the same type, and
— their corresponding non-type template-arguments of integral or enumeration type have identical values, and
— their corresponding non-type template-arguments of pointer type refer to the same external object or function or are both the null pointer value, and
— their corresponding non-type template-arguments of pointer-to-member type refer to the same class member or are both the null member pointer value, and
— their corresponding non-type template-arguments of reference type refer to the same external object or function, and
— their corresponding template template-arguments refer to the same template.

[ Example:
    template<class E, int size> class buffer { /* ... */};
    buffer<char,2*512> x;
    buffer<char,1024> y;
]

declares x and y to be of the same type, and

[ Example:
    template<class T, void(*err_fct)()> class list { /* ... */};
    list<int,&error_handler1> x1;
    list<int,&error_handler2> x2;
    list<int,&error_handler2> x3;
    list<char,&error_handler2> x4;
]

declares x2 and x3 to be of the same type. Their type differs from the types of x1 and x4. — end example ]

14.5 Template declarations

A template-id, that is, the template-name followed by a template-argument-list shall not be specified in the declaration of a primary template declaration. [ Example:
    template<class T1, class T2, int I> class A<T1, T2, I> { }; // error
    template<class T1, int I> void sort<T1, I>(T1 data[I]); // error
]
— end example ] [ Note: however, this syntax is allowed in class template partial specializations (14.5.4). — end note ]

For purposes of name lookup and instantiation, default arguments of function templates and default arguments of member functions of class templates are considered definitions; each default argument is a separate definition which is unrelated to the function template definition or to any other default arguments.

14.5.1 Class templates

A class template defines the layout and operations for an unbounded set of related types. [ Example: a single class template List might provide a common definition for list of int, list of float, and list of pointers to Shapes. — end example ]

[ Example: An array class template might be declared like this:
template<class T> class Array {
    T* v;
    int sz;
public:
    explicit Array(int);
    T& operator[](int);
    T& elem(int i) { return v[i]; }  // ...
};

2 The prefix template <class T> specifies that a template is being declared and that a type-name T will be used in the declaration. In other words, Array is a parameterized type with T as its parameter. — end example ]

3 When a member function, a member class, a static data member or a member template of a class template is defined outside of the class template definition, the member definition is defined as a template definition in which the template-parameters are those of the class template. The names of the template parameters used in the definition of the member may be different from the template parameter names used in the class template definition. The template argument list following the class template name in the member definition shall name the parameters in the same order as the one used in the template parameter list of the member. [ Example:

    template<class T1, class T2> struct A {
        void f1();
        void f2();
    };
    template<class T2, class T1> void A<T2,T1>::f1() { }  // OK
    template<class T2, class T1> void A<T1,T2>::f2() { }  // error

    — end example ]

4 In a redeclaration, partial specialization, explicit specialization or explicit instantiation of a class template, the class-key shall agree in kind with the original class template declaration (7.1.5.3).

14.5.1.1 Member functions of class templates

A member function of a class template may be defined outside of the class template definition in which it is declared. [ Example:

    template<class T> class Array {
        T* v;
        int sz;
public:
        explicit Array(int);
        T& operator[](int);
        T& elem(int i) { return v[i]; }  // ...
    };

declares three function templates. The subscript function might be defined like this:

    template<class T> T& Array<T>::operator[](int i)
291  Templates 14.5  Template declarations

2

The template-arguments for a member function of a class template are determined by the template-arguments of the type of the object for which the member function is called. [Example: the template-argument for Array<T>::operator[]() will be determined by the Array to which the subscripting operation is applied.]

```c
Array<int> v1(20);
Array<dcomplex> v2(30);

v1[3] = 7;  // Array<int>::operator[]()
v2[3] = dcomplex(7,8);  // Array<dcomplex>::operator[]()
```

— end example ]

14.5.1.2 Member classes of class templates [temp.mem.class]

A class member of a class template may be defined outside the class template definition in which it is declared. [Note: the class member must be defined before its first use that requires an instantiation (14.7.1). For example,]

```c
template<class T> struct A {
  class B;
};
A<int>::B* b1;  // OK: requires A to be defined but not A::B

template<class T> class A<T>::B { };
A<int>::B b2;  // OK: requires A::B to be defined
```

— end note ]

14.5.1.3 Static data members of class templates [temp.static]

A definition for a static data member may be provided in a namespace scope enclosing the definition of the static member’s class template. [Example:]

```c
template<class T> class X {
  static T s;
};
template<class T> T X<T>::s = 0;
```

— end example ]

14.5.2 Member templates [temp.mem]

A template can be declared within a class or class template; such a template is called a member template. A member template can be defined within or outside its class definition or class template definition. A member template of a class template that is defined outside of its class template definition shall be specified with the template-parameters of the class template followed by the template-parameters of the member template. [Example:
14.5 Template declarations

```cpp
template<class T> class string {
public:
    template<class T2> int compare(const T2&);
    template<class T2> string(const string<T2>& s) { /* ... */ }
    // ...
};

template<class T> template<class T2> int string<T>::compare(const T2& s)
{
    // ...
}

— end example ]
```

2 A local class shall not have member templates. Access control rules (clause 11) apply to member template names. A destructor shall not be a member template. A normal (non-template) member function with a given name and type and a member function template of the same name, which could be used to generate a specialization of the same type, can both be declared in a class. When both exist, a use of that name and type refers to the non-template member unless an explicit template argument list is supplied. [Example:

```cpp
template <class T> struct A {
    void f(int);
    template <class T2> void f(T2);
};

template <> void A<int>::f(int) { }                     // non-template member
template <> template <> void A<int>::f<>(int) { }       // template member

int main()
{
    A<char> ac;
    ac.f(1);     // non-template
    ac.f('c');   // template
    ac.f<>((1);  // template
}

— end example ]
```

3 A member function template shall not be virtual. [Example:

```cpp
template <class T> struct AA {
    template <class C> virtual void g(C);    // error
    virtual void f();                        // OK
};

— end example ]
```

4 A specialization of a member function template does not override a virtual function from a base class. [Example:

```cpp
class B {
    virtual void f(int);
```
};

class D : public B {
    template <class T> void f(T); // does not override B::f(int)
    void f(int i) { f<i>(i); } // overriding function that calls
        // the template instantiation
};

— end example ]

5 A specialization of a template conversion function is referenced in the same way as a non-template conversion function that converts to the same type. [Example:

```c
struct A {
    template <class T> operator T*();
};

template <class T> A::operator T*(){ return 0; }
template <> A::operator char*(){ return 0; } // specialization
template A::operator void*(); // explicit instantiation
```

```c
int main()
{
    A     a;
    int*  ip;

    ip = a.operator int*(); // explicit call to template operator
        //A::operator int()
}
```

— end example ] [ Note: because the explicit template argument list follows the function template name, and because conversion member function templates and constructor member function templates are called without using a function name, there is no way to provide an explicit template argument list for these function templates. — end note ]

6 A specialization of a template conversion function is not found by name lookup. Instead, any template conversion functions visible in the context of the use are considered. For each such operator, if argument deduction succeeds (14.8.2.3), the resulting specialization is used as if found by name lookup.

7 A using-declaration in a derived class cannot refer to a specialization of a template conversion function in a base class.

8 Overload resolution (13.3.3.2) and partial ordering (14.5.5.2) are used to select the best conversion function among multiple template conversion functions and/or non-template conversion functions.

14.5.3 Friends [temp.friend]

1 A friend of a class or class template can be a function template or class template, a specialization of a function template or class template, or an ordinary (non-template) function or class. For a friend function declaration that is not a template declaration:

— if the name of the friend is a qualified or unqualified template-id, the friend declaration refers to a specialization of a function template, otherwise
14.5 Template declarations

— if the name of the friend is a qualified-id and a matching non-template function is found in the specified class or namespace, the friend declaration refers to that function, otherwise,

— if the name of the friend is a qualified-id and a matching specialization of a function template is found in the specified class or namespace, the friend declaration refers to that function template specialization, otherwise,

— the name shall be an unqualified-id that declares (or redeclares) an ordinary (non-template) function.

[Example:

```cpp
template<class T> class task;
template<class T> task<T>* preempt(task<T>);

template<class T> class task {
  // ...
  friend void next_time();
  friend void process(task<T>);
  friend task<T>* preempt<T>(task<T>);
  template<class C> friend int func(C);

  friend class task<int>;
  template<class P> friend class frd;
  // ...
};
```

Here, each specialization of the task class template has the function next_time as a friend; because process does not have explicit template-arguments, each specialization of the task class template has an appropriately typed function process as a friend, and this friend is not a function template specialization; because the friend preempt has an explicit template-argument <T>, each specialization of the task class template has the appropriate specialization of the function template preempt as a friend; and each specialization of the task class template has all specializations of the function template func as friends. Similarly, each specialization of the task class template has the class template specialization task<int> as a friend, and has all specializations of the class template frd as friends. —end example]

2 A friend template may be declared within a class or class template. A friend function template may be defined within a class or class template, but a friend class template may not be defined in a class or class template. In these cases, all specializations of the friend class or friend function template are friends of the class or class template granting friendship. [Example:

```cpp
class A {
  template<class T> friend class B;       // OK
  template<class T> friend void f(T){ /* ... */ } // OK
};

—end example ]

3 A template friend declaration specifies that all specializations of that template, whether they are implicitly instantiated (14.7.1), partially specialized (14.5.4) or explicitly specialized (14.7.3), are friends of the class containing the template friend declaration. [Example:

```cpp
class X {
  template<class T> friend struct A;
class Y { }
};
```

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When a function is defined in a friend function declaration in a class template, the function is instantiated when the function is used. The same restrictions on multiple declarations and definitions that apply to non-template function declarations and definitions also apply to these implicit definitions.

A member of a class template may be declared to be a friend of a non-template class. In this case, the corresponding member of every specialization of the class template is a friend of the class granting friendship. [Example:

```cpp
template<class T> struct A {
    struct B { }
    void f();
};

class C {
    template<class T> friend struct A<T>::B;
    template<class T> friend void A<T>::f();
};
```

— end example ]

[ Note: a friend declaration may first declare a member of an enclosing namespace scope (14.6.5). — end note ]

A friend template shall not be declared in a local class.

Friend declarations shall not declare partial specializations. [Example:

```cpp
template<class T> class A { }
class X {
    template<class T> friend class A<T*>; // error
};
```

— end example ]

When a friend declaration refers to a specialization of a function template, the function parameter declarations shall not include default arguments, nor shall the inline specifier be used in such a declaration.

### 14.5.4 Class template partial specializations

A primary class template declaration is one in which the class template name is an identifier. A template declaration in which the class template name is a template-id, is a partial specialization of the class template named in the template-id. A partial specialization of a class template provides an alternative definition of the template that is used instead of the primary definition when the arguments in a specialization match those given in the partial specialization (14.5.4.1). The primary template shall be declared before any specializations of that template. If a template is partially specialized then that partial specialization shall be declared before the first use of that partial specialization that would cause an implicit instantiation to take place, in every translation unit in which such a use occurs; no diagnostic is required.
14.5 Template declarations

2 When a partial specialization is used within the instantiation of an exported template, and the unspecialized template name is non-dependent in the exported template, a declaration of the partial specialization must be declared before the definition of the exported template, in the translation unit containing that definition. A similar restriction applies to explicit specialization; see 14.7.

3 Each class template partial specialization is a distinct template and definitions shall be provided for the members of a template partial specialization (14.5.4.3).

4 [Example:

```cpp
template<class T1, class T2, int I> class A {}; // #1
template<class T, int I> class A<T, T*, I> {}; // #2
template<class T1, class T2, int I> class A<T1*, T2, I> {}; // #3
template<class T> class A<int, T*, 5> {}; // #4
template<class T1, class T2, int I> class A<T1, T2*, I> {}; // #5
```

The first declaration declares the primary (unspecialized) class template. The second and subsequent declarations declare partial specializations of the primary template. — end example]

5 The template parameters are specified in the angle bracket enclosed list that immediately follows the keyword template. For partial specializations, the template argument list is explicitly written immediately following the class template name. For primary templates, this list is implicitly described by the template parameter list. Specifically, the order of the template arguments is the sequence in which they appear in the template parameter list. [Example: the template argument list for the primary template in the example above is <T1, T2, I>. — end example] [Note: the template argument list shall not be specified in the primary template declaration. For example,

```cpp
template<class T1, class T2, int I> class A<T1, T2, I> {}; // error
```

— end note]

6 A class template partial specialization may be declared or redeclared in any namespace scope in which its definition may be defined (14.5.1 and 14.5.2). [Example:

```cpp
template<class T> struct A {
    struct C {
        template<class T2> struct B {};
    };
};
```

// partial specialization of A<T>::C::B<T2>
```cpp
template<class T> template<class T2> struct A<T>::C::B<T2*>
```;

A<short>::C::B<int*> absip; // uses partial specialization?

— end example]

7 Partial specialization declarations themselves are not found by name lookup. Rather, when the primary template name is used, any previously declared partial specializations of the primary template are also considered. One consequence is that a using-declaration which refers to a class template does not restrict the set of partial specializations which may be found through the using-declaration. [Example:

Draft
namespace N {
    template<class T1, class T2> class A { }; // primary template
}

using N::A; // refers to the primary template

namespace N {
    template<class T> class A<T, T*> { }; // partial specialization
}

A<int,int*> a; // uses the partial specialization, which is found through
// the using declaration which refers to the primary template

— end example ]

A non-type argument is non-specialized if it is the name of a non-type parameter. All other non-type arguments are specialized.

Within the argument list of a class template partial specialization, the following restrictions apply:

— A partially specialized non-type argument expression shall not involve a template parameter of the partial specialization except when the argument expression is a simple identifier. [ Example:
    
    template <int I, int J> struct A {};  
    template <int I> struct A<I+5, I*2> {}; // error
    
    template <int I, int J> struct B {};  
    template <int I> struct B<I, I> {};   // OK
    
    — end example ]

— The type of a template parameter corresponding to a specialized non-type argument shall not be dependent on a parameter of the specialization. [ Example:

    template <class T, T t> struct C {};  
    template <class T> struct C<T, 1>;    // error
    
    template< int X, int (*array_ptr)[X] > class A {};  
    int array[5];  
    template< int X > class A<X,&array> { }; // error

    — end example ]

— The argument list of the specialization shall not be identical to the implicit argument list of the primary template. The template parameter list of a specialization shall not contain default template argument values.135)

135) There is no way in which they could be used.
14.5 Template declarations

14.5.4.1 Matching of class template partial specializations

When a class template is used in a context that requires an instantiation of the class, it is necessary to determine whether
the instantiation is to be generated using the primary template or one of the partial specializations. This is done by
matching the template arguments of the class template specialization with the template argument lists of the partial
specializations.

— If exactly one matching specialization is found, the instantiation is generated from that specialization.
— If more than one matching specialization is found, the partial order rules (14.5.4.2) are used to determine whether
one of the specializations is more specialized than the others. If none of the specializations is more specialized
than all of the other matching specializations, then the use of the class template is ambiguous and the program is
ill-formed.
— If no matches are found, the instantiation is generated from the primary template.

A partial specialization matches a given actual template argument list if the template arguments of the partial special-
ization can be deduced from the actual template argument list (14.8.2). [Example:

A<int, int, 1> a1; // uses #1
A<int, int*, 1> a2; // uses #2, T is int, I is 1
A<int, char*, 5> a3; // uses #4, T is char
A<int, char*, 1> a4; // uses #5, T1 is int, T2 is char, I is 1
A<int*, int*, 2> a5; // ambiguous: matches #3 and #5

— end example ]

A non-type template argument can also be deduced from the value of an actual template argument of a non-type param-
eter of the primary template. [Example: the declaration of a2 above. — end example ]

In a type name that refers to a class template specialization, (e.g., A<int, int, 1>) the argument list must match
the template parameter list of the primary template. The template arguments of a specialization are deduced from the
arguments of the primary template.

14.5.4.2 Partial ordering of class template specializations

For two class template partial specializations, the first is at least as specialized as the second if, given the following
rewrite to two function templates, the first function template is at least as specialized as the second according to the
ordering rules for function templates (14.5.5.2):

— the first function template has the same template parameters as the first partial specialization and has a single
function parameter whose type is a class template specialization with the template arguments of the first partial
specialization, and
— the second function template has the same template parameters as the second partial specialization and has a single
function parameter whose type is a class template specialization with the template arguments of the second partial
specialization.

[Example:

template<int I, int J, class T> class X { }; 

template<int I, int J> class X<I, J, int> { }; // #1

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The partial specialization \#2 is more specialized than the partial specialization \#1 because the function template \#B is more specialized than the function template \#A according to the ordering rules for function templates. — end example }

14.5.4.3 Members of class template specializations

The template parameter list of a member of a class template partial specialization shall match the template parameter list of the class template partial specialization. The template argument list of a member of a class template partial specialization shall match the template argument list of the class template partial specialization. A class template specialization is a distinct template. The members of the class template partial specialization are unrelated to the members of the primary template. Class template partial specialization members that are used in a way that requires a definition shall be defined; the definitions of members of the primary template are never used as definitions for members of a class template partial specialization. An explicit specialization of a member of a class template partial specialization is declared in the same way as an explicit specialization of the primary template. [Example:

```cpp
// primary template
template<class T, int I> struct A {
    void f();
};

// class template partial specialization
template<class T> struct A<T,2> {
    void f();
    void g();
    void h();
};

// member of class template partial specialization
template<class T> void A<T,2>::g() { }

// explicit specialization
template<> void A<char,2>::h() { }
```

```cpp
int main()
{
    A<char,0> a0;
    A<char,2> a2;
    a0.f();   // OK, uses definition of primary template's member
    a2.g();   // OK, uses definition of
              // partial specialization's member
    a2.h();   // OK, uses definition of
              // explicit specialization's member
    a2.f();   // ill-formed, no definition of f for A<T,2>
}
If a member template of a class template is partially specialized, the member template partial specializations are member templates of the enclosing class template; if the enclosing class template is instantiated (14.7.1, 14.7.2), a declaration for every member template partial specialization is also instantiated as part of creating the members of the class template specialization. If the primary member template is explicitly specialized for a given (implicit) specialization of the enclosing class template, the partial specializations of the member template are ignored for this specialization of the enclosing class template. If a partial specialization of the member template is explicitly specialized for a given (implicit) specialization of the enclosing class template, the primary member template and its other partial specializations are still considered for this specialization of the enclosing class template. [Example:

```
template<class T> struct A {
    template<class T2> struct B {}; // #1
    template<class T2> struct B<T2*> {}; // #2
};
```

```
template<> template<class T2> struct A<short>::B {}; // #3
```

```
A<char>::B<int*> abcip; // uses #2
A<short>::B<int*> absip; // uses #3
A<char>::B<int> abci; // uses #1
```

— end example ]

### 14.5.5 Function templates [temp.fct]

1. A function template defines an unbounded set of related functions. [Example: a family of sort functions might be declared like this:

```
template<class T> class Array { };  
template<class T> void sort(Array<T>&);
```

— end example ]

2. A function template can be overloaded with other function templates and with normal (non-template) functions. A normal function is not related to a function template (i.e., it is never considered to be a specialization), even if it has the same name and type as a potentially generated function template specialization.\[136)\]

#### 14.5.5.1 Function template overloading [temp.over.link]

1. It is possible to overload function templates so that two different function template specializations have the same type. [Example:

```
\[136)\] That is, declarations of non-template functions do not merely guide overload resolution of function template specializations with the same name. If such a non-template function is used in a program, it must be defined; it will not be implicitly instantiated using the function template definition.
Such specializations are distinct functions and do not violate the one definition rule (3.2).

The signature of a function template specialization consists of the signature of the function template and of the actual template arguments (whether explicitly specified or deduced).

The signature of a function template consists of its function signature, its return type and its template parameter list. The names of the template parameters are significant only for establishing the relationship between the template parameters and the rest of the signature. [Note: two distinct function templates may have identical function return types and function parameter lists, even if overload resolution alone cannot distinguish them.]

When an expression that references a template parameter is used in the function parameter list or the return type in the declaration of a function template, the expression that references the template parameter is part of the signature of the function template. This is necessary to permit a declaration of a function template in one translation unit to be linked with another declaration of the function template in another translation unit and, conversely, to ensure that function templates that are intended to be distinct are not linked with one another. [Example:

```c
template <int I, int J> A<I+J> f(A<I>, A<J>); // #1
template <int K, int L> A<K+L> f(A<K>, A<L>); // same as #1
template <int I, int J> A<I-J> f(A<I>, A<J>); // different from #1
```

[Note: Most expressions that use template parameters use non-type template parameters, but it is possible for an expression to reference a type parameter. For example, a template type parameter can be used in the `sizeof` operator. — end note]

Two expressions involving template parameters are considered equivalent if two function definitions containing the expressions would satisfy the one definition rule (3.2), except that the tokens used to name the template parameters may differ as long as a token used to name a template parameter in one expression is replaced by another token that names the same template parameter in the other expression. [Example:

```c
template <int I, int J> void f(A<I+J>); // #1
template <int K, int L> void f(A<K+L>); // same as #1
```

[Note: Two expressions involving template parameters that are not equivalent are functionally equivalent if, for any given set of template arguments, the evaluation of the expression results in the same value.]

Draft
Two function templates are *equivalent* if they are declared in the same scope, have the same name, have identical template parameter lists, and have return types and parameter lists that are equivalent using the rules described above to compare expressions involving template parameters. Two function templates are *functionally equivalent* if they are equivalent except that one or more expressions that involve template parameters in the return types and parameter lists are functionally equivalent using the rules described above to compare expressions involving template parameters. If a program contains declarations of function templates that are functionally equivalent but not equivalent, the program is ill-formed; no diagnostic is required.

[Note: This rule guarantees that equivalent declarations will be linked with one another, while not requiring implementations to use heroic efforts to guarantee that functionally equivalent declarations will be treated as distinct. For example, the last two declarations are functionally equivalent and would cause a program to be ill-formed:]

```
// Guaranteed to be the same
template <int I> void f(A<I>, A<I+10>);
template <int I> void f(A<I>, A<I+10>);

// Guaranteed to be different
template <int I> void f(A<I>, A<I+10>);
template <int I> void f(A<I>, A<I+11>);

// Ill-formed, no diagnostic required
template <int I> void f(A<I>, A<I+10>);
template <int I> void f(A<I>, A<I+1+2+3+4>);
```

— end note ]

### 14.5.5.2 Partial ordering of function templates

If a function template is overloaded, the use of a function template specialization might be ambiguous because template argument deduction (14.8.2) may associate the function template specialization with more than one function template declaration. *Partial ordering* of overloaded function template declarations is used in the following contexts to select the function template to which a function template specialization refers:

- during overload resolution for a call to a function template specialization (13.3.3);
- when the address of a function template specialization is taken;
- when a placement operator delete that is a function template specialization is selected to match a placement operator new (3.7.3.2, 5.3.4);
- when a friend function declaration (14.5.3), an explicit instantiation (14.7.2) or an explicit specialization (14.7.3) refers to a function template specialization.

Partial ordering selects which of two function templates is more specialized than the other by transforming each template in turn (see next paragraph) and performing template argument deduction using the function parameter types, or in the case of a conversion function the return type. The deduction process determines whether one of the templates is more specialized than the other. If so, the more specialized template is the one chosen by the partial ordering process.

To produce the transformed template, for each type, non-type, or template template parameter synthesize a unique type, value, or class template respectively and substitute it for each occurrence of that parameter in the function type of the template.
Using the transformed function template’s function parameter list, or in the case of a conversion function its transformed return type, perform type deduction against the function parameter list (or return type) of the other function. The mechanism for performing these deductions is given in 14.8.2.4.

Example:

```cpp
template<class T> struct A { A(); };

template<class T> void f(T);
template<class T> void f(T*);
template<class T> void f(const T*);

template<class T> void g(T);
template<class T> void g(T&);

template<class T> void h(const T&);
template<class T> void h(A<T>&);

void m() {
    const int *p;
    f(p); // f(const T*) is more specialized than f(T) or f(T*)
    float x;
    g(x); // Ambiguous: g(T) or g(T&)
    A<int> z;
    h(z); // overload resolution selects h(A<T>&)
    const A<int> z2;
    h(z2); // h(const T&) is called because h(A<T>&) is not callable
}
```

--- end example ---

The presence of unused ellipsis and default arguments has no effect on the partial ordering of function templates.

Example:

```cpp
template<class T> void f(T); // #1
template<class T> void f(T*, int=1); // #2
template<class T> void g(T); // #3
template<class T> void g(T*, ...); // #4

int main() {
    int* ip;
    f(ip); // calls #2
    g(ip); // calls #4
}
```

--- end example ---

14.6 Name resolution

Three kinds of names can be used within a template definition:
The name of the template itself, and names declared within the template itself.

Names dependent on a template-parameter (14.6.2).

Names from scopes which are visible within the template definition.

A name used in a template declaration or definition and that is dependent on a template-parameter is assumed not to name a type unless the applicable name lookup finds a type name or the name is qualified by the keyword typename.

```cpp
// no B declared here
class X;

template<class T> class Y {
    class Z;
    // forward declaration of member class

    void f() {
        X* a1;         // declare pointer to X
        T* a2;         // declare pointer to T
        Y* a3;         // declare pointer to Y<T>
        Z* a4;         // declare pointer to Z
typedef typename T::A TA;
        TA* a5;        // declare pointer to T's A
        typename T::A* a6; // declare pointer to T's A
        T::A* a7;      // T::A is not a type name:
                        // multiply T::A by a7; ill-formed,
                        // no visible declaration of a7
        B* a8;         // B is not a type name:
                        // multiply B by a8; ill-formed,
                        // no visible declarations of B and a8
    }
};
```

When a qualified-id in which the nested-name-specifier depends on a template-parameter (14.6.2) is intended to refer to a type, it shall be prefixed by the keyword typename, forming a typename-specifier. When a qualified-id is intended to refer to a type that is not a member of the current instantiation (14.6.2.1) and its nested-name-specifier depends on a template-parameter (14.6.2), it shall be prefixed by the keyword typename, forming a typename-specifier. If the qualified-id in a typename-specifier does not denote a type, the program is ill-formed.

```cpp
typename-specifier:
  typename ::opt nested-name-specifier identifier
  typename ::opt nested-name-specifier template ::opt template-id
```

If a specialization of a template is instantiated for a set of template-arguments such that the qualified-id prefixed by typename does not denote a type, the specialization is ill-formed. The usual qualified name lookup (3.4.3) is used to find the qualified-id even in the presence of typename. [Example:

```cpp
struct A {
    struct X { };
int X;
};
struct B {
  struct X {
  }
};
template<class T> void f(T t) {
  typename T::X x;
}
void foo() {
  A a;
  B b;
  f(b); // OK: T::X refers to B::X
  f(a); // error: T::X refers to the data member A::X not the struct A::X
}

— end example ]

A qualified name used as the name in a mem-initializer-id, a base-specifier, or an elaborated-type-specifier is implicitly assumed to name a type, without the use of the typename keyword. [ Note: the typename keyword is not permitted by the syntax of these constructs. — end note ]

Within the definition of a class template or within the definition of a member of a class template, the keyword typename is not required when referring to the unqualified name of a previously declared member of the class template that declares a type. [ Example:

  template<class T> struct {  
    typedef int B;
    B b; // OK, no typename required
  };

— end example ]

Knowing which names are type names allows the syntax of every template definition to be checked. No diagnostic shall be issued for a template definition for which a valid specialization can be generated. If no valid specialization can be generated for a template definition, and that template is not instantiated, the template definition is ill-formed, no diagnostic required. If a type used in a non-dependent name is incomplete at the point at which a template is defined but is complete at the point at which an instantiation is done, and if the completeness of that type affects whether or not the program is well-formed or affects the semantics of the program, the program is ill-formed; no diagnostic is required. [ Note: if a template is instantiated, errors will be diagnosed according to the other rules in this Standard. Exactly when these errors are diagnosed is a quality of implementation issue. — end note ] [ Example:

  int j;
  template<class T> class X {
    // ...
    void f(T t, int i, char* p)
    {
      t = i;  // diagnosed if X::f is instantiated
               // and the assignment to t is an error
      p = i;  // may be diagnosed even if X::f is
               // not instantiated
      p = j;  // may be diagnosed even if X::f is

      Draft
14.6 Name resolution

// not instantiated

void g(T t) {
  // may be diagnosed even if X::g is not instantiated
  
};

— end example

When looking for the declaration of a name used in a template definition, the usual lookup rules (3.4.1, 3.4.2) are used for non-dependent names. The lookup of names dependent on the template parameters is postponed until the actual template argument is known (14.6.2). [Example:

```cpp
#include <iostream>
using namespace std;

template<class T> class Set {
  T* p;
  int cnt;
public:
  Set();
  Set(T(const Set<T>&));
  void printall()
  {
    for (int i = 0; i<cnt; i++)
      cout << p[i] << '\n';
  }
  // ...
};
```

in the example, i is the local variable i declared in printall, cnt is the member cnt declared in Set, and cout is the standard output stream declared in iostream. However, not every declaration can be found this way; the resolution of some names must be postponed until the actual template-arguments are known. For example, even though the name operator<< is known within the definition of printall() and a declaration of it can be found in <iostream>, the actual declaration of operator<< needed to print p[i] cannot be known until it is known what type T is (14.6.2). [Example:

```cpp
void f(char);

template<class T> void g(T t)
{
  f(t);  // dependent
  f(T(t));  // dependent
  
  // not instantiated
  
  void g(T t) {
    f();  // f(char)
    // f(T(1));  // dependent
    f(t);  // dependent
  }

  // ...}

— end example
```

9 If a name does not depend on a template-parameter (as defined in 14.6.2), a declaration (or set of declarations) for that name shall be in scope at the point where the name appears in the template definition; the name is bound to the declaration (or declarations) found at that point and this binding is not affected by declarations that are visible at the point of instantiation. [Example:

```cpp
void f(char);

template<class T> void g(T t)
{
  f(1);  // f(char)
  f(T(1));  // dependent
  f(t);  // dependent

  // not instantiated
}
```
dd++; // not dependent
// error: declaration for dd not found
}

enum E { e }; void f(E);

double dd; void h()
{
    g(e); // will cause one call of f(char) followed
    // by two calls of f(E)
    g('a'); // will cause three calls of f(char)
}

— end example ]

[ Note: for purposes of name lookup, default arguments of function templates and default arguments of member functions of class templates are considered definitions (14.5). — end note ]

14.6.1 Locally declared names [temp.local]

1 Like normal (non-template) classes, class templates have an injected-class-name (clause 9). The injected-class-name can be used with or without a template-argument-list. When it is used without a template-argument-list, it is equivalent to the injected-class-name followed by the template-parameters of the class template enclosed in <> . When it is used with a template-argument-list, it refers to the specified class template specialization, which could be the current specialization or another specialization.

2 Within the scope of a class template specialization or partial specialization, when the injected-class-name is not followed by a <, it is equivalent to the injected-class-name followed by the template-arguments of the class template specialization or partial specialization enclosed in <> . [ Example:

    template<class T> class Y;
    template<> class Y<int> {
        Y* p; // meaning Y<int>
        Y<char>* q; // meaning Y<char>
    };

— end example ]

3 The injected-class-name of a class template or class template specialization can be used either with or without a template-argument-list wherever it is in scope. [ Example:

    template <class T> struct Base {
        Base* p;
    };

    template <class T> struct Derived: public Base<T> {
        typename Derived::Base* p; // meaning Derived::Base<T>
    };

Draft
A lookup that finds an injected-class-name (10.2) can result in an ambiguity in certain cases (for example, if it is found in more than one base class). If all of the injected-class-names that are found refer to specializations of the same class template, and if the name is followed by a template-argument-list, the reference refers to the class template itself and not a specialization thereof, and is not ambiguous. [Example:

```cpp
template <class T> struct Base { }
template <class T> struct Derived: Base<int>, Base<char> {
    typename Derived::Base b;  // error: ambiguous
    typename Derived::Base<double> d;  // OK
};
```

— end example ]

When the normal name of the template (i.e., the name from the enclosing scope, not the injected-class-name) is used without a template-argument-list, it refers to the class template itself and not a specialization of the template. [ Example:

```cpp
template <class T> class X {
    X* p;  // meaning X<T>
    X<T>* p2;
    X<int>* p3;
    ::X* p4;  // error: missing template argument list  
    // :X does not refer to the injected-class-name
};
```

— end example ]

The scope of a template-parameter extends from its point of declaration until the end of its template. A template-parameter hides any entity with the same name in the enclosing scope. [Note: this implies that a template-parameter can be used in the declaration of subsequent template-parameters and their default arguments but cannot be used in preceding template-parameters or their default arguments. For example,

```cpp
template<class T, T* p, class U = T> class X { /* ... */ }
template<class T> void f(T* p = new T);
```

This also implies that a template-parameter can be used in the specification of base classes. For example,

```cpp
template<class T> class X : public Array<T> { /* ... */ }
template<class T> class Y : public T { /* ... */ }
```

The use of a template-parameter as a base class implies that a class used as a template-argument must be defined and not just declared when the class template is instantiated. — end note ]

A template-parameter shall not be redeclared within its scope (including nested scopes). A template-parameter shall not have the same name as the template name. [ Example:

```cpp
template<class T, int i> class Y {
    int T;  // error: template-parameter redeclared
    void f() {
        char T;  // error: template-parameter redeclared
    }
};
```
In the definition of a member of a class template that appears outside of the class template definition, the name of a member of this template hides the name of a template-parameter. [Example:

```cpp
template<class T> struct A {
    struct B { /* ... */ ;
    void f();
};

template<class B> void A<B>::f() {
    B b; // A's B, not the template parameter
}
```

— end example ]

In the definition of a member of a class template that appears outside of the namespace containing the class template definition, the name of a template-parameter hides the name of a member of this namespace. [Example:

```cpp
namespace N {
    class C { };
    template<class T> class B {
        void f(T);
    };
}

template<class C> void N::B<C>::f(C) {
    C b; // C is the template parameter, not N::C
}
```

— end example ]

In the definition of a class template or in the definition of a member of such a template that appears outside of the template definition, for each base class which does not depend on a template-parameter (14.6.2), if the name of the base class or the name of a member of the base class is the same as the name of a template-parameter, the base class name or member name hides the template-parameter name (3.3.7). [Example:

```cpp
struct A {
    struct B { /* ... */ ;
    int a;
    int Y;
};

template<class B, class a> struct X : A {
    B b; // A's B
    a b; // error: A's a isn't a type name
};
```

Draft
14.6 Name resolution

14.6.2 Dependent names

Inside a template, some constructs have semantics which may differ from one instantiation to another. Such a construct depends on the template parameters. In particular, types and expressions may depend on the type and/or value of template parameters (as determined by the template arguments) and this determines the context for name lookup for certain names. Expressions may be type-dependent (on the type of a template parameter) or value-dependent (on the value of a non-type template parameter). In an expression of the form:

```
postfix-expression ( expression-list )
```

where the postfix-expression is an identifier, the identifier denotes a dependent name if and only if any of the expressions in the expression-list is a type-dependent expression (14.6.2.2). If an operand of an operator is a type-dependent expression, the operator also denotes a dependent name. Such names are unbound and are looked up at the point of the template instantiation (14.6.4.1) in both the context of the template definition and the context of the point of instantiation.

Example:

```cpp
template<class T> struct X : B<T> { 
    typename T::A* pa;
    void f(B<T>* pb) { 
        static int i = B<T>::i;
        pb->j++;
    }
};
```

the base class name `B<T>`, the type name `T::A`, the names `B<T>::i` and `pb->j` explicitly depend on the template-parameter. — end example ]

Example:

```cpp
template<class T> struct X : B<T> { 
    A a; // a has type double
};
```

The type name `A` in the definition of `X<T>` binds to the typedef name defined in the global namespace scope, not to the typedef name defined in the base class `B<T>`. — end example ]

Example:

```cpp
struct A {
    struct B { /* ... */
        int a;
        int Y;
    
    int a;
};
```
template<
class T> struct Y : T {
    struct B { /* ... */ };
    B b; // The B defined in Y
    void f(int i) { a = i; } // ::a
    Y* p; // Y<T>
};

Y<A> ya;

The members A::B, A::a, and A::Y of the template argument A do not affect the binding of names in Y<A>. — end example]  

14.6.2.1 Dependent types [temp.dep.type]

1 In the definition of a class template, a nested class of a class template, a member of a class template, or a member of a nested class of a class template, a name refers to the current instantiation if it is
   — the injected-class-name (9) of the class template or nested class,
   — in the definition of a primary class template, the name of the class template followed by the template argument list of the primary template (as described below) enclosed in <>,
   — in the definition of a nested class of a class template, the name of the nested class referenced as a member of the current instantiation, or
   — in the definition of a partial specialization, the name of the class template followed by the template argument list of the partial specialization enclosed in <>.

2 The template argument list of a primary template is a template argument list in which the n-th template argument has the value of the n-th template parameter of the class template.

3 A template argument that is equivalent to a template parameter (i.e., has the same constant value or the same type as the template parameter) can be used in place of that template parameter in a reference to the current instantiation. In the case of a non-type template argument, the argument must have been given the value of the template parameter and not an expression involving the template parameter. [ Example:

    template <class T> class A {
        A* p1; // a is the current instantiation
        A<T>* p2; // A<T> is the current instantiation
        A<T*>* p3; // A<T> is not the current instantiation
        ::A<T>* p4; // ::A<T> is the current instantiation
    class B {
        B* p1; // B is the current instantiation
        A<T>::B* p2; // A<T>::B is the current instantiation
typename A<T>::B* p3; // A<T>::B is not the current instantiation
    };
};

    template <class T> class A<T*> {
        A<T>* p1; // A<T> is the current instantiation

Draft
A<T>* p2; // A<T> is not the current instantiation
};

template <class T1, class T2, int I> struct B {
    B<T1, T2, I>* b1; // refers to the current instantiation
    B<T2, T1, I>* b2; // not the current instantiation
    typedef T1 my_T1;
    static const int my_I = I;
    static const int my_I2 = I+0;
    static const int my_I3 = my_I;
    B<my_T1, T2, my_I>* b3; // refers to the current instantiation
    B<my_T1, T2, my_I2>* b4; // not the current instantiation
    B<my_T1, T2, my_I3>* b5; // refers to the current instantiation
};

— end example }

4 A name is a member of the current instantiation if it is
   — An unqualified name that, when looked up, refers to a member of a class template. [Note: this can only occur when looking up a name in a scope enclosed by the definition of a class template. — end note]
   — A qualified-id in which the nested-name-specifier refers to the current instantiation.
   — [Example:
       template <class T> class A {
           static const int i = 5;
           int n1[i]; // i refers to a member of the current instantiation
           int n2[A::i]; // A::i refers to a member of the current instantiation
           int n3[A<T>::i]; // A<T>::i refers to a member of the current instantiation
           int f();
       }
       
       template <class T> int A<T>::f()
       {
           return i; // i refers to a member of the current instantiation
       }
   — end example ]

5 A name is a member of an unknown specialization if the name is a qualified-id in which the nested-name-specifier names a dependent type that is not the current instantiation.

6 A type is dependent if it is
   — a template parameter,
   — a member of an unknown specialization,
   — a nested class that is a member of the current instantiation,
   — a cv-qualified type where the cv-unqualified type is dependent,
— a compound type constructed from any dependent type,
— an array type constructed from any dependent type or whose size is specified by a constant expression that is value-dependent, or
— a template-id in which either the template name is a template parameter or any of the template arguments is a dependent type or an expression that is type-dependent or value-dependent.

[Note: because typedefs do not introduce new types, but instead simply refer to other types, a name that refers to a typedef that is a member of the current instantiation is dependent only if the type referred to is dependent. —end note]

14.6.2.2 Type-dependent expressions

Except as described below, an expression is type-dependent if any subexpression is type-dependent.

this is type-dependent if the class type of the enclosing member function is dependent (14.6.2.1).

An id-expression is type-dependent if it contains:
— an identifier that was declared with a dependent type,
— a template-id that is dependent,
— a conversion-function-id that specifies a dependent type,
— a nested-name-specifier or a qualified-id that names a member of an unknown specialization.

Expressions of the following forms are type-dependent only if the type specified by the type-id, simple-type-specifier or new-type-id is dependent, even if any subexpression is type-dependent:

\[
\begin{align*}
\text{simple-type-specifier ( expression-list_{opt} )} \\
\text{::opt new new-placement_{opt} new-type-id new-initializer_{opt}} \\
\text{::opt new new-placement_{opt} ( type-id ) new-initializer_{opt}} \\
\text{dynamic_cast < type-id > ( expression )} \\
\text{static_cast < type-id > ( expression )} \\
\text{const_cast < type-id > ( expression )} \\
\text{reinterpret_cast < type-id > ( expression )} \\
\text{( type-id ) cast-expression}
\end{align*}
\]

Expressions of the following forms are never type-dependent (because the type of the expression cannot be dependent):

\[
\begin{align*}
\text{literal} \\
\text{postfix-expression . pseudo-destructor-name} \\
\text{postfix-expression -> pseudo-destructor-name} \\
\text{sizeof unary-expression} \\
\text{sizeof ( type-id )} \\
\text{typeid ( expression )} \\
\text{typeid ( type-id )} \\
\text{::opt delete cast-expression} \\
\text{::opt delete [ ] cast-expression} \\
\text{throw assignment-expression_{opt}}
\end{align*}
\]

[Note: For the standard library macro offsetof, see 18.1. —end note]
A class member access expression (5.2.5) is type-dependent if the type of the referenced member is dependent. [Note: in an expression of the form \( x.y \) or \( xp->y \) the type of the expression is usually the type of the member \( y \) of the class of \( x \) (or the class pointed to by \( xp \)). However, if \( x \) or \( xp \) refers to a dependent type that is not the current instantiation, the type of \( y \) is always dependent. If \( x \) or \( xp \) refers to a non-dependent type or refers to the current instantiation, the type of \( y \) is the type of the class member access expression. — end note]

14.6.2.3 Value-dependent expressions

Except as described below, a constant expression is value-dependent if any subexpression is value-dependent.

An identifier is value-dependent if it is:

— a name declared with a dependent type,
— the name of a non-type template parameter,
— a constant with integral or enumeration type and is initialized with an expression that is value-dependent.

Expressions of the following form are value-dependent if the unary-expression is type-dependent or the type-id is dependent (even if \( \text{sizeof} \) unary-expression and \( \text{sizeof} \) (type-id) are not type-dependent):

\[
\text{sizeof \ unary-expression} \\
\text{sizeof (type-id)}
\]

[Note: For the standard library macro \( \text{offsetof} \), see 18.1. — end note]

Expressions of the following form are value-dependent if either the type-id or simple-type-specifier is dependent or the expression or cast-expression is value-dependent:

\[
\text{simple-type-specifier ( expression-list?option )} \\
\text{static_cast < type-id > ( expression )} \\
\text{const_cast < type-id > ( expression )} \\
\text{reinterpret_cast < type-id > ( expression )} \\
\text{( type-id ) cast-expression}
\]

14.6.2.4 Dependent template arguments

A type template-argument is dependent if the type it specifies is dependent.

An integral non-type template-argument is dependent if the constant expression it specifies is value-dependent.

A non-integral non-type template-argument is dependent if its type is dependent or it has either of the following forms

qualified-id \\
& qualified-id

and contains a nested-name-specifier which specifies a class-name that names a dependent type.

A template template-argument is dependent if it names a template-parameter or is a qualified-id with a nested-name-specifier which contains a class-name that names a dependent type.

14.6.3 Non-dependent names

Non-dependent names used in a template definition are found using the usual name lookup and bound at the point they
are used. [Example:

```cpp
void g(double);
void h();

template<class T> class Z {
public:
    void f() {
        g(1); // calls g(double)
        h++; // ill-formed: cannot increment function;
        // this could be diagnosed either here or
        // at the point of instantiation
    }
};

void g(int); // not in scope at the point of the template
    // definition, not considered for the call g(1)
```

— end example ]

14.6.4 Dependent name resolution

In resolving dependent names, names from the following sources are considered:

1. Declarations that are visible at the point of definition of the template.
2. Declarations from namespaces associated with the types of the function arguments both from the instantiation context (14.6.4.1) and from the definition context.

14.6.4.1 Point of instantiation

1. For a function template specialization, a member function template specialization, or a specialization for a member function or static data member of a class template, if the specialization is implicitly instantiated because it is referenced from within another template specialization and the context from which it is referenced depends on a template parameter, the point of instantiation of the specialization is the point of instantiation of the enclosing specialization. Otherwise, the point of instantiation for such a specialization immediately follows the namespace scope declaration or definition that refers to the specialization.

2. If a function template or member function of a class template is called in a way which uses the definition of a default argument of that function template or member function, the point of instantiation of the default argument is the point of instantiation of the function template or member function specialization.

3. For a class template specialization, a class member template specialization, or a specialization for a class member of a class template, if the specialization is implicitly instantiated because it is referenced from within another template specialization, if the context from which the specialization is referenced depends on a template parameter, and if the specialization is not instantiated previous to the instantiation of the enclosing template, the point of instantiation is immediately before the point of instantiation of the enclosing template. Otherwise, the point of instantiation for such a specialization immediately precedes the namespace scope declaration or definition that refers to the specialization.

4. If a virtual function is implicitly instantiated, its point of instantiation is immediately following the point of instantiation of its enclosing class template specialization.
An explicit instantiation is an instantiation point for the specialization or specializations specified by the explicit instantiation directive.

The instantiation context of an expression that depends on the template arguments is the set of declarations with external linkage declared prior to the point of instantiation of the template specialization in the same translation unit.

A specialization for a function template, a member function template, or of a member function or static data member of a class template may have multiple points of instantiations within a translation unit. A specialization for a class template has at most one point of instantiation within a translation unit. A specialization for any template may have points of instantiation in multiple translation units. If two different points of instantiation give a template specialization different meanings according to the one definition rule (3.2), the program is ill-formed, no diagnostic required.

14.6.4.2 Candidate functions

For a function call that depends on a template parameter, if the function name is an unqualified-id but not a template-id, the candidate functions are found using the usual lookup rules (3.4.1, 3.4.2) except that:

- For the part of the lookup using unqualified name lookup (3.4.1), only function declarations with external linkage from the template definition context are found.
- For the part of the lookup using associated namespaces (3.4.2), only function declarations with external linkage found in either the template definition context or the template instantiation context are found.

If the call would be ill-formed or would find a better match had the lookup within the associated namespaces considered all the function declarations with external linkage introduced in those namespaces in all translation units, not just considering those declarations found in the template definition and template instantiation contexts, then the program has undefined behavior.

14.6.5 Friend names declared within a class template

Friend classes or functions can be declared within a class template. When a template is instantiated, the names of its friends are treated as if the specialization had been explicitly declared at its point of instantiation.

As with non-template classes, the names of namespace-scope friend functions of a class template specialization are not visible during an ordinary lookup unless explicitly declared at namespace scope (11.4). Such names may be found under the rules for associated classes (3.4.2).  

Example:

```cpp
template<typename T> class number {
    public:
        number(int); // ...
        friend number gcd(number x, number y) { return 0; }; // ...
    private:
        // ...
};

void g()
{
    number<double> a(3), b(4);
```

Friend declarations do not introduce new names into any scope, either when the template is declared or when it is instantiated.
The act of instantiating a function, a class, a member of a class template or a member template is referred to as **template instantiation**.

A function instantiated from a function template is called an instantiated function. A class instantiated from a class template is called an instantiated class. A member function, a member class, or a static data member of a class template instantiated from the member definition of the class template is called, respectively, an instantiated member function, member class or static data member. A function function instantiated from a function template is called an instantiated member function. A member class instantiated from a member class template is called an instantiated member class.

An explicit specialization may be declared for a function template, a class template, a member of a class template or a member template. An explicit specialization declaration is introduced by `template<>`. In an explicit specialization declaration for a class template, a member of a class template or a class member template, the name of the class that is explicitly specialized shall be a **template-id**. In the explicit specialization declaration for a function template or a member function template, the name of the function or member function explicitly specialized may be a **template-id**.

```cpp
// Example:
template<class T = int> struct A {
    static int x;
};
template<class U> void g(U) { }

template<> struct A<double> { }; // specialize for T == double
template<> struct A<> { }; // specialize for T == int
template<> void g(char) { } // specialize for U == char
    // U is deduced from the parameter type
template<> void g<int>(int) { } // specialize for U == int
template<> int A<char>::x = 0; // specialize for T == char

template<class T = int> struct B {
    static int x;
};
template<> int B<>::x = 1; // specialize for T == int
```

An instantiated template specialization can be either implicitly instantiated (14.7.1) for a given argument list or be explicitly instantiated (14.7.2). A specialization is a class, function, or class member that is either instantiated or explicitly specialized (14.7.3).
For a given template and a given set of template-arguments,

— an explicit instantiation definition shall appear at most once in a program,

— an explicit specialization shall be defined at most once in a program (according to 3.2), and

— both an explicit instantiation and a declaration of an explicit specialization shall not appear in a program unless the explicit instantiation follows a declaration of the explicit specialization.

An implementation is not required to diagnose a violation of this rule.

Each class template specialization instantiated from a template has its own copy of any static members. [Example:

```cpp
template<class T> class X {
  static T s;
  // ...
};
template<class T> T X<T>::s = 0;
X<int> aa;
X<char*> bb;
```

X<int> has a static member s of type int and X<char*> has a static member s of type char*. — end example ]

14.7.1 Implicit instantiation [temp.inst]

1 Unless a class template specialization has been explicitly instantiated (14.7.2) or explicitly specialized (14.7.3), the class template specialization is implicitly instantiated when the specialization is referenced in a context that requires a completely-defined object type or when the completeness of the class type affects the semantics of the program. The implicit instantiation of a class template specialization causes the implicit instantiation of the declarations, but not of the definitions or default arguments, of the class member functions, member classes, static data members and member templates; and it causes the implicit instantiation of the definitions of member anonymous unions. Unless a member of a class template or a member template has been explicitly instantiated or explicitly specialized, the specialization of the member is implicitly instantiated when the specialization is referenced in a context that requires the member definition to exist; in particular, the initialization (and any associated side-effects) of a static data member does not occur unless the static data member is itself used in a way that requires the definition of the static data member to exist.

2 Unless a function template specialization has been explicitly instantiated or explicitly specialized, the function template specialization is implicitly instantiated when the specialization is referenced in a context that requires a function definition to exist. Unless a call is to a function template explicit specialization or to a member function of an explicitly specialized class template, a default argument for a function template or a member function of a class template is implicitly instantiated when the function is called in a context that requires the value of the default argument.

3 [Example:

```cpp
template<class T> class Z {
public:
  void f();
  void g();
};
void h()
```

Draft
Nothing in this example requires \texttt{class Z\langle double\rangle}, \texttt{Z\langle int\rangle::g()} or \texttt{Z\langle char\rangle::f()} to be implicitly instantiated. 
— end example ]

A class template specialization is implicitly instantiated if the class type is used in a context that requires a completely-defined object type or if the completeness of the class type might affect the semantics of the program. [ \textit{Note: in particular, if the semantics of an expression depend on the member or base class lists of a class template specialization, the class template specialization is implicitly generated. For instance, deleting a pointer to class type depends on whether or not the class declares a destructor, and conversion between pointer to class types depends on the inheritance relationship between the two classes involved. — end note } ] [ \textit{Example:} \\
\begin{verbatim}
template<class T> class B { /* ... */ }; 
template<class T> class D : public B\langle T\rangle { /* ... */ }; 

void f(void*);
void f(B\langle int\rangle*);

void g(D\langle int\rangle* p, D\langle char\rangle* pp, D\langle double\rangle* ppp)
{
  f(p); // instantiation of D\langle int\rangle required: call f(B\langle int\rangle*)

  B\langle char\rangle* q = pp; // instantiation of D\langle char\rangle required:
  // convert D\langle char\rangle* to B\langle char\rangle*

  delete ppp; // instantiation of D\langle double\rangle required
}
\end{verbatim}
— end example ]

If the overload resolution process can determine the correct function to call without instantiating a class template definition, it is unspecified whether that instantiation actually takes place. [ \textit{Example:} \\
\begin{verbatim}
template <class T> struct S { 
  operator int();
}; 

void f(int);
void f(S\langle int\rangle&);
void f(S\langle float\rangle);
\end{verbatim}
Draft
14.7 Template instantiation and specialization

void g(S<int>& sr) {
    f(sr);  // instantiation of S<int> allowed but not required
    // instantiation of S<float> allowed but not required
};

— end example

6 If an implicit instantiation of a class template specialization is required and the template is declared but not defined, the program is ill-formed. [Example:

    template<class T> class X;

    X<char> ch;  // error: definition of X required

— end example]

7 The implicit instantiation of a class template does not cause any static data members of that class to be implicitly instantiated.

8 If a function template or a member function template specialization is used in a way that involves overload resolution, a declaration of the specialization is implicitly instantiated (14.8.3).

9 An implementation shall not implicitly instantiate a function template, a member template, a non-virtual member function, a member class or a static data member of a class template that does not require instantiation. It is unspecified whether or not an implementation implicitly instantiates a virtual member function of a class template if the virtual member function would not otherwise be instantiated. The use of a template specialization in a default argument shall not cause the template to be implicitly instantiated except that a class template may be instantiated where its complete type is needed to determine the correctness of the default argument. The use of a default argument in a function call causes specializations in the default argument to be implicitly instantiated.

10 Implicitly instantiated class and function template specializations are placed in the namespace where the template is defined. Implicitly instantiated specializations for members of a class template are placed in the namespace where the enclosing class template is defined. Implicitly instantiated member templates are placed in the namespace where the enclosing class or class template is defined. [Example:

    namespace N {
        template<class T> class List {
            public:
                T* get();
                // ...
            }
        }

        template<class K, class V> class Map {
            N::List<V> lt;
            V get(K);
            // ...
        }

        void g(Map<char*,int>& m) {
        }

Draft
int i = m.get("Nicholas");
   // ...
}

A call of \texttt{lt.get()} from Map<char*,int>::get() would place List<int>::get() in the namespace \texttt{N} rather than in the global namespace. — end example

If a function template \texttt{f} is called in a way that requires a default argument expression to be used, the dependent names are looked up, the semantics constraints are checked, and the instantiation of any template used in the default argument expression is done as if the default argument expression had been an expression used in a function template specialization with the same scope, the same template parameters and the same access as that of the function template \texttt{f} used at that point. This analysis is called default argument instantiation. The instantiated default argument is then used as the argument of \texttt{f}.

Each default argument is instantiated independently. [ Example:

\begin{verbatim}
template<class T> void f(T x, T y = ydef(T()), T z = zdef(T()));

class A { }

A zdef(A);

void g(A a, A b, A c) {
   f(a, b, c);  // no default argument instantiation
   f(a, b);    // default argument \texttt{z} = \texttt{zdef(T())} instantiated
   f(a);      // ill-formed; \texttt{ydef} is not declared
}
\end{verbatim}

— end example ]

[ Note: \ref{14.6.4.1} defines the point of instantiation of a template specialization. — end note ]

There is an implementation-defined quantity that specifies the limit on the total depth of recursive instantiations, which could involve more than one template. The result of an infinite recursion in instantiation is undefined. [ Example:

\begin{verbatim}
template<class T> class X {
   X<T>* p;    // OK
   X<T**> a;   // implicit generation of \texttt{X<T>} requires
   // the implicit instantiation of \texttt{X<T>} which requires
   // the implicit instantiation of \texttt{X<T**>} which ...
};
\end{verbatim}

— end example ]

14.7.2 Explicit instantiation [temp.explicit]

A class, a function or member template specialization can be explicitly instantiated from its template. A member function, member class or static data member of a class template can be explicitly instantiated from the member definition associated with its class template.

The syntax for explicit instantiation is:
explicit-instantiation:

`extern opt template declaration`

There are two forms of explicit instantiation: an explicit instantiation definition and an explicit instantiation declaration. An explicit instantiation declaration begins with the `extern` keyword.

If the explicit instantiation is for a class, a function or a member template specialization, the `unqualified-id` in the `declaration` shall be either a `template-id` or, where all template arguments can be deduced, a `template-name`. [ Note: the declaration may declare a `qualified-id`, in which case the `unqualified-id` of the `qualified-id` must be a `template-id`. — end note ] If the explicit instantiation is for a member function, a member class or a static data member of a class template specialization, the name of the class template specialization in the `qualified-id` for the member name shall be a `template-id`. An explicit instantiation shall appear in an enclosing namespace of its template. If the name declared in the explicit instantiation is an unqualified name, the explicit instantiation shall appear in the namespace where its template is declared. [ Note: regarding qualified names in declarators, see 8.3. — end note ] [ Example:

```cpp
template<class T> class Array { void mf(); }; 
template class Array<char>; 
template void Array<int>::mf();

template<class T> void sort(Array<T>& v) { /* ... */ }
template void sort(Array<char>&); // argument is deduced here

namespace N {
    template<class T> void f(T&) { }
} 
template void N::f<int>(int&);

— end example ]

3 A declaration of a function template shall be in scope at the point of the explicit instantiation of the function template. A definition of the class or class template containing a member function template shall be in scope at the point of the explicit instantiation of the member function template. A definition of a class template or class member template shall be in scope at the point of the explicit instantiation of the class template or class member template. A definition of a class template shall be in scope at the point of an explicit instantiation of a member function or a static data member of the class template. A definition of a member class of a class template shall be in scope at the point of an explicit instantiation of the member class. If the `declaration` of the explicit instantiation names an implicitly-declared special member function (clause 12), the program is ill-formed.

4 For a given set of template parameters, if an explicit instantiation of a template appears after a declaration of an explicit specialization for that template, the explicit instantiation has no effect. Otherwise, for an explicit instantiation definition the definition of a non-exported function template, a non-exported member function template, or a non-exported member function or static data member of a class template shall be present in every translation unit in which it is explicitly instantiated.

5 An explicit instantiation of a class or function template specialization is placed in the namespace in which the template is defined. An explicit instantiation for a member of a class template is placed in the namespace where the enclosing class template is defined. An explicit instantiation for a member template is placed in the namespace where the enclosing class or class template is defined. [ Example:

```cpp
namespace N {
    template<class T> class Y { void mf() { } }; 

    template<class T> class Z { void mf() { } }; 

    template void Y::mf(); 
    template void Z::mf(); 

    — end example ]

6 A declaration of an explicitly-instantiated non-exported function template shall be in scope at the point of the explicit instantiation of the function template. A declaration of an explicitly-instantiated non-exported member function template shall be in scope at the point of the explicit instantiation of the member function template. A declaration of a non-exported function template or non-exported member function shall be in scope at the point of an explicit instantiation of the template or member function template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exported member function or static data member of a class template shall be in scope at the point of an explicit instantiation of the class template. A declaration of a non-exp
A trailing template-argument can be left unspecified in an explicit instantiation of a function template specialization or of a member function template specialization provided it can be deduced from the type of a function parameter (14.8.2).

Example:

```cpp
template<class T> class Array { /* ... */
    template<T> void sort(Array<T>& v);

    // instantiate sort(Array<int>&) - template-argument deduced
    template void sort<Array<int>&>;

    — end example ]
```

6 An explicit instantiation of that names a class template specialization also explicitly instantiates an explicit instantiation of the same kind (declaration or definition) of each of its members (not including members inherited from base classes) whose definition is visible at the point of instantiation and that has not been previously explicitly specialized in the translation unit containing the explicit instantiation, except as described below.

7 An explicit instantiation definition that names a class template specialization explicitly instantiates the class template specialization and is only an explicit instantiation definition of members whose definition is visible at the point of instantiation.

8 An explicit instantiation declaration that names a class template specialization has no effect on the class template specialization itself (except for perhaps resulting in its implicit instantiation). Except for inline functions, other explicit instantiation declarations have the effect of suppressing the implicit instantiation of the entity to which they refer. [Note: The intent is that an inline function that is the subject of an explicit instantiation declaration will still be implicitly instantiated when used so that the body can be considered for inlining, but that no out-of-line copy of the inline function would be generated in the translation unit. — end note ]

9 If an entity is the subject of both an explicit instantiation declaration and an explicit instantiation definition in the same translation unit, the definition shall follow the declaration. An entity that is the subject of an explicit instantiation declaration and that is also used in the translation unit shall be the subject of an explicit instantiation definition somewhere in the program; otherwise the program is ill-formed, no diagnostic required. [Note: This rule does apply to inline functions even though an explicit instantiation declaration of such an entity has no other normative effect. This is needed to ensure that if the address of an inline function is taken in a translation unit in which the implementation chose to suppress the out-of-line body, another translation unit will supply the body. — end note ] An explicit instantiation declaration shall not name a specialization of a template with internal linkage.
14.7 Template instantiation and specialization

The usual access checking rules do not apply to names used to specify explicit instantiations. [Note: In particular, the template arguments and names used in the function declarator (including parameter types, return types and exception specifications) may be private types or objects which would normally not be accessible and the template may be a member template or member function which would not normally be accessible. — end note]

An explicit instantiation does not constitute a use of a default argument, so default argument instantiation is not done. [Example:

```cpp
char* p = 0;
template<class T> T g(T = &p);
template int g<int>(int);
// OK even though &p isn't an int.
```
— end example]

14.7.3 Explicit specialization

An explicit specialization of any of the following:

- function template
- class template
- member function of a class template
- static data member of a class template
- member class of a class template
- member class template of a class template
- member function template of a class template

can be declared by a declaration introduced by `template<>`; that is:

```cpp
   explicit-specialization:
   template < > declaration
```

[Example:

```cpp
   template<class T> class stream;
   template<> class stream<char> { /* ... */ };
   template<class T> class Array { /* ... */ };
   template<class T> void sort(Array<T>& v) { /* ... */ }
   template<> void sort<char*>(Array<char*>&) ;
```

Given these declarations, `stream<char>` will be used as the definition of streams of `char`s; other streams will be handled by class template specializations instantiated from the class template. Similarly, `sort<char*>` will be used as the sort function for arguments of type `Array<char*>`; other `Array` types will be sorted by functions generated from the template. — end example]

An explicit specialization shall be declared in the namespace of which the template is a member, or, for member templates, in the namespace of which the enclosing class or enclosing class template is a member. An explicit specialization
of a member function, member class or static data member of a class template shall be declared in the namespace of which the class template is a member. Such a declaration may also be a definition. If the declaration is not a definition, the specialization may be defined later (7.3.1.2).

2 A declaration of a function template or class template being explicitly specialized shall be in scope at the point of declaration of an explicit specialization. [Note: a declaration, but not a definition of the template is required. —end note] The definition of a class or class template shall be in scope at the point of declaration of an explicit specialization for a member template of the class or class template. [Example:

```cpp
template<> class X<int> { /* ... */ };       // error: X not a template

template<class T> class X;

template<> class X<char*> { /* ... */ };     // OK: X is a template
```
— end example ]

3 A member function, a member class or a static data member of a class template may be explicitly specialized for a class specialization that is implicitly instantiated; in this case, the definition of the class template shall be in scope at the point of declaration of the explicit specialization for the member of the class template. If such an explicit specialization for the member of a class template names an implicitly-declared special member function (clause 12), the program is ill-formed.

4 A member of an explicitly specialized class is not implicitly instantiated from the member declaration of the class template; instead, the member of the class template specialization shall itself be explicitly defined. In this case, the definition of the class template explicit specialization shall be in scope at the point of declaration of the explicit specialization of the member. The definition of an explicitly specialized class is unrelated to the definition of a generated specialization. That is, its members need not have the same names, types, etc. as the members of a generated specialization. Definitions of members of an explicitly specialized class are defined in the same manner as members of normal classes, and not using the explicit specialization syntax. [Example:

```cpp
template<class T> struct A {
    void f(T) { /* ... */ }
};

template<> struct A<int> {
    void f(int);
};

void h()
{
    A<int> a;
    a.f(16);          // A<int>::f must be defined somewhere
}
```
— end example ]
If a template, a member template or the member of a class template is explicitly specialized then that specialization shall be declared before the first use of that specialization that would cause an implicit instantiation to take place, in every translation unit in which such a use occurs; no diagnostic is required. If the program does not provide a definition for an explicit specialization and either the specialization is used in a way that would cause an implicit instantiation to take place or the member is a virtual member function, the program is ill-formed, no diagnostic required. An implicit instantiation is never generated for an explicit specialization that is declared but not defined. [Example:

```cpp
template<class T> class Array { /* ... */ };  
template<class T> void sort(Array<T>& v) { /* ... */ }

void f(Array<String>& v)
{
    sort(v);  // use primary template
    // sort(Array<T>&), T is String
}

template<> void sort<String>(Array<String>& v);  // error: specialization
        // after use of primary template

template<> void sort<char*>(Array<char*>& v);  // OK: sort<char*> not yet used
```

—end example—

The placement of explicit specialization declarations for function templates, class templates, member functions of class templates, static data members of class templates, member functions of non-template classes, member classes of class templates, static data members of non-template classes, member classes of non-template classes, etc., and the placement of partial specialization declarations of class templates, member classes of non-template classes, static data members of non-template classes, etc., can affect whether a program is well-formed according to the relative positioning of the explicit specialization declarations and their points of instantiation in the translation unit as specified above and below. When writing a specialization, be careful about its location; or to make it compile will be such a trial as to kindle its self-immolation.

When a specialization for which an explicit specialization exists is used within the instantiation of an exported template, and the unspecialized template name is non-dependent in the exported template, a declaration of the explicit specialization shall be declared before the definition of the exported template, in the translation unit containing that definition. [Example:

```cpp
// file #1
#include <vector>
// Primary class template vector
export template<class T> void f(t) {
    std::vector<T>; vec;  // should match the specialization
    /* ... */
}

// file #2
#include <vector>
class B { };
// Explicit specialization of vector for vector<B>
namespace std {

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template<> class vector<B> { /* ... */};
}
template<class T> void f(T);
void g(B b) {
  f(b);  // ill-formed:
  // f<B> should refer to vector<B>, but the
  // specialization was not declared with the
  // definition of f in file #1
}

— end example ]

8 A template explicit specialization is in the scope of the namespace in which the template was defined. [Example:

namespace N {
  template<class T> class X { /* ... */};
  template<class T> class Y { /* ... */};

  template<> class X<int> { /* ... */};  // OK: specialization
  // in same namespace
  template<> class Y<double>;          // forward declare intent to
  // specialize for double
}

template<> class N::Y<double> { /* ... */};  // OK: specialization
  // in same namespace

— end example ]

9 A template-id that names a class template explicit specialization that has been declared but not defined can be used exactly like the names of other incompletely-defined classes (3.9). [Example:

template<class T> class X;  // X is a class template
template<> class X<int>;

X<int>* p;  // OK: pointer to declared class X<int>
X<int> x;   // error: object of incomplete class X<int>

— end example ]

10 A trailing template-argument can be left unspecified in the template-id naming an explicit function template specialization provided it can be deduced from the function argument type. [Example:

template<class T> class Array { /* ... */};
template<class T> void sort(Array<T>& v);

  // explicit specialization for sort(Array<int>&)
  // with deduces template-argument of type int
  template<> void sort(Array<int>&);

— end example ]
A function with the same name as a template and a type that exactly matches that of a template specialization is not an explicit specialization (14.5.5).

An explicit specialization of a function template is inline only if it is explicitly declared to be, and independently of whether its function template is. [Example:

```cpp
template<class T> void f(T) { /* ... */ }
template<class T> inline T g(T) { /* ... */ }

template<> inline void f<int>(int) { /* ... */ } // OK: inline
template<> int g<int>(int) { /* ... */ } // OK: not inline
```

— end example ]

An explicit specialization of a static data member of a template is a definition if the declaration includes an initializer; otherwise, it is a declaration. [Note: there is no syntax for the definition of a static data member of a template that requires default initialization.

```cpp
template<> X Q<int>::x;
```

This is a declaration regardless of whether X can be default initialized (8.5). — end note ]

A member or a member template of a class template may be explicitly specialized for a given implicit instantiation of the class template, even if the member or member template is defined in the class template definition. An explicit specialization of a member or member template is specified using the template specialization syntax. [Example:

```cpp
template<class T> struct A {
    void f(T);
    template<class X1> void g1(T, X1);
    template<class X2> void g2(T, X2);
    void h(T) { }
};

// specialization
template<> void A<int>::f(int);

// out of class member template definition
template<class T> template<class X1> void A<T>:::g1(T, X1) { }

// member template specialization
template<> template<class X1> void A<int>::g1(int, X1);

// member template specialization
template<> template<>
    void A<int>:::g1(int, char); // X1 deduced as char
template<> template<>
    void A<int>:::g2<char>(int, char); // X2 specified as char

// member specialization even if defined in class definition
template<> void A<int>::h(int) { }
```

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A member or a member template may be nested within many enclosing class templates. In an explicit specialization for such a member, the member declaration shall be preceded by a `template<>` for each enclosing class template that is explicitly specialized. [Example:

```c++
template<class T1> class A {
    template<class T2> class B {
        void mf();
    };
    template<> template<> class A<int>::B<double>;
    template<> template<> void A<char>::B<char>::mf();
}
```

— end example ]

In an explicit specialization declaration for a member of a class template or a member template that appears in namespace scope, the member template and some of its enclosing class templates may remain unspecialized, except that the declaration shall not explicitly specialize a class member template if its enclosing class templates are not explicitly specialized as well. In such explicit specialization declaration, the keyword `template` followed by a `template-parameter-list` shall be provided instead of the `template<>` preceding the explicit specialization declaration of the member. The types of the `template-parameters` in the `template-parameter-list` shall be the same as those specified in the primary template definition. [Example:

```c++
template <class T1> class A {
    template<class T2> class B {
        template<class T3> void mf1(T3);
        void mf2();
    };
    template <> template <class X>
    class A<int>::B {
        template <class T> void mf1(T);
    };
    template <> template <> template<class T>
    void A<int>::B<double>::mf1(T) { } // ill-formed; B<double> is specialized but
    template <class Y> template <>
    void A<Y>::B<double>::mf2() { } // its enclosing class template A is not
}
```

— end example ]

A specialization of a member function template or member class template of a non-specialized class template is itself a template.

An explicit specialization declaration shall not be a friend declaration.

Default function arguments shall not be specified in a declaration or a definition for one of the following explicit specializations:

— the explicit specialization of a function template;

Draft
14.8 Function template specializations

1 The explicit specialization of a member function template;

2 The explicit specialization of a member function of a class template where the class template specialization to which the member function specialization belongs is implicitly instantiated. [Note: default function arguments may be specified in the declaration or definition of a member function of a class template specialization that is explicitly specialized. — end note]

14.8 Function template specializations

1 A function instantiated from a function template is called a function template specialization; so is an explicit specialization of a function template. Template arguments can be explicitly specified when naming the function template specialization, deduced from the context (e.g., deduced from the function arguments in a call to the function template specialization, see 14.8.2), or obtained from default template arguments.

2 Each function template specialization instantiated from a template has its own copy of any static variable. [Example:

```c++
template<class T> void f(T* p)
{
    static T s;
    // ...
};

void g(int a, char* b)
{
    f(&a); // call f<int>(int*)
    f(&b); // call f<char*>(char**)  
}
```

Here `f<int*>(int*)` has a static variable `s` of type `int` and `f<char*>(char**)` has a static variable `s` of type `char*`. — end example]

14.8.1 Explicit template argument specification

1 Template arguments can be specified when referring to a function template specialization by qualifying the function template name with the list of template-arguments in the same way as template-arguments are specified in uses of a class template specialization. [Example:

```c++
template<class T> void sort(Array<T>& v);
void f(Array<dcomplex>& cv, Array<int>& ci)
{
    sort<dcomplex>(cv); // sort(Array<dcomplex>&)
    sort<int>(ci); // sort(Array<int>&)
}
```

and

```c++
template<class U, class V> U convert(V v);
void g(double d)
{
    int i = convert<int,double>(d); // convert(double)
}
```
char c = convert<char,double>(d);      // char convert(double)
}

— end example ]

2 A template argument list may be specified when referring to a specialization of a function template

— when a function is called,
— when the address of a function is taken, when a function initializes a reference to function, or when a pointer to
  member function is formed,
— in an explicit specialization,
— in an explicit instantiation, or
— in a friend declaration.

3 Trailing template arguments that can be deduced (14.8.2) or obtained from default template-arguments may be omitted
  from the list of explicit template-arguments. If all of the template arguments can be deduced, they may all be omitted;
  in this case, the empty template argument list <> itself may also be omitted. In contexts where deduction is done and
  fails, or in contexts where deduction is not done, if a template argument list is specified and it, along with any default
  template arguments, identifies a single function template specialization, then the template-id is an lvalue for the function
  template specialization. [Example:

  template<class X, class Y> X f(Y);
  void g()
  {
    int i = f<int>(5.6);         // Y is deduced to be double
    int j = f(5.6);              // ill-formed: X cannot be deduced
    f<void>(f<int, bool>);      // Y for outer f deduced to be
                               // int (*)(bool)
    f<void>(f<int>);            // ill-formed: f<int> does not denote a
                               // single function template specialization
  }

  — end example ]

4 [ Note: An empty template argument list can be used to indicate that a given use refers to a specialization of a function
  template even when a normal (i.e., non-template) function is visible that would otherwise be used. For example:

  template <class T> int f(T);     // #1
  int f(int);                     // #2
  int k = f(1);                   // uses #2
  int l = f<>();                   // uses #1

  — end note ]

5 Template arguments that are present shall be specified in the declaration order of their corresponding template-parameters. The template argument list shall not specify more template-arguments than there are corresponding template-parameters. [Example:
template<class X, class Y, class Z> X f(Y,Z);
void g()
{
  f<int,char*,double>("aa",3.0);
  f<int,char*>("aa",3.0); // Z is deduced to be double
  f<int>("aa",3.0);       // Y is deduced to be char*, and
                      // Z is deduced to be double
  f("aa",3.0);            // error: X cannot be deduced
}
— end example ]

6 Implicit conversions (clause 4) will be performed on a function argument to convert it to the type of the corresponding function parameter if the parameter type contains no template-parameters that participate in template argument deduction. [ Note: template parameters do not participate in template argument deduction if they are explicitly specified. For example,

\[
\text{template<class T> void f(T);} \]

7 [ Note: because the explicit template argument list follows the function template name, and because conversion member function templates and constructor member function templates are called without using a function name, there is no way to provide an explicit template argument list for these function templates. — end note ]

8 [ Note: For simple function names, argument dependent lookup (3.4.2) applies even when the function name is not visible within the scope of the call. This is because the call still has the syntactic form of a function call (3.4.1). But when a function template with explicit template arguments is used, the call does not have the correct syntactic form unless there is a function template with that name visible at the point of the call. If no such name is visible, the call is not syntactically well-formed and argument-dependent lookup does not apply. If some such name is visible, argument dependent lookup applies and additional function templates may be found in other namespaces. [ Example:]
A::f<3>(b);  // well-formed
C::f<3>(b);   // ill-formed; argument dependent lookup
              // applies only to unqualified names
using C::f;
f<3>(b);      // well-formed because C::f is visible; then
              // A::f is found by argument dependent lookup
}

— end example ] — end note ]

14.8.2 Template argument deduction [temp.deduct]

1 When a function template specialization is referenced, all of the template arguments must have values. The values can be
explicitly specified or, in some cases, be deduced from the use or obtained from default template-arguments. [ Example:

```c
void f(Array<dcomplex>& cv, Array<int>& ci)
{
  sort(cv);  // call sort(Array<dcomplex>&)
  sort(ci);  // call sort(Array<int>&)
}
```

and

```c
void g(double d)
{
  int i = convert<int>(d);  // call convert<int,double>(double)
  int c = convert<char>(d); // call convert<char,double>(double)
}
```

— end example ]

2 When an explicit template argument list is specified, the template arguments must be compatible with the template
parameter list and must result in a valid function type as described below; otherwise type deduction fails. Specifically,
the following steps are performed when evaluating an explicitly specified template argument list with respect to a given
function template:

— The specified template arguments must match the template parameters in kind (i.e., type, non-type, template), and
  there must not be more arguments than there are parameters; otherwise type deduction fails.

— Non-type arguments must match the types of the corresponding non-type template parameters, or must be con-
  vertible to the types of the corresponding non-type parameters as specified in 14.3.2, otherwise type deduction
  fails.

— All references in the function type of the function template to the corresponding template parameters are replaced
  by the specified template argument values. If a substitution in a template parameter or in the function type
  of the function template results in an invalid type, type deduction fails. [ Note: The equivalent substitution in
  exception specifications is done only when the function is instantiated, at which point a program is ill-formed if
  the substitution results in an invalid type. ] Type deduction may fail for the following reasons:

— Attempting to create an array with an element type that is void, a function type, a reference type, or an
  abstract class type, or attempting to create an array with a size that is zero or negative. [ Example:

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template <class T> int f(T[5]);
int I = f<int>(0);
int j = f<void>(0); // invalid array

— end example ]

— Attempting to use a type that is not a class type in a qualified name. [ Example:

    template <class T> int f(typename T::B*);
    int i = f<int>(0);

    — end example ]

— Attempting to use a type in a nested-name-specifier of a qualified-id when that type does not contain the specified member, or
— the specified member is not a type where a type is required, or
— the specified member is not a template where a template is required, or
— the specified member is not a non-type where a non-type is required.

[ Example:

    template <int I> struct X { }; 
    template <template <class T> class> struct Z { }; 
    template <class T> void f(typename T::Y*){} 
    template <class T> void g(X<T::N>*){} 
    template <class T> void h(Z<T::template TT>*){} 
    struct A {}; 
    struct B { int Y; }; 
    struct C {
      typedef int N; 
    }; 
    struct D {
      typedef int TT; 
    };

    int main()
    {
      // Deduction fails in each of these cases:
      f<A>(0); // k does not contain a member Y 
      f<B>(0); // The Y member of B is not a type 
      g<C>(0); // The N member of C is not a non-type 
      h<D>(0); // The TT member of D is not a template 
    }

    — end example ]

— Attempting to create a pointer to reference type.
— Attempting to create a reference to void.
— Attempting to create “pointer to member of T” when T is not a class type. [ Example:
template <class T> int f(int T::*);
int i = f<int>(0);

— end example ]

— Attempting to give an invalid type to a non-type template parameter. [ Example:

    template <class T, T> struct S {}; 
    template <class T> int f(S<T, T>()*); 
    struct X {}; 
    int i0 = f<X>(0);

— end example ]

— Attempting to perform an invalid conversion in either a template argument expression, or an expression used 
in the function declaration. [ Example:

    template <class T, T*> int f(int); 
    int i2 = f<int,1>(0); // can’t conv 1 to int*

— end example ]

— Attempting to create a function type in which a parameter has a type of void, or in which the return type is 
a function type or array type.

3 After this substitution is performed, the function parameter type adjustments described in 8.3.5 are performed. [ Example: A parameter type of “void ()(const int, int [5])” becomes “void(*) (int, int*)”. — end example ] [ Note: A top-level qualifier in a function parameter declaration does not affect the function type but still affects the type of the function parameter variable within the function. — end note ] [ Example:

    template <class T> void f(T t); 
    template <class X> void g(const X x); 
    template <class Z> void h(Z, Z*);

int main()
{
   // #1: function type is f(int). t is non const
   f<int>(1);

   // #2: function type is f(int). t is const
   f<const int>(1);

   // #3: function type is g(int). x is const
   g<int>(1);

   // #4: function type is g(int). x is const
   g<const int>(1);

   // #5: function type is h(int, const int*)
   h<const int>(1,0);
}

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4 [Note: \( f<int>(1) \) and \( f<const \text{ int}>(1) \) call distinct functions even though both of the functions called have the same function type. — end note]

5 The resulting substituted and adjusted function type is used as the type of the function template for template argument deduction. If a template argument has not been deduced, its default template argument, if any, is used. [Example:

```cpp
template <class T, class U = double>
void f(T t = 0, U u = 0);

void g()
{
    f(1, 'c'); // f<int,char>(1,'c')
    f(1); // f<int,double>(1,0)
    f(); // error: T cannot be deduced
    f<int>(); // f<int,double>(0,0)
    f<int,char>(); // f<int,char>(0,0)
}
```

— end example]

When all template arguments have been deduced or obtained from default template arguments, all uses of template parameters in non-deduced contexts are replaced with the corresponding deduced or default argument values. If the substitution results in an invalid type, as described above, type deduction fails.

6 Except as described above, the use of an invalid value shall not cause type deduction to fail. [Example: In the following example 1000 is converted to \texttt{signed char} and results in an implementation-defined value as specified in (4.7). In other words, both templates are considered even though 1000, when converted to \texttt{signed char}, results in an implementation-defined value.

```cpp
template <int> int f(int);
template <signed char> int f(int);
int i1 = f<1>(0); // ambiguous
int i2 = f<1000>(0); // ambiguous
```

— end example]

14.8.2.1 Deducing template arguments from a function call [temp.deduct.call]

1 Template argument deduction is done by comparing each function template parameter type (call it \( P \)) with the type of the corresponding argument of the call (call it \( A \)) as described below.

2 If \( P \) is not a reference type:

   — If \( A \) is an array type, the pointer type produced by the array-to-pointer standard conversion (4.2) is used in place of \( A \) for type deduction; otherwise,

   — If \( A \) is a function type, the pointer type produced by the function-to-pointer standard conversion (4.3) is used in place of \( A \) for type deduction; otherwise,

   — If \( A \) is a cv-qualified type, the top level cv-qualifiers of \( A \)'s type are ignored for type deduction.
If \( P \) is a cv-qualified type, the top level cv-qualifiers of \( P \)'s type are ignored for type deduction. If \( P \) is a reference type, the type referred to by \( P \) is used for type deduction.

In general, the deduction process attempts to find template argument values that will make the deduced \( A \) identical to \( A \) (after the type \( A \) is transformed as described above). However, there are three cases that allow a difference:

- If the original \( P \) is a reference type, the deduced \( A \) (i.e., the type referred to by the reference) can be more cv-qualified than \( A \).
- \( A \) can be another pointer or pointer to member type that can be converted to the deduced \( A \) via a qualification conversion (4.4).
- If \( P \) is a class, and \( P \) has the form \( \text{template-id} \), then \( A \) can be a derived class of the deduced \( A \). Likewise, if \( P \) is a pointer to a class of the form \( \text{template-id} \), \( A \) can be a pointer to a derived class pointed to by the deduced \( A \).

These alternatives are considered only if type deduction would otherwise fail. If they yield more than one possible deduced \( A \), the type deduction fails. [Note: if a \( \text{template-parameter} \) is not used in any of the function parameters of a function template, or is used only in a non-deduced context, its corresponding \( \text{template-argument} \) cannot be deduced from a function call and the \( \text{template-argument} \) must be explicitly specified. — end note ]

When \( P \) is a function type, pointer to function type, or pointer to member function type:

- If the argument is an overload set containing one or more function templates, the parameter is treated as a non-deduced context.
- If the argument is an overload set (not containing function templates), trial argument deduction is attempted using each of the members of the set. If deduction succeeds for only one of the overload set members, that member is used as the argument value for the deduction. If deduction succeeds for more than one member of the overload set the parameter is treated as a non-deduced context.

[Example:

```
// Only one function of an overload set matches the call so the function
// parameter is a deduced context.
template <class T> int f(T (*p)(T));
int g(int);
int g(char);
int i = f(g); // calls f(int (*)(int))
```

— end example ]

[Example:

```
// Ambiguous deduction causes the second function parameter to be a
// non-deduced context.
template <class T> int f(T, T (*p)(T));
int g(int);
char g(char);
int i = f(1, g); // calls f(int, int (*)(int))
```

— end example ]

[Example:
14.8 Function template specializations

// The overload set contains a template, causing the second function
// parameter to be a non-deduced context.
template <class T> int f(T, T (*p)(T));
char g(char);
template <class T> T g(T);
int i = f(1, g);  // calls f(int, int (*)(int))

— end example

14.8.2.2 Deducing template arguments taking the address of a function template

Template arguments can be deduced from the type specified when taking the address of an overloaded function (13.4). The function template’s function type and the specified type are used as the types of P and A, and the deduction is done as described in 14.8.2.5.

14.8.2.3 Deducing conversion function template arguments

Template argument deduction is done by comparing the return type of the template conversion function (call it P) with the type that is required as the result of the conversion (call it A) as described in 14.8.2.5.

If A is not a reference type:

— If P is an array type, the pointer type produced by the array-to-pointer standard conversion (4.2) is used in place of P for type deduction; otherwise,
— If P is a function type, the pointer type produced by the function-to-pointer standard conversion (4.3) is used in place of P for type deduction; otherwise,
— If P is a cv-qualified type, the top level cv-qualifiers of P’s type are ignored for type deduction.

If A is a cv-qualified type, the top level cv-qualifiers of A’s type are ignored for type deduction. If A is a reference type, the type referred to by A is used for type deduction. If P is a reference type, the type referred to by P is used for type deduction.

In general, the deduction process attempts to find template argument values that will make the deduced A identical to A. However, there are two cases that allow a difference:

— If the original A is a reference type, A can be more cv-qualified than the deduced A (i.e., the type referred to by the reference)
— The deduced A can be another pointer or pointer to member type that can be converted to A via a qualification conversion.

These alternatives are considered only if type deduction would otherwise fail. If they yield more than one possible deduced A, the type deduction fails.

When the deduction process requires a qualification conversion for a pointer or pointer to member type as described above, the following process is used to determine the deduced template argument values:

If A is a type

\[ cv_{1,0} \text{ “pointer to ...” } cv_{1,n-1} \text{ “pointer to” } cv_{1,n}T \]
and P is a type

\[cv_{2,0} \text{ “pointer to ...” } cv_{2,n-1} \text{ “pointer to” } cv_{2,n}T2\]

The cv-unqualified T1 and T2 are used as the types of A and P respectively for type deduction. [Example:

```cpp
struct A {
    template <class T> operator T***();
};
A a;
const int * const * const * p1 = a;    // T is deduced as int, not const int
```

— end example ]

### 14.8.2.4 Deducing template arguments during partial ordering [temp.deduct.partial]

Template argument deduction is done by comparing certain types associated with the two function templates being compared.

Two sets of types are used to determine the partial ordering. For each of the templates involved there is the original function type and the transformed function type. [Note: the creation of the transformed type is described in 14.5.5.2. — end note ] The deduction process uses the transformed type as the argument template and the original type of the other template as the parameter template. This process is done twice for each type involved in the partial ordering comparison: once using the transformed template-1 as the argument template and template-2 as the parameter template and again using the transformed template-2 as the argument template and template-1 as the parameter template.

The types used to determine the ordering depend on the context in which the partial ordering is done:

- In the context of a function call, the function parameter types are used.
- In the context of a call to a conversion operator, the return types of the conversion function templates are used.
- In other contexts (14.5.5.2) the function template’s function type is used.

Each type from the parameter template and the corresponding type from the argument template are used as the types of P and A.

Before the partial ordering is done, certain transformations are performed on the types used for partial ordering:

- If P is a reference type, P is replaced by the type referred to.
- If A is a reference type, A is replaced by the type referred to.

If both P and A were reference types (before being replaced with the type referred to above), determine which of the two types (if any) is more cv-qualified than the other; otherwise the types are considered to be equally cv-qualified for partial ordering purposes. The result of this determination will be used below.

Remove any top-level cv-qualifiers:

- If P is a cv-qualified type, P is replaced by the cv-unqualified version of P.
- If A is a cv-qualified type, A is replaced by the cv-unqualified version of A.
Using the resulting types \( P \) and \( A \) the deduction is then done as described in 14.8.2.5. If deduction succeeds for a given type, the type from the argument template is considered to be at least as specialized as the type from the parameter template.

If, for a given type, deduction succeeds in both directions (i.e., the types are identical after the transformations above) and if the type from the argument template is more cv-qualified than the type from the parameter template (as described above) that type is considered to be more specialized than the other. If neither type is more cv-qualified than the other then neither type is more specialized than the other.

If for each type being considered a given template is at least as specialized for all types and more specialized for some set of types and the other template is not more specialized for any types or is not at least as specialized for any types, then the given template is more specialized than the other template. Otherwise, neither template is more specialized than the other.

In most cases, all template parameters must have values in order for deduction to succeed, but for partial ordering purposes a template parameter may remain without a value provided it is not used in the types being used for partial ordering. [Note: a template parameter used in a non-deduced context is considered used. — end note] [Example:

```cpp
template <class T> T f(int);       // #1
template <class T, class U> T f(U); // #2
void g() {
    f<int>(1);  // Calls #1
}
```

— end example ]

### 14.8.2.5 Deducing template arguments from a type

Template arguments can be deduced in several different contexts, but in each case a type that is specified in terms of template parameters (call it \( P \)) is compared with an actual type (call it \( A \)), and an attempt is made to find template argument values (a type for a type parameter, a value for a non-type parameter, or a template for a template parameter) that will make \( P \), after substitution of the deduced values (call it the deduced \( A \)), compatible with \( A \).

In some cases, the deduction is done using a single set of types \( P \) and \( A \), in other cases, there will be a set of corresponding types \( P \) and \( A \). Type deduction is done independently for each \( P/A \) pair, and the deduced template argument values are then combined. If type deduction cannot be done for any \( P/A \) pair, or if for any pair the deduction leads to more than one possible set of deduced values, or if different pairs yield different deduced values, or if any template argument remains neither deduced nor explicitly specified, template argument deduction fails.

A given type \( P \) can be composed from a number of other types, templates, and non-type values:

- A function type includes the types of each of the function parameters and the return type.
- A pointer to member type includes the type of the class object pointed to and the type of the member pointed to.
- A type that is a specialization of a class template (e.g., \( A<int> \)) includes the types, templates, and non-type values referenced by the template argument list of the specialization.
- An array type includes the array element type and the value of the array bound.
In most cases, the types, templates, and non-type values that are used to compose P participate in template argument deduction. That is, they may be used to determine the value of a template argument, and the value so determined must be consistent with the values determined elsewhere. In certain contexts, however, the value does not participate in type deduction, but instead uses the values of template arguments that were either deduced elsewhere or explicitly specified.

If a template parameter is used only in non-deduced contexts and is not explicitly specified, template argument deduction fails.

The non-deduced contexts are:

- The nested-name-specifier of a type that was specified using a qualified-id.
- A non-type template argument or an array bound that is an expression that references a template parameter.
- A template parameter used in the parameter type of a function parameter that has a default argument that is being used in the call for which argument deduction is being done.
- A function parameter for which argument deduction cannot be done because the associated function argument is a function, or a set of overloaded functions (13.4), and one or more of the following apply:
  - more than one function matches the function parameter type (resulting in an ambiguous deduction), or
  - no function matches the function parameter type, or
  - the set of functions supplied as an argument contains one or more function templates.
- An array bound that is an expression that references a template-parameter.

When a type name is specified in a way that includes a non-deduced context, all of the types that comprise that type name are also non-deduced. However, a compound type can include both deduced and non-deduced types. [Example: If a type is specified as A<T>::B<T2>, both T and T2 are non-deduced. Likewise, if a type is specified as A<I+J>::X<T>, I, J, and T are non-deduced. If a type is specified as void f(typename A<T>::B, A<T>), the T in A<T>::B is non-deduced but the T in A<T> is deduced. — end example]

Here is an example in which different parameter/argument pairs produce inconsistent template argument deductions:

```cpp
template<class T> void f(T x, T y) { /* ... */ }  
struct A { /* ... */ };  
struct B : A { /* ... */ };  
int g(A a, B b)  
{  
f(a,b); // error: T could be A or B  
f(b,a); // error: T could be A or B  
f(a,a); // OK: T is A  
f(b,b); // OK: T is B  
}
```

Here is an example where two template arguments are deduced from a single function parameter/argument pair. This can lead to conflicts that cause type deduction to fail:

```cpp
template <class T, class U> void f(T (*)(T, U, U));  
int g1( int, float, float);  
```

Draft
14.8 Function template specializations

```cpp
char g2( int, float, float);
int g3( int, char, float);

void r()
{
    f(g1);       // OK: T is int and U is float
    f(g2);       // error: T could be char or int
    f(g3);       // error: U could be char or float
}
```

Here is an example where a qualification conversion applies between the argument type on the function call and the
deduced template argument type:

```cpp
template<class T> void f(const T*) {}
int *p;
void s()
{
    f(p);       // f(const int*)
}
```

Here is an example where the template argument is used to instantiate a derived class type of the corresponding function
parameter type:

```cpp
template <class T> struct B { };  
template <class T> struct D : public B<T> {};  
struct D2 : public B<int> {};  
template <class T> void f(B<T>&){}
void t()
{
    D<int> d;
    D2 d2;
    f(d);       // calls f(B<int>&)
    f(d2);      // calls f(B<int>&)
}
```

— end example ]

8 A template type argument T, a template template argument TT or a template non-type argument i can be deduced if P
and A have one of the following forms:

T  
cu-list T  
T*  
T&  
T[integer-constant]  
template-name<T>  (where template-name refers to a class template)

type(T)  
T()  
T(T)  
T type::*  
type T::*
343  Templates  14.8  Function template specializations

\begin{verbatim}
T T::*
T (type::*())
  type (T::*())
  type (type::*)(T)
  type (T::*)(T)
  T (type::*)(T)
  T (T::*())
  T (T::*)(T)
  type [i]
  template-name<i> (where template-name refers to a class template)
  TT<T>
  TT<i>
  TT<> \\
\end{verbatim}

where \((T)\) represents argument lists where at least one argument type contains a \(T\), and \(()\) represents argument lists where no parameter contains a \(T\). Similarly, \(<T>\) represents template argument lists where at least one argument contains a \(T\), \(<i>\) represents template argument lists where at least one argument contains an \(i\) and \(<\>\) represents template argument lists where no argument contains a \(T\) or an \(i\).

9  These forms can be used in the same way as \(T\) is for further composition of types. \[ Example: \]

\begin{verbatim}
X<int> (*)(char[6])
\end{verbatim}

is of the form

\begin{verbatim}
  template-name<T> (*)(type[i])
\end{verbatim}

which is a variant of

\begin{verbatim}
  type (*)(T)
\end{verbatim}

where \(type\) is \(X<int>\) and \(T\) is \(char[6]\). \textit{— end example}]

10  Template arguments cannot be deduced from function arguments involving constructs other than the ones specified above.

11  A template type argument cannot be deduced from the type of a non-type template-argument.  

12  \[ Example: \]

\begin{verbatim}
template<class T, T i> void f(double a[10][i]);
int v[10][20];
f(v);
\end{verbatim}

// error: argument for template-parameter \(T\) cannot be deduced

\textit{— end example}]

13  \[ Note: except for reference and pointer types, a major array bound is not part of a function parameter type and cannot be deduced from an argument: \]

\begin{verbatim}
template<int i> void f1(int a[10][i]);
template<int i> void f2(int a[i][20]);
template<int i> void f3(int (&a)[i][20]);
\end{verbatim}

Draft
14.8 Function template specializations

void g()
{
    int v[10][20];
    f1(v);          // OK: \( i \) deduced to be 20
    f1<20>(v);     // OK
    f2(v);         // error: cannot deduce template-argument \( i \)
    f2<10>(v);     // OK
    f3(v);         // OK: \( i \) deduced to be 10
}

If, in the declaration of a function template with a non-type template parameter, the non-type template parameter is used in an expression in the function parameter list, the expression is a non-deduced context. [Example:

```cpp
template <int i> class A { /* ... */ };
template <int i> void g(A<i+1>);
template <int i> void f(A<i>, A<i+1>);
void k() {
    A<1> a1;
    A<2> a2;
    g(a1);          // error: deduction fails for expression i+1
    g<0>(a1);       // OK
    f(a1, a2);      // OK
}
```

— end example ] — end note ] [Note: template parameters do not participate in template argument deduction if they are used only in non-deduced contexts. For example,

```cpp
template<int i, typename T>
T deduce(typename A<T>::X x,     // T is not deduced here
         T t,          // but T is deduced here
         typename B<i>::Y y);  // i is not deduced here
A<int> a;
B<77> b;

int x = deduce<77>(a.xm, 62, y.ym);     // T is deduced to be int, a.xm must be convertible to
// A<int>::X
// i is explicitly specified to be 77, y.ym must be convertible
// to B<77>::Y
```

— end note ]

15 If, in the declaration of a function template with a non-type template-parameter, the non-type template-parameter is used in an expression in the function parameter-list and, if the corresponding template-argument is deduced, the template-argument type shall match the type of the template-parameter exactly, except that a template-argument deduced from an array bound may be of any integral type.\(^{(138)}\) [Example:

```cpp
template<int i> class A { /* ... */ };
```

\(^{(138)}\) Although the template-argument corresponding to a template-parameter of type bool may be deduced from an array bound, the resulting value will always be true because the array bound will be non-zero.
template<short s> void f(A<s>);
void k1() {
  A<1> a;
  f(a);  // error: deduction fails for conversion from int to short
  f<1>(a);  // OK
}

template<const short cs> class B { }; template<short s> void h(B<s>);
void k2() {
  B<1> b;
  g(b);  // OK: cv-qualifiers are ignored on template parameter types
}

— end example ]

A template-argument can be deduced from a function, pointer to function, or pointer to member function type. [ Example:

    template<class T> void f(void(*)(T,int));
    template<class T> void foo(T,int);
    void g(int,int);
    void g(char,int);
    void h(int,int,int);
    void h(char,int);
    int m()
    {
      f(&g);  // error: ambiguous
      f(&h);  // OK: void h(char,int) is a unique match
      f(&foo);  // error: type deduction fails because foo is a template
    }

— end example ]

A template type-parameter cannot be deduced from the type of a function default argument. [ Example:

    template <class T> void f(T = 5, T = 7);
    void g()
    {
      f(1);  // OK: call f<int>(1,7)
      f();  // error: cannot deduce T
      f<int>();  // OK: call f<int>(5,7)
    }

— end example ]

The template-argument corresponding to a template template-parameter is deduced from the type of the template-argument of a class template specialization used in the argument list of a function call. [ Example:

    template <template <class T> class X> struct A { };
14.8 Function template specializations

```
template <template <class T> class X> void f(A<X>) { }
template<class T> struct B { }; 
A<B> ab;
f(ab); // calls f(A<B>)
```

— end example ]

[ Note: a default template-argument cannot be specified in a function template declaration or definition; therefore default template-arguments cannot be used to influence template argument deduction. — end note ]

14.8.3 Overload resolution

1 A function template can be overloaded either by (non-template) functions of its name or by (other) function templates of the same name. When a call to that name is written (explicitly, or implicitly using the operator notation), template argument deduction (14.8.2) and checking of any explicit template arguments (14.3) are performed for each function template to find the template argument values (if any) that can be used with that function template to instantiate a function template specialization that can be invoked with the call arguments. For each function template, if the argument deduction and checking succeeds, the template-arguments (deduced and/or explicit) are used to instantiate a single function template specialization which is added to the candidate functions set to be used in overload resolution. If, for a given function template, argument deduction fails, no such function is added to the set of candidate functions for that template. The complete set of candidate functions includes all the function templates instantiated in this way and all of the non-template overloaded functions of the same name. The function template specializations are treated like any other functions in the remainder of overload resolution, except as explicitly noted in 13.3.3.139)

[ Example:
```
template<class T> T max(T a, T b) { return a>b?a:b; }

void f(int a, int b, char c, char d)
{
  int m1 = max(a,b); // max(int, int)
  char m2 = max(c,d); // max(char, char)
  int m3 = max(a,c); // error: cannot generate max(int,char)
}
```

2 Adding the non-template function
```
  int max(int,int);
```
to the example above would resolve the third call, by providing a function that could be called for max(a,c) after using the standard conversion of char to int for c.

3 Here is an example involving conversions on a function argument involved in template-argument deduction:

139) The parameters of function template specializations contain no template parameter types. The set of conversions allowed on deduced arguments is limited, because the argument deduction process produces function templates with parameters that either match the call arguments exactly or differ only in ways that can be bridged by the allowed limited conversions. Non-deduced arguments allow the full range of conversions. Note also that 13.3.3 specifies that a non-template function will be given preference over a template specialization if the two functions are otherwise equally good candidates for an overload match.

Draft
Here is an example involving conversions on a function argument not involved in template-parameter deduction:

```cpp
template<class T> void f(T*, int);  // #1
template<class T> void f(T, char);   // #2

void h(int* pi, int i, char c)
{
    f(pi, i);  // #1: f<int*>(pi, i)
    f(pi, c);  // #2: f<int*>(pi, c)
    f(i, c);   // #2: f<int>(i, c);
    f(i, i);   // #2: f<int>(i, char(i))
}
```

— end example ]

Only the signature of a function template specialization is needed to enter the specialization in a set of candidate functions. Therefore only the function template declaration is needed to resolve a call for which a template specialization is a candidate.  [ Example:

```cpp
template<class T> void f(T);  // declaration

void g()
{
    f("Annemarie");  // call of f<const char*>  
}
```

The call of f is well-formed even if the template f is only declared and not defined at the point of the call. The program will be ill-formed unless a specialization for f<const char*>, either implicitly or explicitly generated, is present in some translation unit. — end example ]
Chapter 15  Exception handling

1 Exception handling provides a way of transferring control and information from a point in the execution of a program to an exception handler associated with a point previously passed by the execution. A handler will be invoked only by a throw-expression invoked in code executed in the handler’s try block or in functions called from the handler’s try block.

try-block:
    try compound-statement handler-seq
function-try-block:
    try ctor-initializer_opt function-body handler-seq
handler-seq:
    handler handler-seq_opt
handler:
    catch (exception-declaration) compound-statement
exception-declaration:
    type-specifier-seq declarator
    type-specifier-seq abstract-declarator
    type-specifier-seq
    ...
throw-expression:
    throw assignment-expression_opt

2 A try-block is a statement (clause 6). A throw-expression is of type void. Code that executes a throw-expression is said to “throw an exception;” code that subsequently gets control is called a “handler.” [Note: within this clause “try block” is taken to mean both try-block and function-try-block. — end note]

3 A goto or switch statement shall not be used to transfer control into a try block or into a handler. [Example:

```c
void f() {
    goto 11;  // Ill-formed
    goto 12;  // Ill-formed
    try {
        goto 11;  // OK
        goto 12;  // Ill-formed
    } catch (...) {
        12;  // Ill-formed
        goto 11;  // OK
    }
```
A goto, break, return, or continue statement can be used to transfer control out of a try block or handler. When this happens, each variable declared in the try block will be destroyed in the context that directly contains its declaration. [Example:

```cpp
lab: try {
    T1 t1;
    try {
        T2 t2;
        if (condition)
            goto lab;
    } catch(...) { /* handler 2 */ }
    } catch(...) { /* handler 1 */ }
```

Here, executing goto lab; will destroy first t2, then t1, assuming the `condition` does not declare a variable. Any exception raised while destroying t2 will result in executing `handler 2`; any exception raised while destroying t1 will result in executing `handler 1`. — end example]

A function-try-block associates a `handler-seq` with the `ctor-initializer`, if present, and the `function-body`. An exception thrown during the execution of the initializer expressions in the `ctor-initializer` or during the execution of the `function-body` transfers control to a handler in a `function-try-block` in the same way as an exception thrown during the execution of a `try-block` transfers control to other handlers. [Example:

```cpp
int f(int);
class C {
    int i;
    double d;
public:
    C(int, double);
};
C::C(int ii, double id)
try
    : i(f(ii)), d(id)
    {
        // constructor function body
    }
catch (...)
    {
        // handles exceptions thrown from the ctor-initializer
        // and from the constructor function body
    }
```

— end example ]

15.1 Throwing an exception [except.throw]

1 Throwing an exception transfers control to a handler. An object is passed and the type of that object determines which handlers can catch it. [Example:
throw "Help!";

can be caught by a handler of const char* type:

```cpp
try {
    // ...
} catch(const char* p) {
    // handle character string exceptions here
}
```

and

```cpp
class Overflow {
    // ...
    public:
    Overflow(char,double,double);
};
```

```cpp
void f(double x) {
    // ...
    throw Overflow('+',x,3.45e107);
}
```

can be caught by a handler for exceptions of type Overflow

```cpp
try {
    // ...
    f(1.2);
    // ...
} catch(Overflow& oo) {
    // handle exceptions of type Overflow here
}
```

— end example ]

2 When an exception is thrown, control is transferred to the nearest handler with a matching type (15.3); “nearest” means the handler for which the compound-statement, ctor-initializer, or function-body following the try keyword was most recently entered by the thread of control and not yet exited.

3 A throw-expression initializes a temporary object, called the exception object, the type of which is determined by removing any top-level cv-qualifiers from the static type of the operand of throw and adjusting the type from “array of T” or “function returning T” to “pointer to T” or “pointer to function returning T”, respectively. [ Note: the temporary object created for a throw-expression that is a string literal is never of type char* or wchar_t*; that is, the special conversions for string literals from the types “array of const char” and “array of const wchar_t” to the types “pointer to char” and “pointer to wchar_t”, respectively (4.2), are never applied to a throw-expression. — end note ] The temporary is an lvalue and is used to initialize the variable named in the matching handler (15.3). The type of the throw-expression shall not be an incomplete type, or a pointer to an incomplete type other than (possibly cv-qualified) void. Except for
these restrictions and the restrictions on type matching mentioned in 15.3, the operand of `throw` is treated exactly as a function argument in a call (5.2.2) or the operand of a return statement.

4 The memory for the temporary copy of the exception being thrown is allocated in an unspecified way, except as noted in 3.7.3.1. The temporary persists as long as there is a handler being executed for that exception. In particular, if a handler exits by executing a `throw` statement, that passes control to another handler for the same exception, so the temporary remains. When the last remaining active handler for the exception exits by any means other than `throw`; the temporary object is destroyed and the implementation may deallocate the memory for the temporary object; any such deallocation is done in an unspecified way. The destruction occurs immediately after the destruction of the object declared in the `exception-declaration` in the handler.

5 If the use of the temporary object can be eliminated without changing the meaning of the program except for the execution of constructors and destructors associated with the use of the temporary object (12.2), then the exception in the handler can be initialized directly with the argument of the `throw` expression. When the thrown object is a class object, and the copy constructor used to initialize the temporary copy is not accessible, the program is ill-formed (even when the temporary object could otherwise be eliminated). Similarly, if the destructor for that object is not accessible, the program is ill-formed. When the thrown object is a class object, the copy constructor and the destructor shall be accessible, even if the copy operation is elided (12.8).

6 An exception is considered caught when a handler for that exception becomes active (15.3). [Note: an exception can have active handlers and still be considered uncaught if it is rethrown. —end note]

7 A `throw-expression` with no operand rethrows the currently handled exception (15.3). The exception is reactivated with the existing temporary; no new temporary exception object is created. The exception is no longer considered to be caught; therefore, the value of `std::uncaught_exception()` will again be `true`. [Example: code that must be executed because of an exception yet cannot completely handle the exception can be written like this:

```cpp
try {
    // ...
}
catch (...) {  // catch all exceptions
    // respond (partially) to exception
    throw;  // pass the exception to some other handler
}
```

—end example ]

8 If no exception is presently being handled, executing a `throw-expression` with no operand calls `std::terminate()` (15.5.1).

### 15.2 Constructors and destructors

1 As control passes from a `throw-expression` to a handler, destructors are invoked for all automatic objects constructed since the try block was entered. The automatic objects are destroyed in the reverse order of the completion of their construction.

2 An object that is partially constructed or partially destroyed will have destructors executed for all of its fully constructed subobjects, that is, for subobjects for which the principal constructor (12.6.2) has completed execution and the destructor has not yet begun execution. Similarly, if the non-delegating constructor for an object has completed execution and a delegating constructor for that object exits with an exception, the object’s destructor will be invoked. Should a constructor
for an element of an automatic array throw an exception, only the constructed elements of that array will be destroyed. If the object or array was allocated in a new-expression, the matching deallocation function (3.7.3.2, 5.3.4, 12.5), if any, is called to free the storage occupied by the object.

3 The process of calling destructors for automatic objects constructed on the path from a try block to a throw-expression is called “stack unwinding.” [Note: If a destructor called during stack unwinding exits with an exception, std::terminate is called (15.5.1). So destructors should generally catch exceptions and not let them propagate out of the destructor. —end note]

15.3 Handling an exception [except.handle]

1 The exception-declaration in a handler describes the type(s) of exceptions that can cause that handler to be entered. The exception-declaration shall not denote an incomplete type. The exception-declaration shall not denote a pointer or reference to an incomplete type, other than void*, const void*, volatile void*, or const volatile void*. Types shall not be defined in an exception-declaration.

2 A handler of type “array of T” or “function returning T” is adjusted to be of type “pointer to T” or “pointer to function returning T”, respectively.

3 A handler is a match for an exception object of type E if
   — The handler is of type cv T or cv T& and E and T are the same type (ignoring the top-level cv-qualifiers), or
   — the handler is of type cv T or cv T& and T is an unambiguous public base class of E, or
   — the handler is of type cv1 T* cv2 and E is a pointer type that can be converted to the type of the handler by either or both of
     — a standard pointer conversion (4.10) not involving conversions to pointers to private or protected or ambiguous classes
     — a qualification conversion
   [Note: a throw-expression which is an integral constant expression of integer type that evaluates to zero does not match a handler of pointer type; that is, the null pointer constant conversions (4.10, 4.11) do not apply. —end note]

   [Example:
    
    class Matherr { /* ... */ virtual vf(); };  
    class Overflow: public Matherr { /* ... */ };  
    class Underflow: public Matherr { /* ... */ };  
    class Zerodivide: public Matherr { /* ... */ };  
    
    void f()
    {
        try {
            g();
        }
    }

    catch (Overflow oo) {
        // ...
    }
    ]
15.3 Handling an exception  

```c++
catch (Matherr mm) {
    //...
}
```

Here, the Overflow handler will catch exceptions of type Overflow and the Matherr handler will catch exceptions of type Matherr and of all types publicly derived from Matherr including exceptions of type Underflow and Zerodivide. — end example }

The handlers for a try block are tried in order of appearance. That makes it possible to write handlers that can never be executed, for example by placing a handler for a derived class after a handler for a corresponding base class.

A ... in a handler’s exception-declaration functions similarly to ... in a function parameter declaration; it specifies a match for any exception. If present, a ... handler shall be the last handler for its try block.

If no match is found among the handlers for a try block, the search for a matching handler continues in a dynamically surrounding try block.

A handler is considered active when initialization is complete for the formal parameter (if any) of the catch clause. [ Note: the stack will have been unwound at that point. — end note ] Also, an implicit handler is considered active when std::terminate() or std::unexpected() is entered due to a throw. A handler is no longer considered active when the catch clause exits or when std::unexpected() exits after being entered due to a throw.

The exception with the most recently activated handler that is still active is called the currently handled exception.

If no matching handler is found in a program, the function std::terminate() is called; whether or not the stack is unwound before this call to std::terminate() is implementation-defined (15.5.1).

Referring to any non-static member or base class of an object in the handler for a function-try-block of a constructor or destructor for that object results in undefined behavior.

The fully constructed base classes and members of an object shall be destroyed before entering the handler of a function-try-block of a constructor or destructor for that object. Similarly, if a delegating constructor for an object exits with an exception after the non-delegating constructor for that object has completed execution, the object’s destructor shall be executed before entering the handler of a function-try-block of a constructor for that object.

The scope and lifetime of the parameters of a function or constructor extend into the handlers of a function-try-block.

Exceptions thrown in destructors of objects with static storage duration or in constructors of namespace-scope objects are not caught by a function-try-block on main().

If a return statement appears in a handler of the function-try-block of a constructor, the program is ill-formed.

The currently handled exception is rethrown if control reaches the end of a handler of the function-try-block of a constructor or destructor. Otherwise, a function returns when control reaches the end of a handler for the function-try-block (6.6.3). Flowing off the end of a function-try-block is equivalent to a return with no value; this results in undefined behavior in a value-returning function (6.6.3).

When the exception-declaration specifies a class type, a copy constructor is used to initialize either the object declared in the exception-declaration or, if the exception-declaration does not specify a name, a temporary object
of that type. The object shall not have an abstract class type. The object is destroyed when the handler exits, after the destruction of any automatic objects initialized within the handler. The copy constructor and destructor shall be accessible in the context of the handler. If the copy constructor and destructor are implicitly declared (12.8), such a use in the handler causes these functions to be implicitly defined; otherwise, the program shall provide a definition for these functions.

If the use of a temporary object can be eliminated without changing the meaning of the program except for execution of constructors and destructors associated with the use of the temporary object, then the optional name can be bound directly to the temporary object specified in a throw-expression causing the handler to be executed. The copy constructor and destructor associated with the object shall be accessible even when the temporary object is eliminated if the copy operation is elided (12.8).

When the handler declares a non-constant object, any changes to that object will not affect the temporary object that was initialized by execution of the throw-expression. When the handler declares a reference to a non-constant object, any changes to the referenced object are changes to the temporary object initialized when the throw-expression was executed and will have effect should that object be rethrown.

15.4 Exception specifications

A function declaration lists exceptions that its function might directly or indirectly throw by using an exception-specification as a suffix of its declarator.

```plaintext
exception-specification:
  throw ( type-id-listopt )
```

A type denoted in an exception-specification shall not denote an incomplete type. A type denoted in an exception-specification shall not denote a pointer or reference to an incomplete type, other than void*, const void*, volatile void*, or const volatile void*.

If any declaration of a function has an exception-specification, all declarations, including the definition and an explicit specialization, of that function shall have an exception-specification with the same set of type-ids. If any declaration of a pointer to function, reference to function, or pointer to member function has an exception-specification, all occurrences of that declaration shall have an exception-specification with the same set of type-ids. In an explicit instantiation directive an exception-specification may be specified, but is not required. If an exception-specification is specified in an explicit instantiation directive, it shall have the same set of type-ids as other declarations of that function. A diagnostic is required only if the sets of type-ids are different within a single translation unit.
4 If a virtual function has an exception-specification, all declarations, including the definition, of any function that overrides that virtual function in any derived class shall only allow exceptions that are allowed by the exception-specification of the base class virtual function. [Example:

```cpp
struct B {
    virtual void f() throw (int, double);
    virtual void g();
};

struct D: B {
    void f();           // ill-formed
    void g() throw (int); // OK
};
```

The declaration of D::f is ill-formed because it allows all exceptions, whereas B::f allows only int and double. — end example ] A similar restriction applies to assignment to and initialization of pointers to functions, pointers to member functions, and references to functions: the target entity shall allow at least the exceptions allowed by the source value in the assignment or initialization. [Example:

```cpp
class A { /* ... */ };  // no exception specification
void (*pf1)();
void (*pf2)() throw(A);

void f()
{
    pf1 = pf2;           // OK: pf1 is less restrictive
    pf2 = pf1;           // error: pf2 is more restrictive
}
```

— end example ]

5 In such an assignment or initialization, exception-specifications on return types and parameter types shall match exactly. In other assignments or initializations, exception-specifications shall match exactly.

6 Types shall not be defined in exception-specifications.

7 An exception-specification can include the same type more than once and can include classes that are related by inheritance, even though doing so is redundant. An exception-specification can also include the class std::bad_exception (18.7.2.1).

8 A function is said to allow an exception of type E if its exception-specification contains a type T for which a handler of type T would be a match (15.3) for an exception of type E.

9 Whenever an exception is thrown and the search for a handler (15.3) encounters the outermost block of a function with an exception-specification, the function std::unexpected() is called (15.5.2) if the exception-specification does not allow the exception. [Example:

```cpp
class X { };
class Y { };
class Z: public X { };
class W { };
```
void f() throw (X, Y)
{
    int n = 0;
    if (n) throw X();  // OK
    if (n) throw Z();  // also OK
    throw W();        // will call std::unexpected()
}

— end example ]

The function std::unexpected() may throw an exception that will satisfy the exception-specification for which it was invoked, and in this case the search for another handler will continue at the call of the function with this exception-specification (see 15.5.2), or it may call std::terminate().

An implementation shall not reject an expression merely because when executed it throws or might throw an exception that the containing function does not allow. [ Example:

    extern void f() throw(X, Y);

    void g() throw(X)
    {
        f();                // OK
    }

    the call to f is well-formed even though when called, f might throw exception Y that g does not allow. — end example ]

A function with no exception-specification allows all exceptions. A function with an empty exception-specification, throw(), does not allow any exceptions.

An exception-specification is not considered part of a function’s type.

An implicitly declared special member function (clause 12) shall have an exception-specification. If f is an implicitly declared default constructor, copy constructor, destructor, or copy assignment operator, its implicit exception-specification specifies the type-id T if and only if T is allowed by the exception-specification of a function directly invoked by f’s implicit definition; f shall allow all exceptions if any function it directly invokes allows all exceptions, and f shall allow no exceptions if every function it directly invokes allows no exceptions. [ Example:

    struct A {
        A();
        A(const A&) throw();
        "A() throw(X);
    };

    struct B {
        B() throw();
        B(const B&) throw();
        "B() throw(Y);
    };

    struct D : public A, public B {
        // Implicit declaration of D::D();
        // Implicit declaration of D::D(const D&) throw();
        // Implicit declaration of D::~D() throw(X,Y);
    };

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Furthermore, if A::"A() or B::"B() were virtual, D::"D() would not be as restrictive as that of A::"A, and the program would be ill-formed since a function that overrides a virtual function from a base class shall have an exception-specification at least as restrictive as that in the base class. — end example]

15.5 Special functions

The exception handling mechanism relies on two functions, std::terminate() and std::unexpected(), for coping with errors related to the exception handling mechanism itself (18.7).

15.5.1 The std::terminate() function

In the following situations exception handling must be abandoned for less subtle error handling techniques:

- when the exception handling mechanism, after completing evaluation of the expression to be thrown but before the exception is caught (15.1), calls a user function that exits via an uncaught exception,[140]
- when the exception handling mechanism cannot find a handler for a thrown exception (15.3), or
- when the destruction of an object during stack unwinding (15.2) exits using an exception, or
- when construction or destruction of a non-local object with static storage duration exits using an exception (3.6.2), or
- when execution of a function registered with std::atexit exits using an exception (18.4), or
- when a throw-expression with no operand attempts to rethrow an exception and no exception is being handled (15.1), or
- when std::unexpected throws an exception which is not listed in the exception-specification, and std::bad_exception is not included in that exception-specification (15.5.2), or
- when the implementation’s default unexpected exception handler is called (18.7.2.2).

In such cases, std::terminate() is called (18.7.3). In the situation where no matching handler is found, it is implementation-defined whether or not the stack is unwound before std::terminate() is called. In all other situations, the stack shall not be unwound before std::terminate() is called. An implementation is not permitted to finish stack unwinding prematurely based on a determination that the unwind process will eventually cause a call to std::terminate().

15.5.2 The std::unexpected() function

If a function with an exception-specification throws an exception that is not listed in the exception-specification, the function std::unexpected() is called (18.7.2) immediately after completing the stack unwinding for the former function.

The std::unexpected() function shall not return, but it can throw (or re-throw) an exception. If it throws a new exception which is allowed by the exception specification which previously was violated, then the search for another handler will continue at the call of the function whose exception specification was violated. If it throws or rethrows an exception that the exception-specification does not allow then the following happens: If the exception-specification does not include the class std::bad_exception (18.7.2.1) then the function std::terminate() is called, otherwise the

[140] For example, if the object being thrown is of a class with a copy constructor, std::terminate() will be called if that copy constructor exits with an exception during a throw.
thrown exception is replaced by an implementation-defined object of the type `std::bad_exception` and the search for another handler will continue at the call of the function whose `exception-specification` was violated.

Thus, an `exception-specification` guarantees that only the listed exceptions will be thrown. If the `exception-specification` includes the type `std::bad_exception` then any exception not on the list may be replaced by `std::bad_exception` within the function `std::unexpected()`.

15.5.3 The `std::uncaught_exception()` function

The function `std::uncaught_exception()` returns `true` after completing evaluation of the object to be thrown until completing the initialization of the `exception-declaration` in the matching handler (18.7.4). This includes stack unwinding. If the exception is rethrown (15.1), `std::uncaught_exception()` returns `true` from the point of rethrow until the rethrown exception is caught again.

15.6 Exceptions and access

If the `exception-declaration` in a catch clause has class type, and the function in which the catch clause occurs does not have access to the destructor of that class, the program is ill-formed.

An object can be thrown if it can be copied and destroyed in the context of the function in which the `throw-expression` occurs.
A preprocessing directive consists of a sequence of preprocessing tokens. The first token in the sequence is a \# preprocessing token that (at the start of translation phase 4) is either the first character in the source file (optionally after white space containing no new-line characters) or that follows white space containing at least one new-line character. The last token in the sequence is the first new-line character that follows the first token in the sequence.\[141\] A new-line character ends the preprocessing directive even if it occurs within what would otherwise be an invocation of a function-like macro.

```
preprocessing-file:
  group
  group-part
    if-section
    control-line
    text-line
    # non-directive
if-section:
  if-group elif-groups opt else-group opt endif-line
if-group:
  # if constant-expression new-line group
  # ifdef identifier new-line group
  # ifndef identifier new-line group
elif-groups:
  elif-group
  elif-groups elif-group
elif-group:
  # elif constant-expression new-line group
else-group:
  # else new-line group
endif-line:
  # endif new-line
```

\[141\] Thus, preprocessing directives are commonly called “lines.” These “lines” have no other syntactic significance, as all white space is equivalent except in certain situations during preprocessing (see the \# character string literal creation operator in 16.3.2, for example).
A text line shall not begin with a # preprocessing token. A non-directive shall not begin with any of the directive names appearing in the syntax.

When in a group that is skipped (16.1), the directive syntax is relaxed to allow any sequence of preprocessing tokens to occur between the directive name and the following new-line character.

The only white-space characters that shall appear between preprocessing tokens within a preprocessing directive (from just after the introducing # preprocessing token through just before the terminating new-line character) are space and horizontal-tab (including spaces that have replaced comments or possibly other white-space characters in translation phase 3).

The implementation can process and skip sections of source files conditionally, include other source files, and replace macros. These capabilities are called preprocessing, because conceptually they occur before translation of the resulting translation unit.

The preprocessing tokens within a preprocessing directive are not subject to macro expansion unless otherwise stated.

[Example: In:

#define EMPTY

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the sequence of preprocessing tokens on the second line is *not* a preprocessing directive, because it does not begin with a # at the start of translation phase 4, even though it will do so after the macro undefined has been replaced. — end example }

16.1 Conditional inclusion [cpp.cond]

The expression that controls conditional inclusion shall be an integral constant expression except that: it shall not contain a cast; identifiers (including those lexically identical to keywords) are interpreted as described below; \(^{142}\) and it may contain unary operator expressions of the form

\[
\text{defined identifier}
\]

or

\[
\text{defined ( identifier )}
\]

which evaluate to 1 if the identifier is currently defined as a macro name (that is, if it is predefined or if it has been the subject of a \#define preprocessing directive without an intervening \#undef directive with the same subject identifier), 0 if it is not.

2 Each preprocessing token that remains after all macro replacements have occurred shall be in the lexical form of a token (2.6).

3 Preprocessing directives of the forms

\[
\text{# if constant-expression new-line group}_{\text{opt}} \\
\text{# elif constant-expression new-line group}_{\text{opt}}
\]

check whether the controlling constant expression evaluates to nonzero.

4 Prior to evaluation, macro invocations in the list of preprocessing tokens that will become the controlling constant expression are replaced (except for those macro names modified by the defined unary operator), just as in normal text. If the token defined is generated as a result of this replacement process or use of the defined unary operator does not match one of the two specified forms prior to macro replacement, the behavior is undefined. After all replacements due to macro expansion and the defined unary operator have been performed, all remaining identifiers and keywords, except for true and false, are replaced with the pp-number 0, and then each preprocessing token is converted into a token. The resulting tokens comprise the controlling constant expression which is evaluated according to the rules of 5.19 using arithmetic that has at least the ranges specified in 18.2, except that all signed and unsigned integer types act as if they have the same representation as, respectively, long long int and unsigned long long int. This includes interpreting character literals, which may involve converting escape sequences into execution character set members. Whether the numeric value for these character literals matches the value obtained when an identical character literal occurs in an expression (other than within a \#if or \#elif directive) is implementation-defined. \(^{144}\) Also, whether a

\(^{142}\) Because the controlling constant expression is evaluated during translation phase 4, all identifiers either are or are not macro names — there simply are no keywords, enumeration constants, and so on.

\(^{143}\) An alternative token (2.5) is not an identifier, even when its spelling consists entirely of letters and underscores. Therefore it is not subject to this replacement.

\(^{144}\) Thus, the constant expression in the following \#if directive and if statement is not guaranteed to evaluate to the same value in these two contexts.

\[
\text{#if 'z' - 'a' == 25} \\
\text{if ('z' - 'a' == 25)}
\]
16.2 Source file inclusion

Preprocessing directives of the forms

```cpp
#include <h-char-sequence> new-line
#include "q-char-sequence" new-line
```

searches a sequence of implementation-defined places for a header identified uniquely by the specified sequence between the `<` and `>` delimiters, and causes the replacement of that directive by the entire contents of the header. How the places are specified or the header identified is implementation-defined.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.

A preprocessing directive of the form

```cpp
#include pp-tokens new-line
```

causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the `"` delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read

```cpp
#include <h-char-sequence> new-line
```

with the identical contained sequence (including `>` characters, if any) from the original directive.
and a > preprocessing token pair or a pair of " characters is combined into a single header name preprocessing token is implementation-defined.

5 The implementation provides unique mappings for sequences consisting of one or more nondigits or digits (2.10) followed by a period (.) and a single nondigit. The first character shall not be a digit. The implementation may ignore the distinctions of alphabetical case.

6 A #include preprocessing directive may appear in a source file that has been read because of a #include directive in another file, up to an implementation-defined nesting limit.

[Example: The most common uses of #include preprocessing directives are as in the following:

```
#include <stdio.h>
#include "myprog.h"
```

— end example ]

[Example: Here is a macro-replaced #include directive:

```
#include <stdio.h>
#include "myprog.h"
```

— end example ]

16.3 Macro replacement

1 Two replacement lists are identical if and only if the preprocessing tokens in both have the same number, ordering, spelling, and white-space separation, where all white-space separations are considered identical.

2 An identifier currently defined as an object-like macro may be redefined by another #define preprocessing directive provided that the second definition is an object-like macro definition and the two replacement lists are identical, otherwise the program is ill-formed. Likewise, an identifier currently defined as a function-like macro may be redefined by another #define preprocessing directive provided that the second definition is a function-like macro definition that has the same number and spelling of parameters, and the two replacement lists are identical, otherwise the program is ill-formed.

3 There shall be white-space between the identifier and the replacement list in the definition of an object-like macro.

4 If the identifier-list in the macro definition does not end with an ellipsis, the number of arguments (including those arguments consisting of no preprocessing tokens) in an invocation of a function-like macro shall equal the number of parameters in the macro definition. Otherwise, there shall be more arguments in the invocation than there are parameters in the macro definition (excluding the . . .). There shall exist a ) preprocessing token that terminates the invocation.

5 The identifier _ _ VA_ARGS _ _ shall occur only in the replacement-list of a function-like macro that uses the ellipsis notation in the parameters.

6 A parameter identifier in a function-like macro shall be uniquely declared within its scope.
The identifier immediately following the `define` is called the *macro name*. There is one name space for macro names. Any white-space characters preceding or following the replacement list of preprocessing tokens are not considered part of the replacement list for either form of macro.

If a `#` preprocessing token, followed by an identifier, occurs lexically at the point at which a preprocessing directive could begin, the identifier is not subject to macro replacement.

A preprocessing directive of the form

```
#define identifier replacement-list new-line
```

defines an *object-like macro* that causes each subsequent instance of the macro name\(^{147}\) to be replaced by the replacement list of preprocessing tokens that constitute the remainder of the directive.\(^{148}\) The replacement list is then rescanned for more macro names as specified below.

A preprocessing directive of the form

```
#define identifier lparen identifier-list opt ) replacement-list new-line
#define identifier lparen ) replacement-list new-line
#define identifier lparen identifier-list , ... ) replacement-list new-line
```

defines a *function-like macro* with parameters, similar syntactically to a function call. The parameters are specified by the optional list of identifiers, whose scope extends from their declaration in the identifier list until the new-line character that terminates the `#define` preprocessing directive. Each subsequent instance of the function-like macro name followed by a `(` as the next preprocessing token introduces the sequence of preprocessing tokens that is replaced by the replacement list in the definition (an invocation of the macro). The replaced sequence of preprocessing tokens is terminated by the matching `)` preprocessing token, skipping intervening matched pairs of left and right parenthesis preprocessing tokens. Within the sequence of preprocessing tokens making up an invocation of a function-like macro, new-line is considered a normal white-space character.

The sequence of preprocessing tokens bounded by the outside-most matching parentheses forms the list of arguments for the function-like macro. The individual arguments within the list are separated by comma preprocessing tokens, but comma preprocessing tokens between matching inner parentheses do not separate arguments. If there are sequences of preprocessing tokens within the list of arguments that would otherwise act as preprocessing directives, the behavior is undefined.

If there is a `...` in the identifier-list in the macro definition, then the trailing arguments, including any separating comma preprocessing tokens, are merged to form a single item: the variable arguments. The number of arguments so combined is such that, following merger, the number of arguments is one more than the number of parameters in the macro definition (excluding the `...`).

### 16.3.1 Argument substitution

After the arguments for the invocation of a function-like macro have been identified, argument substitution takes place. A parameter in the replacement list, unless preceded by a `#` or `##` preprocessing token or followed by a `##` preprocessing token (see below), is replaced by the corresponding argument after all macros contained therein have been expanded.

\(^{147}\) Since, by macro-replacement time, all character literals and string literals are preprocessing tokens, not sequences possibly containing identifier-like subsequences (see 2.1.1.2, translation phases), they are never scanned for macro names or parameters.

\(^{148}\) An alternative token (2.5) is not an identifier, even when its spelling consists entirely of letters and underscores. Therefore it is not possible to define a macro whose name is the same as that of an alternative token.
Before being substituted, each argument’s preprocessing tokens are completely macro replaced as if they formed the rest of the preprocessing file; no other preprocessing tokens are available.

An identifier \_\_VA_ARGS\_\_ that occurs in the replacement list shall be treated as if it were a parameter, and the variable arguments shall form the preprocessing tokens used to replace it.

### 16.3.2 The # operator [cpp.stringize]

1. Each # preprocessing token in the replacement list for a function-like macro shall be followed by a parameter as the next preprocessing token in the replacement list.

2. If, in the replacement list, a parameter is immediately preceded by a # preprocessing token, both are replaced by a single character string literal preprocessing token that contains the spelling of the preprocessing token sequence for the corresponding argument. Each occurrence of white space between the argument’s preprocessing tokens becomes a single space character in the character string literal. White space before the first preprocessing token and after the last preprocessing token comprising the argument is deleted. Otherwise, the original spelling of each preprocessing token in the argument is retained in the character string literal, except for special handling for producing the spelling of string literals and character literals: a \ character is inserted before each " and \ character of a character literal or string literal (including the delimiting " characters). If the replacement that results is not a valid character string literal, the behavior is undefined. The character string literal corresponding to an empty argument is ". The order of evaluation of # and ## operators is unspecified.

### 16.3.3 The ## operator [cpp.concat]

1. A ## preprocessing token shall not occur at the beginning or at the end of a replacement list for either form of macro definition.

2. If, in the replacement list of a function-like macro, a parameter is immediately preceded or followed by a ## preprocessing token, the parameter is replaced by the corresponding argument’s preprocessing token sequence; however, if an argument consists of no preprocessing tokens, the parameter is replaced by a placemarker preprocessing token instead.

3. For both object-like and function-like macro invocations, before the replacement list is reexamined for more macro names to replace, each instance of a ## preprocessing token in the replacement list (not from an argument) is deleted and the preceding preprocessing token is concatenated with the following preprocessing token. Placemarker preprocessing tokens are handled specially; concatenation of two placemarkers results in a single placemarker preprocessing token, and concatenation of a placemarker with a non-placemarker preprocessing token results in the non-placemarker preprocessing token. If the result is not a valid preprocessing token, the behavior is undefined. The resulting token is available for further macro replacement. The order of evaluation of ## operators is unspecified.

[Example: In the following fragment:

```c
#define hash_hash # ## #
#define mkstr(a) # a
#define in_between(a) mkstr(a)
#define join(c, d) in_between(c hash_hash d)
char p[] = join(x, y); // equivalent to
    // char p[] = "x ## y";
```

The expansion produces, at various stages:

149) Placemarker preprocessing tokens do not appear in the syntax because they are temporary entities that exist only within translation phase 4.
16.3 Macro replacement

In other words, expanding hash_hash produces a new token, consisting of two adjacent sharp signs, but this new token is not the ## operator. — end example

16.3.4 Rescanning and further replacement

After all parameters in the replacement list have been substituted and # and ## processing has taken place, all placeholder preprocessing tokens are removed. Then the resulting preprocessing token sequence is rescanned along with all subsequent preprocessing tokens of the source file, for more macro names to replace.

If the name of the macro being replaced is found during this scan of the replacement list (not including the rest of the source file’s preprocessing tokens), it is not replaced. Furthermore, if any nested replacements encounter the name of the macro being replaced, it is not replaced. These nonreplaced macro name preprocessing tokens are no longer available for further replacement even if they are later (re)examined in contexts in which that macro name preprocessing token would otherwise have been replaced.

The resulting completely macro-replaced preprocessing token sequence is not processed as a preprocessing directive even if it resembles one, but all pragma unary operator expressions within it are then processed as specified in 16.9 below.

16.3.5 Scope of macro definitions

A macro definition lasts (independent of block structure) until a corresponding #undef directive is encountered or (if none is encountered) until the end of the translation unit. Macro definitions have no significance after translation phase 4.

A preprocessing directive of the form

```
# undef identifier new-line
```

causes the specified identifier no longer to be defined as a macro name. It is ignored if the specified identifier is not currently defined as a macro name.

[Note: The simplest use of this facility is to define a “manifest constant,” as in

```
#define TABSIZE 100
int table[TABSIZE];
```

The following defines a function-like macro whose value is the maximum of its arguments. It has the advantages of working for any compatible types of the arguments and of generating in-line code without the overhead of function calling. It has the disadvantages of evaluating one or the other of its arguments a second time (including side effects) and generating more code than a function if invoked several times. It also cannot have its address taken, as it has none.

```
#define max(a, b) ((a) > (b) ? (a) : (b))
```

The parentheses ensure that the arguments and the resulting expression are bound properly.

To illustrate the rules for redefinition and reexamination, the sequence
#define x 3
#define f(a) f(x * (a))
#undef x
#define x 2
#define g f
#define z z[0]
#define h g(~
#define m(a) a(w)
#define w 0,1
#define t(a) a
#define p() int
#define q(x) x
#define r(x,y) x ## y
#define str(x) # x

f(y+1) + f(f(z)) % t(t(g)(0) + t)(1);
g(x+(3,4)-w) | h 5) & m
(f)^m(m);
p() iq() = { q(1), r(2,3), r(4,), r(5), r(.) }
char c[2][6] = { str(hello), str() };

results in
f(2 * (y+1)) + f(2 * (f(2 * (z[0]))))) % f(2 * (0)) + t(1);
f(2 * (2+(3,4)-0,1)) | f(2 * (~5)) & f(2 * (0,1))^m(0,1);
int i[] = { 1, 23, 4, 5, }; char c[2][6] = { "hello", "" };

6 To illustrate the rules for creating character string literals and concatenating tokens, the sequence

#define str(s) # s
#define xstr(s) str(s)
#define debug(s, t) printf("x" # s "= %d, x" # t "= %s", \ x ## s, x ## t)
#define INCFILE(n) vers ## n
#define glue(a, b) a ## b
#define xglue(a, b) glue(a, b)
#define HIGHLOW "hello"
#define LOW LOW ", world"

dump(1, 2);
puts(str(strncmp("abc\0d", "abc", '\4') == 0) str(\n include xstr(INCFILE(2).h)
 glue(HIGH, LOW);
xglue(HIGH, LOW)

results in
printf("x" "1" "= %d, x" "2" "= %s", x1, x2);
puts("strncpy("abc\0d", "abc", '\4') == 0" "\n Draft
or, after concatenation of the character string literals,

```c
printf("x1= %d, x2= %s", x1, x2);
fputs("strncmp("abc\0d", "abc", '\4') == 0: @
", s);
```

Space around the # and ## tokens in the macro definition is optional.

7 To illustrate the rules for placemarker preprocessing tokens, the sequence

```c
#define t(x,y,z) x ## y ## z
int j[] = { t(1,2,3), t(4,5), t(6,7), t(8,9),
               t(10,), t(11,), t(12), t(,) }
```

results in

```c
int j[] = { 123, 45, 67, 89,
            10, 11, 12, }
```

8 To demonstrate the redefinition rules, the following sequence is valid.

```c
#define OBJ_LIKE (1-1)
#define OBJ_LIKE /* white space */(1-1)/ other */
#define FTN_LIKE(a) ( a )
#define FTN_LIKE( a )/
   a /* note the white space */
   /* other stuff on this line */
```

9 But the following redefinitions are invalid:

```c
#define OBJ_LIKE (0)     // different token sequence.
#define OBJ_LIKE (1 - 1)  // different white space.
#define FTN_LIKE(b) ( a ) ( // different parameter usage.
#define FTN_LIKE(b) ( b ) ( // different parameter spelling.
```

— end note ]

10 Finally, to show the variable argument list macro facilities:

```c
#define debug(...) fprintf(stderr, __VA_ARGS__)
#define showlist(...) puts(__VA_ARGS__)
#define report(test, ...) ((test) ? puts(#test) : printf(__VA_ARGS__))
debug("Flag");
debug("x = %d
", x);
showlist(The first, second, and third items.);
report(x>y, "x is %d but y is %d", x, y);
```
results in

    fprintf(stderr, "Flag");
    fprintf(stderr, "X = %d\n", x);
    puts("The first, second, and third items.");
    ((x>y) ? puts("x>y") : printf("x is %d but y is %d", x, y));

16.4 Line control

1 The string literal of a #line directive, if present, shall be a character string literal.

2 The line number of the current source line is one greater than the number of new-line characters read or introduced in translation phase 1 (2.1) while processing the source file to the current token.

3 A preprocessing directive of the form

    # line digit-sequence new-line

causes the implementation to behave as if the following sequence of source lines begins with a source line that has a line number as specified by the digit sequence (interpreted as a decimal integer). If the digit sequence specifies zero or a number greater than 2147483647, the behavior is undefined.

4 A preprocessing directive of the form

    # line digit-sequence " s-char-sequence_opt " new-line

sets the line number similarly and changes the presumed name of the source file to be the contents of the character string literal.

5 A preprocessing directive of the form

    # line pp-tokens new-line

(that does not match one of the two previous forms) is permitted. The preprocessing tokens after line on the directive are processed just as in normal text (each identifier currently defined as a macro name is replaced by its replacement list of preprocessing tokens). If the directive resulting after all replacements does not match one of the two previous forms, the behavior is undefined; otherwise, the result is processed as appropriate.

16.5 Error directive

1 A preprocessing directive of the form

    # error pp-tokens_opt new-line

causes the implementation to produce a diagnostic message that includes the specified sequence of preprocessing tokens, and renders the program ill-formed.

16.6 Pragma directive

1 A preprocessing directive of the form

    # pragma pp-tokens_opt new-line

Draft
16.7 Null directive

A preprocessing directive of the form

```
# new-line
```

has no effect.

16.8 Predefined macro names

The following macro names shall be defined by the implementation:

- `_cplusplus`
  - The name `_cplusplus` is defined to the value [tbd] when compiling a C++ translation unit.\(^{(50)}\)
- `_DATE_`
  - The date of translation of the source file (a character string literal of the form "Mmm dd yyyy", where the names of the months are the same as those generated by the `asctime` function, and the first character of `dd` is a space character if the value is less than 10). If the date of translation is not available, an implementation-defined valid date is supplied.
- `_FILE_`
  - The presumed name of the source file (a character string literal).
- `_LINE_`
  - The line number of the current source line (a decimal constant).
- `_STDC_HOSTED_`
  - The integer constant 1 if the implementation is a hosted implementation or the integer constant 0 if it is not.
- `_TIME_`
  - The time of translation of the source file (a character string literal of the form "hh:mm:ss" as in the time generated by the `asctime` function). If the time of translation is not available, an implementation-defined valid time is supplied.

The following macro names are conditionally defined by the implementation:

- `_STDC_`
  - Whether `_STDC_` is predefined and if so, what its value is, are implementation-defined.
- `_STDC_VERSION_`
  - Whether `_STDC_VERSION_` is predefined and if so, what its value is, are implementation-defined.
- `_STDC_ISO_10646_`
  - An integer constant of the form `yyyymmL` (for example, `199712L`), intended to indicate that values of type `wchar_t` are the coded representations of the characters defined by ISO/IEC 10646, along with all amendments and technical corrigenda as of the specified year and month.

\(^{(50)}\) It is intended that future versions of this standard will replace the value of this macro with a greater value. Non-conforming compilers should use a value with at most five decimal digits.
The values of the predefined macros (except for `_LINE_` and `_FILE_`) remain constant throughout the translation unit.

If any of the pre-defined macro names in this subclause, or the identifier `defined`, is the subject of a `#define` or a `#undef` preprocessing directive, the behavior is undefined. Any other predefined macro names shall begin with a leading underscore followed by an uppercase letter or a second underscore.

### 16.9 Pragma operator

A unary operator expression of the form:

```
Pragma (string-literal)
```

is processed as follows: The string literal is *destringized* by deleting the `L` prefix, if present, deleting the leading and trailing double-quotes, replacing each escape sequence `"` by a double-quote, and replacing each escape sequence `\` by a single backslash. The resulting sequence of characters is processed through translation phase 3 to produce preprocessing tokens that are executed as if they were the *pp-tokens* in a pragma directive. The original four preprocessing tokens in the unary operator expression are removed.

*Example:*

```
#define LISTING(x) PRAGMA(listing on #x)
#define PRAGMA(x) _Pragma(#x)

LISTING( ..\listing.dir )
```

The latter form is processed in the same way whether it appears literally as shown, or results from macro replacement, as in:

```
#pragma listing on "..\listing.dir"
```

...end example
Chapter 17  Library introduction

This clause describes the contents of the C++ Standard Library, how a well-formed C++ program makes use of the library, and how a conforming implementation may provide the entities in the library.

The C++ Standard Library provides an extensible framework, and contains components for: language support, diagnostics, general utilities, strings, locales, containers, iterators, algorithms, numerics, and input/output. The language support components are required by certain parts of the C++ language, such as memory allocation (5.3.4, 5.3.5) and exception processing (clause 15).

The general utilities include components used by other library elements, such as a predefined storage allocator for dynamic storage management (3.7.3). The diagnostics components provide a consistent framework for reporting errors in a C++ program, including predefined exception classes.

The strings components provide support for manipulating text represented as sequences of type char, sequences of type wchar_t, or sequences of any other “character-like” type. The localization components extend internationalization support for such text processing.

The containers, iterators, and algorithms provide a C++ program with access to a subset of the most widely used algorithms and data structures.

Numeric algorithms and the complex number components extend support for numeric processing. The valarray components provide support for n-at-a-time processing, potentially implemented as parallel operations on platforms that support such processing.

The iostreams components are the primary mechanism for C++ program input/output. They can be used with other elements of the library, particularly strings, locales, and iterators.

This library also makes available the facilities of the Standard C library, suitably adjusted to ensure static type safety.

The descriptions of many library functions rely on the Standard C99 Library for the signatures and semantics of those functions. In all such cases, any use of the restrict qualifier shall be omitted.

The following subclauses describe the definitions (17.1), and method of description (17.3) for the library. Clause 17.4, and clauses 18 through 27, and Annex D specify the contents of the library, and library requirements and constraints on both well-formed C++ programs and conforming implementations.

17.1  Definitions

17.1.1 arbitrary-positional stream

A stream (described in clause 27) that can seek to any integral position within the length of the stream. Every arbitrary-
positional stream is also a repositionable stream (17.1.16).

17.1.2 character

in clauses 21, 22, and 27, means any object which, when treated sequentially, can represent text. The term does not only mean char and wchar_t objects, but any value that can be represented by a type that provides the definitions specified in these clauses.

17.1.3 character container type

a class or a type used to represent a character (17.1.2). It is used for one of the template parameters of the string and iostream class templates. A character container class shall be a POD (3.9) type.

17.1.4 comparison function

an operator function (13.5) for any of the equality (5.10) or relational (5.9) operators.

17.1.5 component

a group of library entities directly related as members, parameters, or return types. For example, the class template basic_string and the non-member function templates that operate on strings are referred to as the string component.

17.1.6 default behavior

a description of replacement function and handler function semantics. Any specific behavior provided by the implementation, within the scope of the required behavior.

17.1.7 handler function

a non-reserved function whose definition may be provided by a C++ program. A C++ program may designate a handler function at various points in its execution, by supplying a pointer to the function when calling any of the library functions that install handler functions (clause 18).

17.1.8 iostream class templates

templates, defined in clause 27, that take two template arguments: charT and traits. The argument charT is a character container class, and the argument traits is a structure which defines additional characteristics and functions of the character type represented by charT necessary to implement the iostream class templates.

17.1.9 modifier function

a class member function (9.3), other than constructors, assignment, or destructor, that alters the state of an object of the class.

17.1.10 object state

the current value of all non-static class members of an object (9.2). The state of an object can be obtained by using one or more observer functions.

17.1.11 narrow-oriented iostream classes

the instantiations of the iostream class templates on the character container class char and the default value of the
traits parameter. The traditional iostream classes are regarded as the narrow-oriented iostream classes (27.3.1).

17.1.12 NTCTS

[defns.ntcts]
a sequence of values that have character type, that precede the terminating null character type value charT().

17.1.13 observer function

[defns.observer]
a class member function (9.3) that accesses the state of an object of the class, but does not alter that state. Observer functions are specified as const member functions (9.3.2).

17.1.14 replacement function

[defns.replacement]
a non-reserved function whose definition is provided by a C++ program. Only one definition for such a function is in effect for the duration of the program’s execution, as the result of creating the program (2.1) and resolving the definitions of all translation units (3.5).

17.1.15 required behavior

[defns.required.behavior]
a description of replacement function and handler function semantics, applicable to both the behavior provided by the implementation and the behavior that shall be provided by any function definition in the program. If a function defined in a C++ program fails to meet the required behavior when it executes, the behavior is undefined.

17.1.16 repositional stream

[defns.repositional.stream]
a stream (described in clause 27) that can seek only to a position that was previously encountered.

17.1.17 reserved function

[defns.reserved.function]
a function, specified as part of the C++ Standard Library, that must be defined by the implementation. If a C++ program provides a definition for any reserved function, the results are undefined.

17.1.18 stable algorithm

[defns.stable]
an algorithm that preserves, as appropriate to the particular algorithm, the order of elements.

— For the sort algorithms the relative order of equivalent elements is preserved.

— For the remove algorithms the relative order of the elements that are not removed is preserved.

— For the merge algorithms, for equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range.

17.1.19 traits class

[defns.traits]
a class that encapsulates a set of types and functions necessary for class templates and function templates to manipulate objects of types for which they are instantiated. Traits classes defined in clauses 21, 22 and 27 are character traits, which provide the character handling support needed by the string and iostream classes.

17.1.20 wide-oriented iostream classes

[defns.wide.iostream]
the instantiations of the iostream class templates on the character container class wchar_t and the default value of the
17.2 Additional definitions

1.3 defines additional terms used elsewhere in this International Standard.

17.3 Method of description (Informative)

17.3 describes the conventions used to describe the C++ Standard Library. It describes the structures of the normative clauses 18 through 27 (17.3.1), Annex D and other editorial conventions (17.3.2).

17.3.1 Structure of each subclause

17.4.1 provides a summary of the C++ Standard library’s contents. Other Library clauses provide detailed specifications for each of the components in the library, as shown in Table 11.

Table 11: Library Categories

<table>
<thead>
<tr>
<th>Clause</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Language support</td>
</tr>
<tr>
<td>19</td>
<td>Diagnostics</td>
</tr>
<tr>
<td>20</td>
<td>General utilities</td>
</tr>
<tr>
<td>21</td>
<td>Strings</td>
</tr>
<tr>
<td>22</td>
<td>Localization</td>
</tr>
<tr>
<td>23</td>
<td>Containers</td>
</tr>
<tr>
<td>24</td>
<td>Iterators</td>
</tr>
<tr>
<td>25</td>
<td>Algorithms</td>
</tr>
<tr>
<td>26</td>
<td>Numerics</td>
</tr>
<tr>
<td>27</td>
<td>Input/output</td>
</tr>
</tbody>
</table>

1 Each Library clause contains the following elements, as applicable:\textsuperscript{151)

- Summary
- Requirements
- Detailed specifications
- References to the Standard C library

17.3.1.1 Summary

The Summary provides a synopsis of the category, and introduces the first-level subclauses. Each subclause also provides a summary, listing the headers specified in the subclause and the library entities provided in each header.

2 Paragraphs labelled “Note(s):” or “Example(s):” are informative, other paragraphs are normative.

3 The summary and the detailed specifications are presented in the order:

\textsuperscript{151) To save space, items that do not apply to a clause are omitted. For example, if a clause does not specify any requirements, there will be no “Requirements” subclause.

Draft
17.3 Method of description (Informative)

17.3.1.2 Requirements

The library can be extended by a C++ program. Each clause, as applicable, describes the requirements that such extensions must meet. Such extensions are generally one of the following:

- Template arguments
- Derived classes
- Containers, iterators, and/or algorithms that meet an interface convention

The string and iostreams components use an explicit representation of operations required of template arguments. They use a class template `char_traits` to define these constraints.

Interface convention requirements are stated as generally as possible. Instead of stating “class X has to define a member function `operator++()`,” the interface requires “for any object x of class X, ++x is defined.” That is, whether the operator is a member is unspecified.

Requirements are stated in terms of well-defined expressions, which define valid terms of the types that satisfy the requirements. For every set of requirements there is a table that specifies an initial set of the valid expressions and their semantics (20.1.6, 23.1, 24.1). Any generic algorithm (clause 25) that uses the requirements is described in terms of the valid expressions for its formal type parameters.

Template argument requirements are sometimes referenced by name. See 17.3.2.1.

In some cases the semantic requirements are presented as C++ code. Such code is intended as a specification of equivalence of a construct to another construct, not necessarily as the way the construct must be implemented.\(^{152}\)

17.3.1.3 Specifications

The detailed specifications each contain the following elements:\(^{153}\)

- Name and brief description
- Synopsis (class definition or function prototype, as appropriate)
- Restrictions on template arguments, if any
- Description of class invariants

\(^{152}\) Although in some cases the code given is unambiguously the optimum implementation.

\(^{153}\) The form of these specifications was designed to follow the conventions established by existing C++ library vendors.
17.3 Method of description (Informative) Library introduction

— Description of function semantics

2 Descriptions of class member functions follow the order (as appropriate):\textsuperscript{154)
— Constructor(s) and destructor
— Copying & assignment functions
— Comparison functions
— Modifier functions
— Observer functions
— Operators and other non-member functions

3 Descriptions of function semantics contain the following elements (as appropriate):\textsuperscript{155)
— \textit{Requires}: the preconditions for calling the function
— \textit{Effects}: the actions performed by the function
— \textit{Postconditions}: the observable results established by the function
— \textit{Returns}: a description of the value(s) returned by the function
— \textit{Throws}: any exceptions thrown by the function, and the conditions that would cause the exception
— \textit{Complexity}: the time and/or space complexity of the function

4 For non-reserved replacement and handler functions, clause \textsuperscript{18} specifies two behaviors for the functions in question: their required and default behavior. The default behavior describes a function definition provided by the implementation. The required behavior describes the semantics of a function definition provided by either the implementation or a C++ program. Where no distinction is explicitly made in the description, the behavior described is the required behavior.

5 Complexity requirements specified in the library clauses are upper bounds, and implementations that provide better complexity guarantees satisfy the requirements.

17.3.1.4 C Library \textsuperscript{[lib.structure.see.also]}

1 Paragraphs labelled “See also:” contain cross-references to the relevant portions of this Standard and the ISO C standard, which is incorporated into this Standard by reference.

17.3.2 Other conventions \textsuperscript{[lib.conventions]}

1 This subclause describes several editorial conventions used to describe the contents of the C++ Standard Library. These

\textsuperscript{154) To save space, items that do not apply to a class are omitted. For example, if a class does not specify any comparison functions, there will be no “Comparison functions” subclause.

\textsuperscript{155) To save space, items that do not apply to a function are omitted. For example, if a function does not specify any further preconditions, there will be no “Requires” paragraph.

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conventions are for describing implementation-defined types (17.3.2.1), and member functions (17.3.2.2).

17.3.2.1 Type descriptions [lib.type.descriptions]

1 The Requirements subclauses may describe names that are used to specify constraints on template arguments.\footnote{Examples from 20.1 include: EqualityComparable, LessThanComparable, CopyConstructable, etc. Examples from 24.1 include: InputIterator, ForwardIterator, Function, Predicate, etc.} These names are used in library clauses 20, 23, 25, and 26 to describe the types that may be supplied as arguments by a C++ program when instantiating template components from the library.

2 Certain types defined in clause 27 are used to describe implementation-defined types. They are based on other types, but with added constraints.

17.3.2.1.1 Enumerated types [lib.enumerated.types]

1 Several types defined in clause 27 are enumerated types. Each enumerated type may be implemented as an enumeration or as a synonym for an enumeration.\footnote{Such as an integer type, with constant integer values (3.9.1).}

2 The enumerated type enumerated can be written:

```cpp
eenum enumerated { V0, V1, V2, V3, .....);
static const enumerated C0 (V0);
static const enumerated C1 (V1);
static const enumerated C2 (V2);
static const enumerated C3 (V3);
....
```

3 Here, the names C0, C1, etc. represent enumerated elements for this particular enumerated type. All such elements have distinct values.

17.3.2.1.2 Bitmask types [lib.bitmask.types]

1 Several types defined in clauses 18 through 27 and Annex D are bitmask types. Each bitmask type can be implemented as an enumerated type that overloads certain operators, as an integer type, or as a bitset (23.3.5).

2 The bitmask type bitmask can be written:

```cpp
eenum bitmask {
    V0 = 1 << 0, V1 = 1 << 1, V2 = 1 << 2, V3 = 1 << 3, .....;
};
static const bitmask C0(V0);
static const bitmask C1(V1);
static const bitmask C2(V2);
static const bitmask C3(V3);
....
```

```cpp
bitmask operator& (bitmask X, bitmask Y)
// For exposition only.
// int_type is an integral type capable of
```

\footnote{Examples from 20.1 include: EqualityComparable, LessThanComparable, CopyConstructable, etc. Examples from 24.1 include: InputIterator, ForwardIterator, Function, Predicate, etc.}
17.3 Method of description (Informative) Library introduction

// representing all values of bitmask
{ return static_cast<bitmask>(
    static_cast<int_type>(X) &
    static_cast<int_type>(Y)); }

bitmask operator| (bitmask X, bitmask Y)
{ return static_cast<bitmask>(
    static_cast<int_type>(X) |
    static_cast<int_type>(Y)); }

bitmask operator^ (bitmask X, bitmask Y)
{ return static_cast<bitmask>(
    static_cast<int_type>(X) ^
    static_cast<int_type>(Y)); }

bitmask operator~ (bitmask X)
{ return static_cast<bitmask>(∼static_cast<int_type>(X)); }

bitmask& operator&=(bitmask& X, bitmask Y)
{ X = X&Y; return X; }

bitmask& operator|=(bitmask& X, bitmask Y)
{ X = X|Y; return X; }

bitmask& operator^=(bitmask& X, bitmask Y)
{ X = X^Y; return X; }

3 Here, the names \(C_0\), \(C_1\), etc. represent bitmask elements for this particular bitmask type. All such elements have distinct values such that, for any pair \(C_i\) and \(C_j\), \(C_i \& C_j\) is nonzero and \(C_i \& C_j\) is zero.

4 The following terms apply to objects and values of bitmask types:

— To set a value \(Y\) in an object \(X\) is to evaluate the expression \(X \| Y\).

— To clear a value \(Y\) in an object \(X\) is to evaluate the expression \(X \&= \sim Y\).

— The value \(Y\) is set in the object \(X\) if the expression \(X \& Y\) is nonzero.

17.3.2.1.3 Character sequences

The Standard C library makes widespread use of characters and character sequences that follow a few uniform conventions:

— A letter is any of the 26 lowercase or 26 uppercase letters in the basic execution character set.\(^{158}\)

— The decimal-point character is the (single-byte) character used by functions that convert between a (single-byte) character sequence and a value of one of the floating-point types. It is used in the character sequence to denote the beginning of a fractional part. It is represented in clauses 18 through 27 and Annex D by a period, ‘.’, which is also its value in the "C" locale, but may change during program execution by a call to setlocale(int, const char*),\(^{159}\) or by a change to a locale object, as described in clauses 22.1 and 27.

\(^{158}\) Note that this definition differs from the definition in ISO C subclause 7.1.1.

\(^{159}\) declared in <locale> (22.3).
A character sequence is an array object (8.3.4) $T A[N]$, where $T$ is any of the types char, unsigned char, or signed char (3.9.1), optionally qualified by any combination of const or volatile. The initial elements of the array have defined contents up to and including an element determined by some predicate. A character sequence can be designated by a pointer value $S$ that points to its first element.

17.3.2.1.3.1 Byte strings

A null-terminated byte string, or NTBS, is a character sequence whose highest-addressed element with defined content has the value zero (the terminating null character).

The length of an NTBS is the number of elements that precede the terminating null character. An empty NTBS has a length of zero.

The value of an NTBS is the sequence of values of the elements up to and including the terminating null character.

A static NTBS is an NTBS with static storage duration.

17.3.2.1.3.2 Multibyte strings

A null-terminated multibyte string, or NTMBS, is an NTBS that constitutes a sequence of valid multibyte characters, beginning and ending in the initial shift state.

A static NTMBS is an NTMBS with static storage duration.

17.3.2.1.3.3 Wide-character sequences

A wide-character sequence is an array object (8.3.4) $T A[N]$, where $T$ is type wchar_t (3.9.1), optionally qualified by any combination of const or volatile. The initial elements of the array have defined contents up to and including an element determined by some predicate. A character sequence can be designated by a pointer value $S$ that designates its first element.

A null-terminated wide-character string, or NTWCS, is a wide-character sequence whose highest-addressed element with defined content has the value zero.

The length of an NTWCS is the number of elements that precede the terminating null wide character. An empty NTWCS has a length of zero.

The value of an NTWCS is the sequence of values of the elements up to and including the terminating null character.

A static NTWCS is an NTWCS with static storage duration.

17.3.2.2 Functions within classes

For the sake of exposition, clauses 18 through 27 and Annex D do not describe copy constructors, assignment operators, or (non-virtual) destructors with the same apparent semantics as those that can be generated by default (12.1, 12.4, 12.8).

Many of the objects manipulated by function signatures declared in <string> (21.4) are character sequences or NTBSs. The size of some of these character sequences is limited by a length value, maintained separately from the character sequence.

A string literal, such as "abc", is a static NTBS.

An NTBS that contains characters only from the basic execution character set is also an NTMBS. Each multibyte character then consists of a single byte.

Many of the objects manipulated by function signatures declared in <cwchar> are wide-character sequences or NTWCSS.

A wide string literal, such as L"abc" is a static NTWCS.
2 It is unspecified whether the implementation provides explicit definitions for such member function signatures, or for virtual destructors that can be generated by default.

17.3.2.3 Private members

Clauses 18 through 27 and Annex D do not specify the representation of classes, and intentionally omit specification of class members (9.2). An implementation may define static or non-static class members, or both, as needed to implement the semantics of the member functions specified in clauses 18 through 27 and Annex D.

Objects of certain classes are sometimes required by the external specifications of their classes to store data, apparently in member objects. For the sake of exposition, some subclauses provide representative declarations, and semantic requirements, for private member objects of classes that meet the external specifications of the classes. The declarations for such member objects and the definitions of related member types are enclosed in a comment that ends with exposition only, as in:

```
// streambuf* sb;
```

Any alternate implementation that provides equivalent external behavior is equally acceptable.

17.4 Library-wide requirements

This subclause specifies requirements that apply to the entire C++ Standard library. Clauses 18 through 27 and Annex D specify the requirements of individual entities within the library.

The following subclauses describe the library’s contents and organization (17.4.1), how well-formed C++ programs gain access to library entities (17.4.2), constraints on such programs (17.4.3), and constraints on conforming implementations (17.4.4).

17.4.1 Library contents and organization

This subclause provides a summary of the entities defined in the C++ Standard Library. In general, these entities are defined in library headers, which subclause 17.4.1.2 lists alphabetically.

17.4.1.1 Library contents

The C++ Standard Library provides definitions for the following types of entities: Macros, Values, Types, Templates, Classes, Functions, Objects.

All library entities except macros, operator new and operator delete are defined within the namespace std or namespaces nested within namespace std.

Whenever a name x defined in the standard library is mentioned, the name x is assumed to be fully qualified as ::std::x, unless explicitly described otherwise. For example, if the Effects section for library function F is described as calling library function G, the function ::std::G is meant.

17.4.1.2 Headers

The elements of the C++ Standard Library are declared or defined (as appropriate) in a header.
The C++ Standard Library provides 33 C++ headers, as shown in Table 12.

The facilities of the Standard C Library are provided in 18 additional headers, as shown in Table 13.

Except as noted in clauses 18 through 27 and Annex D the contents of each header *name*.h, as specified in ISO/IEC 9899:1990 Programming Languages C (clause 7), or ISO/IEC:1990 Programming Languages — C AMENDMENT 1: C Integrity, (clause 7), as appropriate, as if by inclusion. In the C++ Standard Library, however, the declarations and definitions (except for names which are defined as macros in C) are within namespace scope (3.3.5) of the namespace std.

Names which are defined as macros in C shall be defined as macros in the C++ Standard Library, even if C grants license for implementation as functions. [Note: the names defined as macros in C include the following: assert, offsetof, setjmp, va_arg, va_end, and va_start. — end note]

Names that are defined as functions in C shall be defined as functions in the C++ Standard Library.

Identifiers that are keywords or operators in C++ shall not be defined as macros in C++ standard library headers.

D.5, Standard C library headers, describes the effects of using the *name*.h (C header) form in a C++ program.

### Freestanding implementations

Two kinds of implementations are defined: hosted and freestanding (1.4). For a hosted implementation, this International Standard describes the set of available headers.

A freestanding implementation has an implementation-defined set of headers. This set shall include at least the following headers.
headers, as shown in Table 14.

The supplied version of the header `<cstdlib>` shall declare at least the functions `abort()`, `atexit()`, and `exit()` (18.4).

### 17.4.2 Using the library [lib.using]

This subclause describes how a C++ program gains access to the facilities of the C++ Standard Library. 17.4.2.1 describes effects during translation phase 4, while 17.4.2.2 describes effects during phase 8 (2.1).

#### 17.4.2.1 Headers [lib.using.headers]

The entities in the C++ Standard Library are defined in headers, whose contents are made available to a translation unit when it contains the appropriate `#include` preprocessing directive (16.2).

A translation unit may include library headers in any order (clause 2). Each may be included more than once, with no effect different from being included exactly once, except that the effect of including either `<cassert>` or `<assert.h>` depends each time on the lexically current definition of `NDEBUG`. A translation unit shall include a header only outside of any external declaration or definition, and shall include the header lexically before the first reference to any of the entities it declares in that translation unit.

#### 17.4.2.2 Linkage [lib.using.linkage]

Entities in the C++ Standard Library have external linkage (3.5). Unless otherwise specified, objects and functions have the default `extern "C++"` linkage (7.5).

Whether a name from the Standard C library declared with external linkage has `extern "C"` or `extern "C++"` linkage is implementation-defined. It is recommended that an implementation use `extern "C++"` linkage for this purpose.

---

17.4 Library-wide requirements

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1 Types</td>
<td><code>&lt;cstdlib&gt;</code></td>
</tr>
<tr>
<td>18.2 Implementation properties</td>
<td><code>&lt;limits&gt;</code></td>
</tr>
<tr>
<td>18.4 Start and termination</td>
<td><code>&lt;cstdlib&gt;</code></td>
</tr>
<tr>
<td>18.5 Dynamic memory management</td>
<td><code>&lt;new&gt;</code></td>
</tr>
<tr>
<td>18.6 Type identification</td>
<td><code>&lt;typeinfo&gt;</code></td>
</tr>
<tr>
<td>18.7 Exception handling</td>
<td><code>&lt;exception&gt;</code></td>
</tr>
<tr>
<td>18.8 Other runtime support</td>
<td><code>&lt;cstdio&gt;</code></td>
</tr>
</tbody>
</table>

---

165) A header is not necessarily a source file, nor are the sequences delimited by `<` and `>` in header names necessarily valid source file names (16.2).

166) This disallows the practice, allowed in C, of providing a "masking macro" in addition to the function prototype. The only way to achieve equivalent "inline" behavior in C++ is to provide a definition as an extern inline function.

167) In particular, including the standard header `<iso646.h>` or `<ciso646>` has no effect.

168) The `*.h` headers dump all their names into the global namespace, whereas the newer forms keep their names in namespace `std`. Therefore, the newer forms are the preferred forms for all uses except for C++ programs which are intended to be strictly compatible with C.

169) This is the same as the Standard C library.

170) The only reliable way to declare an object or function signature from the Standard C library is by including the header that declares it, notwithstanding the latitude granted in subclause 7.1.7 of the C Standard.
Objects and functions defined in the library and required by a C++ program are included in the program prior to program startup.

SEE ALSO: replacement functions (17.4.3.4), run-time changes (17.4.3.5).

17.4.3  Constraints on programs

This subclause describes restrictions on C++ programs that use the facilities of the C++ Standard Library. The following subclauses specify constraints on the program’s namespace (17.4.3.1), its use of headers (17.4.3.2), classes derived from standard library classes (17.4.3.3), definitions of replacement functions (17.4.3.4), and installation of handler functions during execution (17.4.3.5).

17.4.3.1  Reserved names

It is undefined for a C++ program to add declarations or definitions to namespace std or namespaces within namespace std unless otherwise specified. A program may add template specializations for any standard library template to namespace std. Such a specialization (complete or partial) of a standard library template results in undefined behavior unless the declaration depends on a user-defined type of external linkage and unless the specialization meets the standard library requirements for the original template.171 A program may explicitly instantiate any templates in the standard library only if the declaration depends on the name of a user-defined type of external linkage and the instantiation meets the standard library requirements for the original template.

2 The C++ Standard Library reserves the following kinds of names:
   — Macros
   — Global names
   — Names with external linkage

3 If the program declares or defines a name in a context where it is reserved, other than as explicitly allowed by this clause, the behavior is undefined.

17.4.3.1.1  Macro names

Each name defined as a macro in a header is reserved to the implementation for any use if the translation unit includes the header. A translation unit that includes a standard library header shall not #define or #undef names declared in any standard library header.172

2 A translation unit that includes a header shall not contain any macros that define names declared or defined in that header. Nor shall such a translation unit define macros for names lexically identical to keywords. A translation unit shall not #define or #undef names lexically identical to keywords.

17.4.3.1.2  Global names

Certain sets of names and function signatures are always reserved to the implementation:
   — Each name that contains a double underscore _ _ or begins with an underscore followed by an uppercase letter (2.11) is reserved to the implementation for any use.

171) Any library code that instantiates other library templates must be prepared to work adequately with any user-supplied specialization that meets the minimum requirements of the Standard.

172) removed footnote

Draft
— Each name that begins with an underscore is reserved to the implementation for use as a name in the global namespace.\(^{173}\)

### 17.4.3.1.3 External linkage

1. Each name declared as an object with external linkage in a header is reserved to the implementation to designate that library object with external linkage,\(^{174}\) both in namespace `std` and in the global namespace.

2. Each global function signature declared with external linkage in a header is reserved to the implementation to designate that function signature with external linkage.\(^{175}\)

3. Each name having two consecutive underscores (2.11) is reserved to the implementation for use as a name with both `extern "C"` and `extern "C++"` linkage.

4. Each name from the Standard C library declared with external linkage is reserved to the implementation for use as a name with `extern "C"` linkage, both in namespace `std` and in the global namespace.

5. Each function signature from the Standard C library declared with external linkage is reserved to the implementation for use as a function signature with both `extern "C"` and `extern "C++"` linkage,\(^{176}\) or as a name of namespace scope in the global namespace.

### 17.4.3.1.4 Types

For each type T from the Standard C library,\(^{177}\) the types `::T` and `std::T` are reserved to the implementation and, when defined, `::T` shall be identical to `std::T`.

### 17.4.3.2 Headers

If a file with a name equivalent to the derived file name for one of the C++ Standard Library headers is not provided as part of the implementation, and a file with that name is placed in any of the standard places for a source file to be included (16.2), the behavior is undefined.

### 17.4.3.3 Derived classes

Virtual member function signatures defined for a base class in the C++ Standard library may be overridden in a derived class defined in the program (10.3).

### 17.4.3.4 Replacement functions

Clauses 18 through 27 and Annex D describe the behavior of numerous functions defined by the C++ Standard Library. Under some circumstances, however, certain of these function descriptions also apply to replacement functions defined in the program (17.1).

\(^{173}\) Such names are also reserved in namespace `::std` (17.4.3.1).
\(^{174}\) The list of such reserved names includes `errno`, declared or defined in `<cerrno>`.
\(^{175}\) The list of such reserved function signatures with external linkage includes `setjmp(jmp_buf)`, declared or defined in `<csetjmp>`, and `va_end(va_list)`, declared or defined in `<cstdio>`.
\(^{176}\) The function signatures declared in `<cstdint>` and `<cwctype>` are always reserved, notwithstanding the restrictions imposed in subclause 4.5.1 of Amendment 1 to the C Standard for these headers.
\(^{177}\) These types are `clock_t`, `div_t`, `FILE`, `fpos_t`, `lconv`, `ldiv_t`, `mbstate_t`, `ptrdiff_t`, `sig_atomic_t`, `size_t`, `time_t`, `tm`, `va_list`, `wctrans_t`, `wctype_t`, and `wint_t`. 

Draft
A C++ program may provide the definition for any of eight dynamic memory allocation function signatures declared in header `<new>` (3.7.3, clause 18):

- `operator new(std::size_t)`
- `operator new(std::size_t, const std::nothrow_t&)`
- `operator new[](std::size_t)`
- `operator new[](std::size_t, const std::nothrow_t&)`
- `operator delete(void*)`
- `operator delete(void*, const std::nothrow_t&)`
- `operator delete[](void*)`
- `operator delete[](void*, const std::nothrow_t&)`

The program’s definitions are used instead of the default versions supplied by the implementation (18.5). Such replacement occurs prior to program startup (3.2, 3.6). The program’s definitions shall not be specified as `inline`. No diagnostic is required.

### 17.4.3.5 Handler functions

The C++ Standard Library provides default versions of the following handler functions (clause 18):

- `unexpected_handler`
- `terminate_handler`

A C++ program may install different handler functions during execution, by supplying a pointer to a function defined in the program or the library as an argument to (respectively):

- `set_new_handler`
- `set_unexpected`
- `set_terminate`

See also: subclauses 18.5.2, Storage allocation errors, and 18.7, Exception handling.

### 17.4.3.6 Other functions

In certain cases (replacement functions, handler functions, operations on types used to instantiate standard library template components), the C++ Standard Library depends on components supplied by a C++ program. If these components do not meet their requirements, the Standard places no requirements on the implementation.

In particular, the effects are undefined in the following cases:

- for replacement functions (18.5.1), if the installed replacement function does not implement the semantics of the applicable `Required behavior` paragraph.
— for handler functions (18.5.2.2, 18.7.3.1, 18.7.2.2), if the installed handler function does not implement the semantics of the applicable Required behavior: paragraph

— for types used as template arguments when instantiating a template component, if the operations on the type do not implement the semantics of the applicable Requirements subclause (20.1.6, 23.1, 24.1, 26.1). Operations on such types can report a failure by throwing an exception unless otherwise specified.

— if any replacement function or handler function or destructor operation throws an exception, unless specifically allowed in the applicable Required behavior: paragraph.

— if an incomplete type (3.9) is used as a template argument when instantiating a template component.

17.4.3.7 Function arguments

Each of the following statements applies to all arguments to functions defined in the C++ Standard Library, unless explicitly stated otherwise.

— If an argument to a function has an invalid value (such as a value outside the domain of the function, or a pointer invalid for its intended use), the behavior is undefined.

— If a function argument is described as being an array, the pointer actually passed to the function shall have a value such that all address computations and accesses to objects (that would be valid if the pointer did point to the first element of such an array) are in fact valid.

17.4.3.8 Required paragraph

Violation of the preconditions specified in a function’s Required behavior: paragraph results in undefined behavior unless the function’s Throws: paragraph specifies throwing an exception when the precondition is violated.

17.4.4 Conforming implementations

This subclause describes the constraints upon, and latitude of, implementations of the C++ Standard library. The following subclauses describe an implementation’s use of headers (17.4.4.1), macros (17.4.4.2), global functions (17.4.4.3), member functions (17.4.4.4), reentrancy (17.4.4.5), access specifiers (17.4.4.6), class derivation (17.4.4.7), and exceptions (17.4.4.8).

17.4.4.1 Headers

A C++ header may include other C++ headers."

Certain types and macros are defined in more than one header. For such an entity, a second or subsequent header that also defines it may be included after the header that provides its initial definition (3.2).

Header inclusion is limited as follows:

— The C headers (.h form, described in Annex D, D.5) shall include only their corresponding C++ header, as described above (17.4.1.2).

178) C++ headers must include a C++ header that contains any needed definition (3.2).
17.4.4.2 Restrictions on macro definitions

The names or global function signatures described in 17.4.1.1 are reserved to the implementation.

All object-like macros defined by the Standard C library and described in this clause as expanding to integral constant expressions are also suitable for use in #if preprocessing directives, unless explicitly stated otherwise.

17.4.4.3 Global or non-member functions

It is unspecified whether any global or non-member functions in the C++ Standard Library are defined as inline (7.1.2).

A call to a global or non-member function signature described in clauses 18 through 27 and Annex D behaves the same as if the implementation declares no additional global or non-member function signatures.\(^\text{179}\)

A global or non-member function cannot be declared by the implementation as taking additional default arguments.

Unless otherwise specified, no global or non-member function in the standard library shall use a function from another namespace which is found through argument-dependent name lookup (3.4.2). [Note: The phrase “unless otherwise specified” is intended to allow argument-dependent lookup in cases like that of ostream iterators: Effects:

\[
\begin{align*}
* \text{out\_stream} & \ll \text{value} \\
& \text{if (delim} \neq 0) \\
& * \text{out\_stream} \ll \text{delim} \\
& \text{return (*this);}
\end{align*}
\]

— end note ]

17.4.4.4 Member functions

It is unspecified whether any member functions in the C++ Standard Library are defined as inline (7.1.2).

An implementation can declare additional non-virtual member function signatures within a class:

— by adding arguments with default values to a member function signature;\(^\text{180}\) The same latitude does not extend to the implementation of virtual or global or non-member functions, however.

— by replacing a member function signature with default values by two or more member function signatures with equivalent behavior;

— by adding a member function signature for a member function name.

A call to a member function signature described in the C++ Standard library behaves the same as if the implementation declares no additional member function signatures.\(^\text{181}\)

\(^\text{179}\) A valid C++ program always calls the expected library global or non-member function. An implementation may also define additional global or non-member functions that would otherwise not be called by a valid C++ program.

\(^\text{180}\) Hence, taking the address of a member function has an unspecified type.

\(^\text{181}\) A valid C++ program always calls the expected library member function, or one with equivalent behavior. An implementation may also define additional member functions that would otherwise not be called by a valid C++ program.
17.4 Library-wide requirements

17.4.4.5 Reentrancy

Which of the functions in the C++ Standard Library are not reentrant subroutines is implementation-defined.

17.4.4.6 Protection within classes

It is unspecified whether a function signature or class described in clauses 18 through 27 and Annex D is a friend of another class in the C++ Standard Library.

17.4.4.7 Derived classes

It is unspecified whether a class in the C++ Standard Library is itself derived from other classes (with names reserved to the implementation).

Certain classes defined in the C++ Standard Library are derived from other classes in the C++ Standard Library:

— It is unspecified whether a class described in the C++ Standard Library as derived from another class is derived from that class directly, or through other classes (with names reserved to the implementation) that are derived from the specified base class.

In any case:

— A base class described as virtual is always virtual;
— A base class described as virtual"" non- is never virtual;
— Unless explicitly stated otherwise, types with distinct names are distinct types.\(^\text{182}\)

17.4.4.8 Restrictions on exception handling

Any of the functions defined in the C++ Standard Library can report a failure by throwing an exception of the type(s) described in their Throws: paragraph and/or their exception-specification (15.4). An implementation may strengthen the exception-specification for a non-virtual function by removing listed exceptions.\(^\text{183}\)

None of the functions from the Standard C library shall report an error by throwing an exception,\(^\text{184}\) unless it calls a program-supplied function that throws an exception.\(^\text{185}\)

No destructor operation defined in the C++ Standard Library will throw an exception. Any other functions defined in the C++ Standard Library that do not have an exception-specification may throw implementation-defined exceptions unless otherwise specified.\(^\text{186}\) An implementation may strengthen this implicit exception-specification by adding an explicit one.\(^\text{187}\)

\(^{\text{182}}\) An implicit exception to this rule are types described as synonyms for basic integral types, such as size_t (18.1) and streamoff (27.4.1).

\(^{\text{183}}\) That is, an implementation of the function will have an explicit exception-specification that lists fewer exceptions than those specified in this International Standard. It may not, however, change the types of exceptions listed in the exception-specification from those specified, nor add others.

\(^{\text{184}}\) That is, the C library functions all have a throw() exception-specification. This allows implementations to make performance optimizations based on the absence of exceptions at runtime.

\(^{\text{185}}\) The functions qsort() and bsearch() (25.4) meet this condition.

\(^{\text{186}}\) In particular, they can report a failure to allocate storage by throwing an exception of type bad_alloc, or a class derived from bad_alloc (18.5.2.1). Library implementations are encouraged (but not required) to report errors by throwing exceptions from (or derived from) the standard exception classes (18.5.2.1, 18.7, 19.1).

\(^{\text{187}}\) That is, an implementation may provide an explicit exception-specification that defines the subset of “any” exceptions thrown by that function. This implies that the implementation may list implementation-defined types in such an exception-specification.
Chapter 18  Language support library
[lib.language.support]

This clause describes the function signatures that are called implicitly, and the types of objects generated implicitly, during the execution of some C++ programs. It also describes the headers that declare these function signatures and define any related types.

The following subclauses describe common type definitions used throughout the library, characteristics of the predefined types, functions supporting start and termination of a C++ program, support for dynamic memory management, support for dynamic type identification, support for exception processing, and other runtime support, as summarized in Table 15.

Table 15: Language support library summary

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1 Types</td>
<td><code>&lt;cstdlib&gt;</code></td>
</tr>
<tr>
<td>18.2 Implementation properties</td>
<td><code>&lt;limits&gt;</code></td>
</tr>
<tr>
<td></td>
<td><code>&lt;climits&gt;</code></td>
</tr>
<tr>
<td></td>
<td><code>&lt;cfloat&gt;</code></td>
</tr>
<tr>
<td>TR1:</td>
<td><code>&lt;cstdint&gt;</code></td>
</tr>
<tr>
<td>TR1:</td>
<td><code>&lt;cinttypes&gt;</code></td>
</tr>
<tr>
<td>18.4 Start and termination</td>
<td><code>&lt;cstdlib&gt;</code></td>
</tr>
<tr>
<td>18.5 Dynamic memory management</td>
<td><code>&lt;new&gt;</code></td>
</tr>
<tr>
<td>18.6 Type identification</td>
<td><code>&lt;typeinfo&gt;</code></td>
</tr>
<tr>
<td>18.7 Exception handling</td>
<td><code>&lt;exception&gt;</code></td>
</tr>
<tr>
<td>18.8 Other runtime support</td>
<td><code>&lt;cstdarg&gt;</code></td>
</tr>
<tr>
<td></td>
<td><code>&lt;csetjmp&gt;</code></td>
</tr>
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<td></td>
<td><code>&lt;ctime&gt;</code></td>
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<td></td>
<td><code>&lt;csignal&gt;</code></td>
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<tr>
<td></td>
<td><code>&lt;cstdlib&gt;</code></td>
</tr>
<tr>
<td>TR1:</td>
<td><code>&lt;cstdbool&gt;</code></td>
</tr>
</tbody>
</table>

18.1 Types [lib.support.types]

Common definitions.
18.2 Implementation properties

Table 16: Header `<cstdlib>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros</td>
<td>NULL, offsetof</td>
</tr>
<tr>
<td>Types</td>
<td>ptrdiff_t, size_t</td>
</tr>
</tbody>
</table>

Header `<cstdlib>` (Table 16).

2 The contents are the same as the Standard C library header `<stddef.h>`, with the following changes:

3 The macro `NULL` is an implementation-defined C++ null pointer constant in this International Standard (4.10).\(^{188}\)

4 The macro `offsetof(type, member-designator)` accepts a restricted set of `type` arguments in this International Standard. If `type` is not a POD structure or a POD union (clause 9), the results are undefined.\(^{189}\) The expression `offsetof(type, member-designator)` is never type-dependent (14.6.2.2) and it is value-dependent (14.6.2.3) if and only if `type` is dependent. The result of applying the `offsetof` macro to a field that is a static data member or a function member is undefined.

See also: subclause 5.3.3, `sizeof`, subclause 5.7, Additive operators, subclause 12.5, Free store, and ISO C subclause 7.1.6.

18.2 Implementation properties

1 The headers `<limits>`, `<climits>`, `<cfloat>`, and `<cinttypes>` supply characteristics of implementation-dependent fundamental types (3.9.1).

18.2.1 Numeric limits

1 The `numeric_limits` component provides a C++ program with information about various properties of the implementation’s representation of the fundamental types.

2 Specializations shall be provided for each fundamental type, both floating point and integer, including bool. The member `is_specialized` shall be true for all such specializations of `numeric_limits`.

3 For all members declared `static const` in the `numeric_limits` template, specializations shall define these values in such a way that they are usable as integral constant expressions.

4 Non-fundamental standard types, such as `complex<T>` (26.3.2), shall not have specializations.

Header `<limits>` synopsis

```cpp
namespace std {
    template<class T> class numeric_limits;
    enum float_round_style;
    enum float_denorm_style;

    template<> class numeric_limits<bool>;

    template<> class numeric_limits<char>;
    template<> class numeric_limits<signed char>;
```

\(^{188}\) Possible definitions include 0 and 0L but not `(void*)0`.

\(^{189}\) Note that `offsetof` is required to work as specified even if unary `operator&` is overloaded for any of the types involved.
template<> class numeric_limits<unsigned char>;
template<> class numeric_limits<wchar_t>;
template<> class numeric_limits<short>;
template<> class numeric_limits<int>;
template<> class numeric_limits<long>;
template<> class numeric_limits<unsigned short>;
template<> class numeric_limits<unsigned int>;
template<> class numeric_limits<unsigned long>;
template<> class numeric_limits<float>;
template<> class numeric_limits<double>;
template<> class numeric_limits<long double>;

18.2.1.1 Class template numeric_limits

namespace std {
    template<class T> class numeric_limits {
        public:
            static const bool is_specialized = false;
            static T min() throw();
            static T max() throw();

            static const int digits = 0;
            static const int digits10 = 0;
            static const int max_digits10 = 0;
            static const bool is_signed = false;
            static const bool is_integer = false;
            static const bool is_exact = false;
            static int radix = 0;
            static T epsilon() throw();
            static T round_error() throw();

            static const int min_exponent = 0;
            static const int min_exponent10 = 0;
            static const int max_exponent = 0;
            static const int max_exponent10 = 0;

            static const bool has_infinity = false;
            static const bool has_quiet_NaN = false;
            static const bool has_signaling_NaN = false;
            static const float_denorm_style has_denorm = denorm_absent;
            static const bool has_denorm_loss = false;
            static T infinity() throw();
            static T quiet_NaN() throw();
            static T signaling_NaN() throw();
            static T denorm_min() throw();

            static const bool is_iec559 = false;

    }
18.2 Implementation properties

<table>
<thead>
<tr>
<th>Member</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>is_bounded</code></td>
<td>Indicates if the type is bounded.</td>
</tr>
<tr>
<td><code>is_modulo</code></td>
<td>Indicates if the type is modulo.</td>
</tr>
<tr>
<td><code>traps</code></td>
<td>Indicates if traps are generated.</td>
</tr>
<tr>
<td><code>tinyness_before</code></td>
<td>Indicates if tinyness occurs before.</td>
</tr>
<tr>
<td><code>round_style</code></td>
<td>Specifies the rounding mode.</td>
</tr>
</tbody>
</table>

The default `numeric_limits<T>` template shall have all members, but with 0 or false values.

**18.2.1.2 numeric_limits members**

- **min** (throw());
  - Minimum finite value.\(^{(90)}\)
  - For floating types with denormalization, returns the minimum positive normalized value.
  - Meaningful for all specializations in which `is_bounded` != false, or `is_bounded` == false && `is_signed` == false.
- **max** (throw());
  - Maximum finite value.\(^{(91)}\)
  - Meaningful for all specializations in which `is_bounded` != false.
- **digits**;
  - Number of radix digits that can be represented without change.
  - For built-in integer types, the number of non-sign bits in the representation.
  - For floating point types, the number of radix digits in the mantissa.\(^{(92)}\)
- **digits10**;
  - Number of base 10 digits that can be represented without change.\(^{(93)}\)
  - Meaningful for all specializations in which `is_bounded` != false.
- **max_digits10**;
  - Number of base 10 digits required to ensure that values which differ by only one epsilon are always differentiated.
- **is_signed**;

\(^{(90)}\) Equivalent to `CHAR_MIN`, `SHRT_MIN`, `FLT_MIN`, `DBL_MIN`, etc.
\(^{(91)}\) Equivalent to `CHAR_MAX`, `SHRT_MAX`, `FLT_MAX`, `DBL_MAX`, etc.
\(^{(92)}\) Equivalent to `FLT_MANT_DIG`, `DBL_MANT_DIG`, `LDBL_MANT_DIG`.
\(^{(93)}\) Equivalent to `FLT_DIG`, `DBL_DIG`, `LDBL_DIG`. 

Draft
True if the type is signed.
Meaningful for all specializations.

static const bool is_integer;
True if the type is integer.
Meaningful for all specializations.

static const bool is_exact;
True if the type uses an exact representation. All integer types are exact, but not all exact types are integer. For example, rational and fixed-exponent representations are exact but not integer.
Meaningful for all specializations.

static const int radix;
For floating types, specifies the base or radix of the exponent representation (often 2).\(^{194}\)
For integer types, specifies the base of the representation.\(^{195}\)
Meaningful for all specializations.

static T epsilon() throw();
Machine epsilon: the difference between 1 and the least value greater than 1 that is representable.\(^{196}\)
Meaningful for all floating point types.

static T round_error() throw();
Measure of the maximum rounding error.\(^{197}\)

static const int min_exponent;
Minimum negative integer such that \(\text{radix}^{\text{one less than that integer}}\) is a normalized floating point number.\(^{198}\)
Meaningful for all floating point types.

static const int min_exponent10;
Minimum negative integer such that \(10^{\text{power}}\) is in the range of normalized floating point numbers.\(^{199}\)
Meaningful for all floating point types.

\(^{194}\) Equivalent to \texttt{FLT\_RADIUS}.
\(^{195}\) Distinguishes types with bases other than 2 (e.g. BCD).
\(^{196}\) Equivalent to \texttt{FLT\_EPSILON}, \texttt{DBL\_EPSILON}, \texttt{LDBL\_EPSILON}.
\(^{197}\) Rounding error is described in ISO/IEC 10967-1 Language independent arithmetic - Part 1 Section 5.2.8 and Annex A Rationale Section A.5.2.8 - Rounding constants.
\(^{198}\) Equivalent to \texttt{FLT\_MIN\_EXP}, \texttt{DBL\_MIN\_EXP}, \texttt{LDBL\_MIN\_EXP}.
\(^{199}\) Equivalent to \texttt{FLT\_MIN\_10\_EXP}, \texttt{DBL\_MIN\_10\_EXP}, \texttt{LDBL\_MIN\_10\_EXP}.

Draft
18.2 Implementation properties

static const int max_exponent;
Maximum positive integer such that radix raised to the power one less than that integer is a representable finite floating point number.\textsuperscript{200}
Meaningful for all floating point types.

static const int max_exponent10;
Maximum positive integer such that 10 raised to that power is in the range of representable finite floating point numbers.\textsuperscript{201}
Meaningful for all floating point types.

static const bool has_infinity;
True if the type has a representation for positive infinity.
Meaningful for all floating point types.
Shall be true for all specializations in which is_iec559 \(!=\) false.

static const bool has_quiet_NaN;
True if the type has a representation for a quiet (non-signaling) “Not a Number.”\textsuperscript{202}
Meaningful for all floating point types.
Shall be true for all specializations in which is_iec559 \(!=\) false.

static const bool has_signaling_NaN;
True if the type has a representation for a signaling “Not a Number.”\textsuperscript{203}
Meaningful for all floating point types.
Shall be true for all specializations in which is_iec559 \(!=\) false.

static const float_denorm_style has_denorm;
denorm\_present if the type allows denormalized values (variable number of exponent bits)\textsuperscript{204}, denorm\_absent if the type does not allow denormalized values, and denorm\_indeterminate if it is indeterminate at compile time whether the type allows denormalized values.
Meaningful for all floating point types.

static const bool has_denorm_loss;
True if loss of accuracy is detected as a denormalization loss, rather than as an inexact result.\textsuperscript{205}

\textsuperscript{200} Equivalent to FLT_MAX_EXP, DBL_MAX_EXP, LDBL_MAX_EXP.
\textsuperscript{201} Equivalent to FLT_MAX\_10_EXP, DBL_MAX\_10_EXP, LDBL_MAX\_10_EXP.
\textsuperscript{202} Required by LIA-1.
\textsuperscript{203} Required by LIA-1.
\textsuperscript{204} Required by LIA-1.
\textsuperscript{205} See IEC 559.
static T infinity() throw();
44    Representation of positive infinity, if available.\textsuperscript{206}
45    Meaningful for all specializations for which has\_infinity \(!= \) false. Required in specializations for which
46    is\_iec559 \(!= \) false.

static T quiet\_NaN() throw();
46    Representation of a quiet “Not a Number,” if available.\textsuperscript{207}
47    Meaningful for all specializations for which has\_quiet\_NaN \(!= \) false. Required in specializations for which
48    is\_iec559 \(!= \) false.

static T signaling\_NaN() throw();
48    Representation of a signaling “Not a Number,” if available.\textsuperscript{208}
49    Meaningful for all specializations for which has\_signaling\_NaN \(!= \) false. Required in specializations for which
50    is\_iec559 \(!= \) false.

static T denorm\_min() throw();
50    Minimum positive denormalized value.\textsuperscript{209}
51    Meaningful for all floating point types.
52    In specializations for which has\_denorm \(== \) false, returns the minimum positive normalized value.

static const bool is\_iec559;
53    True if and only if the type adheres to IEC 559 standard.\textsuperscript{210}
54    Meaningful for all floating point types.

static const bool is\_bounded;
55    True if the set of values representable by the type is finite.\textsuperscript{211} All built-in types are bounded, this member would
56    be false for arbitrary precision types.
57    Meaningful for all specializations.

static const bool is\_modulo;
57    True if the type is modulo.\textsuperscript{212} A type is modulo if it is possible to add two positive numbers and have a result that
58    wraps around to a third number that is less.
59    Generally, this is false for floating types, true for unsigned integers, and true for signed integers on most
60    machines.

\textsuperscript{206} Required by LIA-1.
\textsuperscript{207} Required by LIA-1.
\textsuperscript{208} Required by LIA-1.
\textsuperscript{209} Required by LIA-1.
\textsuperscript{210} International Electrotechnical Commission standard 559 is the same as IEEE 754.
\textsuperscript{211} Required by LIA-1.
\textsuperscript{212} Required by LIA-1.
Meaningful for all specializations.

```cpp
static const bool traps;
```

true if trapping is implemented for the type if, at program startup, there exists a value of the type that would cause an arithmetic operation using that value to trap.\(^{213}\)

Meaningful for all specializations.

```cpp
static const bool tinyness_before;
```

true if tinyness is detected before rounding.\(^{214}\)

Meaningful for all floating point types.

```cpp
static const float_round_style round_style;
```

The rounding style for the type.\(^{215}\)

Meaningful for all floating point types. Specializations for integer types shall return round_toward_zero.

### 18.2.1.3 Type \texttt{float\_round\_style} \[\text{lib.round.style}\]

```cpp
namespace std {
    enum float_round_style {
        round_indeterminate = -1,
        round_toward_zero = 0,
        round_to_nearest = 1,
        round_toward_infinity = 2,
        round_toward_neg_infinity = 3
    };
}
```

The rounding mode for floating point arithmetic is characterized by the values:

- round_indeterminate if the rounding style is indeterminable
- round_toward_zero if the rounding style is toward zero
- round_to_nearest if the rounding style is to the nearest representable value
- round_toward_infinity if the rounding style is toward infinity
- round_toward_neg_infinity if the rounding style is toward negative infinity

### 18.2.1.4 Type \texttt{float\_denorm\_style} \[\text{lib.denorm.style}\]

\(^{213}\) Required by LIA-1.

\(^{214}\) Refer to IEC 559. Required by LIA-1.

\(^{215}\) Equivalent to FLT_ROUNDS. Required by LIA-1.
namespace std {
    enum float_denorm_style {
        denorm_indeterminate = -1,
        denorm_absent = 0,
        denorm_present = 1
    }
};

The presence or absence of denormalization (variable number of exponent bits) is characterized by the values:
- denorm_indeterminate if it cannot be determined whether or not the type allows denormalized values
- denorm_absent if the type does not allow denormalized values
- denorm_present if the type does allow denormalized values

18.2.1.5 numeric_limits specializations [lib.numeric.special]

All members shall be provided for all specializations. However, many values are only required to be meaningful under certain conditions (for example, epsilon() is only meaningful if is_integer is false). Any value that is not “meaningful” shall be set to 0 or false.

Example:

namespace std {
    template<> class numeric_limits<float> {
    public:
        static const bool is_specialized = true;

        inline static float min() throw() { return 1.17549435E-38F; }
        inline static float max() throw() { return 3.40282347E+38F; }

        static const int digits = 24;
        static const int digits10 = 6;

        static const bool is_signed = true;
        static const bool is_integer = false;
        static const bool is_exact = false;
        static const int radix = 2;
        inline static float epsilon() throw() { return 1.19209290E-07F; }
        inline static float round_error() throw() { return 0.5F; }

        static const int min_exponent = -125;
        static const int min_exponent10 = -37;
        static const int max_exponent = +128;
        static const int max_exponent10 = +38;

        static const bool has_infinity = true;
        static const bool has_quiet_NaN = true;
        static const bool has_signaling_NaN = true;
    }
}
18.2 Implementation properties

static const float_denorm_style has_denorm = denorm_absent;
static const bool has_denorm_loss = false;

inline static float infinity() throw() { return ...; }
inline static float quiet_NaN() throw() { return ...; }
inline static float signaling_NaN() throw() { return ...; }
inline static float denorm_min() throw() { return min(); }

static const bool is_iec559 = true;
static const bool is_bounded = true;
static const bool is_modulo = false;
static const bool traps = true;
static const bool tininess_before = true;
static const float_round_style round_style = round_to_nearest;

— end example ]

The specialization for bool shall be provided as follows:

namespace std {
    template<> class numeric_limits<bool> {
        public:
            static const bool is_specialized = true;
            static bool min() throw() { return false; }
            static bool max() throw() { return true; }

            static const int digits = 1;
            static const int digits10 = 0;
            static const bool is_signed = false;
            static const bool is_integer = true;
            static const bool is_exact = true;
            static const int radix = 2;
            static bool epsilon() throw() { return 0; }
            static bool round_error() throw() { return 0; }
            static const int min_exponent = 0;
            static const int min_exponent10 = 0;
            static const int max_exponent = 0;
            static const int max_exponent10 = 0;

            static const bool has_infinity = false;
            static const bool has_quiet_NaN = false;
            static const bool has_signaling_NaN = false;
            static const float_denorm_style has_denorm = denorm_absent;
            static const bool has_denorm_loss = false;
            static bool infinity() throw() { return 0; }
            static bool quiet_NaN() throw() { return 0; }
            static bool signaling_NaN() throw() { return 0; }
        }
    }
} // end std::numeric_limits

Draft
static bool denorm_min() throw() { return 0; }
static const bool is_iec559 = false;
static const bool is_bounded = true;
static const bool is_modulo = false;
static const bool traps = false;
static const bool tinyness_before = false;
static const float_round_style round_style = round_toward_zero;
}

18.2.2 C Library

1 Header <climits> (Table 17)\textsuperscript{216}

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values:</td>
<td></td>
</tr>
<tr>
<td>CHAR_BIT</td>
<td>INT_MAX LONG_MAX SCHAR_MIN SHRT_MIN ULLONG_MAX</td>
</tr>
<tr>
<td>CHAR_MAX</td>
<td>LLONG_MAX LONG_MIN SCHAR_MAX UCHAR_MAX ULLONG_MAX</td>
</tr>
<tr>
<td>CHAR_MIN</td>
<td>LLONG_MIN MB_LEN_MAX SHRT_MAX UINT_MAX USHRT_MAX</td>
</tr>
<tr>
<td>INT_MIN</td>
<td></td>
</tr>
</tbody>
</table>

2 The contents are the same as the Standard C library header <limits.h>.

3 Header <cfloat> (Table 18)\textsuperscript{217}

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values:</td>
<td></td>
</tr>
<tr>
<td>DBL_DIG</td>
<td>DBL_MIN_EXP FLT_MAX_EXP LDBL_MANT_DIG</td>
</tr>
<tr>
<td>DBL_EPSILON</td>
<td>DECIMAL_DIG FLT_MIN LDBL_MAX_10_EXP</td>
</tr>
<tr>
<td>DBL_MANT_DIG</td>
<td>FLT_DIG FLT_MIN_10_EXP LDBL_MAXEXP</td>
</tr>
<tr>
<td>DBL_MAX</td>
<td>FLT_EPSILON FLT_MIN_10_EXP LDBL_MAX</td>
</tr>
<tr>
<td>DBL_MAX_10_EXP</td>
<td>FLT_EVAL_METHOD FLT_RADIX LDBL_MIN</td>
</tr>
<tr>
<td>DBL_MAX_EXP</td>
<td>FLT_MANT_DIG FLT_ROUNDS LDBL_MIN_10_EXP</td>
</tr>
<tr>
<td>DBL_MIN</td>
<td>FLT_MAX LDBL_DIG LDBL_MIN_EXP</td>
</tr>
<tr>
<td>DBL_MIN_10_EXP</td>
<td>FLT_MAX_10_EXP LDBL_EPSILON</td>
</tr>
</tbody>
</table>

4 The contents are the same as the Standard C library header <float.h>.

\textsuperscript{216}LLONG_MAX, LONGLONG_MIN, and ULLONG_MAX added by TR1.

\textsuperscript{217}DECIMAL_DIG and FLT_EVAL_METHOD added by TR1.

\textsuperscript{218}SEE ALSO: ISO C subclause 7.1.5, 5.2.4.2.2, 5.2.4.2.1.
18.3 TR1: Integer types

18.3.1 Header `<cstdint>` synopsis

namespace std {
    typedef signed integer type int8_t; // optional
    typedef signed integer type int16_t; // optional
    typedef signed integer type int32_t; // optional
    typedef signed integer type int64_t; // optional

    typedef signed integer type int_fast8_t;
    typedef signed integer type int_fast16_t;
    typedef signed integer type int_fast32_t;
    typedef signed integer type int_fast64_t;

    typedef signed integer type int_least8_t;
    typedef signed integer type int_least16_t;
    typedef signed integer type int_least32_t;
    typedef signed integer type int_least64_t;

    typedef signed integer type intmax_t;
    typedef signed integer type intptr_t;

    typedef unsigned integer type uint8_t; // optional
    typedef unsigned integer type uint16_t; // optional
    typedef unsigned integer type uint32_t; // optional
    typedef unsigned integer type uint64_t; // optional

    typedef unsigned integer type uint_fast8_t;
    typedef unsigned integer type uint_fast16_t;
    typedef unsigned integer type uint_fast32_t;
    typedef unsigned integer type uint_fast64_t;

    typedef unsigned integer type uint_least8_t;
    typedef unsigned integer type uint_least16_t;
    typedef unsigned integer type uint_least32_t;
    typedef unsigned integer type uint_least64_t;

    typedef unsigned integer type uintmax_t;
    typedef unsigned integer type uintptr_t;
} // namespace std

The header also defines numerous macros of the form:

INT[FAST LEAST]{8 16 32 64}_MIN
[U]INT[FAST LEAST]{8 16 32 64}_MAX
INT{MAX PTR}_MIN
[U]INT{MAX PTR}_MAX
{PTRDIFF SIG_ATOMIC WCHAR WINT}{_MAX _MIN}
SIZE_MAX

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plus function macros of the form:

\[ \text{[U]INT\{8 16 32 64 MAX\}_C} \]

2. The header defines all functions, types, and macros the same as C99 subclause 7.18.

18.3.2 The header `<stdint.h>`

The header behaves as if it includes the header `<cstdint>`, and provides sufficient using declarations to declare in the global namespace all type names defined in the header `<cstdint>`. The header `<stdint.h>` behaves as if it includes the header `<cstdint>`, and provides sufficient using declarations to declare in the global namespace all type names defined in the header `<cstdint>`.

18.4 Start and termination

The contents are the same as the Standard C library header `<stdlib.h>`, with the following changes:

```c
abort(void)
```

3. The function `abort()` has additional behavior in this International Standard:

- The program is terminated without executing destructors for objects of automatic or static storage duration and without calling the functions passed to `atexit()` (3.6.3).

```c
extern "C" int atexit(void (*f)(void))
extern "C++" int atexit(void (*f)(void))
```

4. **Effects:** The `atexit()` functions register the function pointed to by `f`, to be called without arguments at normal program termination.

5. For the execution of a function registered with `atexit()`, if control leaves the function because it provides no handler for a thrown exception, `terminate()` is called (18.7.3.3).

6. **Implementation limits:** The implementation shall support the registration of at least 32 functions.

7. **Returns:** The `atexit()` function returns zero if the registration succeeds, nonzero if it fails.

```c
exit(int status)
```

8. The function `exit()` has additional behavior in this International Standard:

- First, objects with static storage duration are destroyed and functions registered by calling `atexit` are called. Non-local objects with static storage duration are destroyed in the reverse order of the completion of their constructor. (Automatic objects are not destroyed as a result of calling `exit()`.)

9. Functions registered with `atexit` are called in the reverse order of their registration, except that a function is called after any

---

218) Objects with automatic storage duration are all destroyed in a program whose function `main()` contains no automatic objects and executes the call to `exit()`. Control can be transferred directly to such a `main()` by throwing an exception that is caught in `main()`.
previously registered functions that had already been called at the time it was registered.\textsuperscript{219} A function registered with \texttt{atexit} before a non-local object \texttt{obj1} of static storage duration is initialized will not be called until \texttt{obj1}’s destruction has completed. A function registered with \texttt{atexit} after a non-local object \texttt{obj2} of static storage duration is initialized will be called before \texttt{obj2}’s destruction starts. A local static object \texttt{obj3} is destroyed at the same time it would be if a function calling the \texttt{obj3} destructor were registered with \texttt{atexit} at the completion of the \texttt{obj3} constructor.

— Next, all open C streams (as mediated by the function signatures declared in \texttt{<cstdio>}) with unwritten buffered data are flushed, all open C streams are closed, and all files created by calling \texttt{tmpfile()} are removed.\textsuperscript{220}

— Finally, control is returned to the host environment. If \texttt{status} is zero or \texttt{EXIT_SUCCESS}, an implementation-defined form of the status \textit{successful termination} is returned. If \texttt{status} is \texttt{EXIT_FAILURE}, an implementation-defined form of the status \textit{unsuccessful termination} is returned. Otherwise the status returned is implementation-defined.\textsuperscript{221}

The function \texttt{exit()} never returns to its caller.

\textbf{SEE ALSO:} subclauses 3.6, 3.6.3, ISO C subclause 7.10.4.

\section*{18.5 Dynamic memory management} \hspace{1em} \textbf{[lib.support.dynamic]}

The header \texttt{<new>} defines several functions that manage the allocation of dynamic storage in a program. It also defines components for reporting storage management errors.

\textbf{Header <new> synopsis}

\begin{verbatim}
namespace std {
    class bad_alloc;
    struct nothrow_t {}; extern const nothrow_t nothrow;
typedef void (*new_handler)();
    new_handler set_new_handler(new_handler new_p) throw();
}

void* operator new(std::size_t size) throw(std::bad_alloc);
void* operator new(std::size_t size, const std::nothrow_t&) throw();
void operator delete(void* ptr) throw();
void operator delete(void* ptr, const std::nothrow_t&) throw();
void* operator new[](std::size_t size) throw(std::bad_alloc);
void* operator new[](std::size_t size, const std::nothrow_t&) throw();
void operator delete[](void* ptr) throw();
void operator delete[](void* ptr, const std::nothrow_t&) throw();

void* operator new (std::size_t size, void* ptr) throw();
void* operator new[](std::size_t size, void* ptr) throw();
\end{verbatim}

\textsuperscript{219} A function is called for every time it is registered.

\textsuperscript{220} Any C streams associated with \texttt{cin}, \texttt{cout}, etc (27.3) are flushed and closed when static objects are destroyed in the previous phase. The function \texttt{tmpfile()} is declared in \texttt{<cstdio>}.

\textsuperscript{221} The macros \texttt{EXIT_FAILURE} and \texttt{EXIT_SUCCESS} are defined in \texttt{<cstdlib>}.
void operator delete (void* ptr, void*) throw();
void operator delete[] (void* ptr, void*) throw();

SEE ALSO: 1.7, 3.7.3, 5.3.4, 5.3.5, 12.5, 20.6.

18.5.1 Storage allocation and deallocation

Except where otherwise specified, the provisions of (3.7.3) apply to the library versions of operator new and operator delete.

18.5.1.1 Single-object forms

void* operator new(std::size_t size) throw(std::bad_alloc);

Effects: The allocation function (3.7.3.1) called by a new-expression (5.3.4) to allocate size bytes of storage suitably aligned to represent any object of that size.

Replaceable: a C++ program may define a function with this function signature that displaces the default version defined by the C++ Standard library.

Required behavior: Return a non-null pointer to suitably aligned storage (3.7.3), or else throw a bad_alloc exception. This requirement is binding on a replacement version of this function.

Default behavior:

— Executes a loop: Within the loop, the function first attempts to allocate the requested storage. Whether the attempt involves a call to the Standard C library function malloc is unspecified.

— Returns a pointer to the allocated storage if the attempt is successful. Otherwise, if the last argument to set_new_handler() was a null pointer, throw bad_alloc.

— Otherwise, the function calls the current new_handler (18.5.2.2). If the called function returns, the loop repeats.

— The loop terminates when an attempt to allocate the requested storage is successful or when a called new_handler function does not return.

void* operator new(std::size_t size, const std::nothrow_t&) throw();

Effects: Same as above, except that it is called by a placement version of a new-expression when a C++ program prefers a null pointer result as an error indication, instead of a bad_alloc exception.

Replaceable: a C++ program may define a function with this function signature that displaces the default version defined by the C++ Standard library.

Required behavior: Return a non-null pointer to suitably aligned storage (3.7.3), or else return a null pointer. This nothrow version of operator new returns a pointer obtained as if acquired from the ordinary version. This requirement is binding on a replacement version of this function.

Default behavior:

— Executes a loop: Within the loop, the function first attempts to allocate the requested storage. Whether the attempt involves a call to the Standard C library function malloc is unspecified.
— Returns a pointer to the allocated storage if the attempt is successful. Otherwise, if the last argument to
set_new_handler() was a null pointer, return a null pointer.

— Otherwise, the function calls the current new_handler (18.5.2.2). If the called function returns, the loop
repeats.

— The loop terminates when an attempt to allocate the requested storage is successful or when a called new-
handler function does not return. If the called new_handler function terminates by throwing a bad_alloc
exception, the function returns a null pointer.

[Example:

T* p1 = new T; // throws bad_alloc if it fails
T* p2 = new(nothrow) T; // returns 0 if it fails

— end example]

void operator delete(void* ptr) throw();
void operator delete(void* ptr, const std::nothrow_t&) throw();

Effects: The deallocation function (3.7.3.2) called by a delete-expression to render the value of ptr invalid.

Replaceable: a C++ program may define a function with this function signature that displaces the default version
defined by the C++ Standard library.

Requires: the value of ptr is null or the value returned by an earlier call to the default operator new(std::size_t)
or operator new(std::size_t,const std::nothrow_t&).

Default behavior:

— For a null value of ptr, do nothing.

— Any other value of ptr shall be a value returned earlier by a call to the default operator new, which was
not invalidated by an intervening call to operator delete(void*) (17.4.3.7). For such a non-null value
of ptr, reclaims storage allocated by the earlier call to the default operator new.

Remarks: It is unspecified under what conditions part or all of such reclaimed storage is allocated by a subsequent
call to operator new or any of calloc, malloc, or realloc, declared in <cstdlib>.

18.5.1.2 Array forms [lib.new.delete.array]

void* operator new[](std::size_t size) throw(std::bad_alloc);

Effects: The allocation function (3.7.3.1) called by the array form of a new-expression (5.3.4) to allocate size
bytes of storage suitably aligned to represent any array object of that size or smaller.222

Replaceable: a C++ program can define a function with this function signature that displaces the default version
defined by the C++ Standard library.

222 It is not the direct responsibility of operator new[](std::size_t) or operator delete[](void*) to note the repetition count or element
size of the array. Those operations are performed elsewhere in the array new and delete expressions. The array new expression, may, however,
increase the size argument to operator new[](std::size_t) to obtain space to store supplemental information.
**Language support library**

**18.5 Dynamic memory management**

3 *Required behavior:* Same as for `operator new(std::size_t)`. This requirement is binding on a replacement version of this function.

4 *Default behavior:* Returns `operator new(size)`.

```cpp
void* operator new[](std::size_t size, const std::nothrow_t&) throw();
```

5 *Effects:* Same as above, except that it is called by a placement version of a *new-expression* when a C++ program prefers a null pointer result as an error indication, instead of a bad_alloc exception.

6 *Replaceable:* a C++ program can define a function with this function signature that displaces the default version defined by the C++ Standard library.

7 *Required behavior:* Same as for `operator new(std::size_t,const std::nothrow_t&)`. This nothrow version of `operator new[]` returns a pointer obtained as if acquired from the ordinary version.

8 *Default behavior:* Returns `operator new(size,nothrow)`.

```cpp
void operator delete[](void* ptr) throw();
```

9 *Replaceable:* a C++ program can define a function with this function signature that displaces the default version defined by the C++ Standard library.

10 *Required behavior:* Same as for `operator new(std::size_t, const std::nothrow_t&)`. This nothrow version of `operator new[]` returns a pointer obtained as if acquired from the ordinary version.

11 *Default behavior:* Calls `operator delete(ptr)` or `operator delete(ptr, std::nothrow)` respectively.

18.5.1.3 Placement forms

These functions are reserved, a C++ program may not define functions that displace the versions in the Standard C++ library (17.4.3). The provisions of (3.7.3) do not apply to these reserved placement forms of `operator new` and `operator delete`.

```cpp
void* operator new[](std::size_t size, void* ptr) throw();
```

2 *Returns:* `ptr`.

3 *Remarks:* Intentionally performs no other action.

4 *Example:* This can be useful for constructing an object at a known address:

```cpp
void* place = operator new(sizeof(Something));
Something* p = new (place) Something();
```

— end example

```cpp
void* operator new[](std::size_t size, void* ptr) throw();
```

Draft
18.5 Dynamic memory management

Returns: \( \textit{ptr} \).

Remarks: Intentionally performs no other action.

\[ \text{void operator delete(void* ptr, void*) throw();} \]

Effects: Intentionally performs no action.

Remarks: Default function called when any part of the initialization in a placement new expression that invokes the library’s non-array placement operator new terminates by throwing an exception (5.3.4).

\[ \text{void operator delete[] (void* ptr, void*) throw();} \]

Effects: Intentionally performs no action.

Remarks: Default function called when any part of the initialization in a placement new expression that invokes the library’s array placement operator new terminates by throwing an exception (5.3.4).

18.5.2 Storage allocation errors

18.5.2.1 Class \texttt{bad_alloc}

namespace std {
    class bad_alloc : public exception {
        public:
            bad_alloc() throw();
            bad_alloc(const bad_alloc&) throw();
            bad_alloc& operator=(const bad_alloc&) throw();
            virtual const char* what() const throw();
        }
    }

The class \texttt{bad_alloc} defines the type of objects thrown as exceptions by the implementation to report a failure to allocate storage.

\[ \text{bad_alloc() throw();} \]

Effects: Constructs an object of class \texttt{bad_alloc}.

Remarks: The result of calling \texttt{what()} on the newly constructed object is implementation-defined.

\[ \text{bad_alloc(const bad_alloc&) throw();} \]

\[ \text{bad_alloc& operator=(const bad_alloc&) throw();} \]

Effects: Copies an object of class \texttt{bad_alloc}.

\[ \text{virtual const char* what() const throw();} \]

Returns: An implementation-defined NTBS.
18.5.2.2 Type new_handler
[lib.new.handler]

typedef void (*new_handler)();

1 The type of a handler function to be called by operator new() or operator new[] () (18.5.1) when they cannot satisfy a request for additional storage.

2 Required behavior: A new_handler shall perform one of the following:
   — make more storage available for allocation and then return;
   — throw an exception of type bad_alloc or a class derived from bad_alloc;
   — call either abort() or exit();

18.5.2.3 set_new_handler
[lib.set.new.handler]

new_handler set_new_handler(new_handler new_p) throw();

1 Effects: Establishes the function designated by new_p as the current new_handler.

2 Returns: 0 on the first call, the previous new_handler on subsequent calls.

18.6 Type identification
[lib.support.rtti]

The header <typeinfo> defines a type associated with type information generated by the implementation. It also defines two types for reporting dynamic type identification errors.

Header <typeinfo> synopsis

namespace std {
    class type_info;
    class bad_cast;
    class bad_typeid;
}

See also: 5.2.7, 5.2.8.

18.6.1 Class type_info
[lib.type.info]

namespace std {
    class type_info {
        public:
            virtual ~type_info();
            bool operator==(const type_info& rhs) const;
            bool operator!=(const type_info& rhs) const;
            bool before(const type_info& rhs) const;
            const char* name() const;
        private:
            type_info(const type_info& rhs);
            type_info& operator=(const type_info& rhs);
    };
}

Draft
The class `type_info` describes type information generated by the implementation. Objects of this class effectively store a pointer to a name for the type, and an encoded value suitable for comparing two types for equality or collating order. The names, encoding rule, and collating sequence for types are all unspecified and may differ between programs.

```cpp
bool operator==(const type_info& rhs) const;
Effects: Compares the current object with `rhs`.

Returns: true if the two values describe the same type.
```

```cpp
bool operator!=(const type_info& rhs) const;
Returns: !(this == rhs).
```

```cpp
bool before(const type_info& rhs) const;
Effects: Compares the current object with `rhs`.

Returns: true if `this` precedes `rhs` in the implementation’s collation order.
```

```cpp
const char* name() const;
Returns: an implementation-defined NTBS.
```

```cpp
type_info(const type_info& rhs);
type_info& operator=(const type_info& rhs);
Effects: Copies a `type_info` object.
```

Remarks: Since the copy constructor and assignment operator for `type_info` are private to the class, objects of this type cannot be copied.

### 18.6.2 Class `bad_cast`

```cpp
namespace std {
class bad_cast : public exception {
public:
    bad_cast() throw();
    bad_cast(const bad_cast&) throw();
    bad_cast& operator=(const bad_cast&) throw();
    virtual const char* what() const throw();
};
}
```

The class `bad_cast` defines the type of objects thrown as exceptions by the implementation to report the execution of an invalid `dynamic_cast` expression (5.2.7).

```cpp
bad_cast() throw();
```
2    \textit{Effects:} Constructs an object of class \texttt{bad\_cast}.
3    \textit{Remarks:} The result of calling \texttt{what()} on the newly constructed object is implementation-defined.

\begin{verbatim}
bad\_cast(const bad\_cast&) throw();
bad\_cast\& operator=(const bad\_cast&) throw();
\end{verbatim}

4    \textit{Effects:} Copies an object of class \texttt{bad\_cast}.

\begin{verbatim}
virtual const char\* what() const throw();
\end{verbatim}

5    \textit{Returns:} An implementation-defined NTBS.

6    \textit{Remarks:} The message may be a null-terminated multibyte string (17.3.2.1.3.2), suitable for conversion and display as a \texttt{wstring} (21.2, 22.2.1.4)

\subsection*{18.6.3 Class \texttt{bad\_typeid} \hfill [lib.bad.typeid]}

\begin{verbatim}
namespace std {
    class bad\_typeid : public exception {
    public:
        bad\_typeid() throw();
        bad\_typeid(const bad\_typeid&) throw();
        bad\_typeid\& operator=(const bad\_typeid&) throw();
        virtual const char\* what() const throw();
    }
}
\end{verbatim}

The class \texttt{bad\_typeid} defines the type of objects thrown as exceptions by the implementation to report a null pointer in a \texttt{typeid} expression (5.2.8).

\begin{verbatim}
bad\_typeid() throw();
\end{verbatim}

2    \textit{Effects:} Constructs an object of class \texttt{bad\_typeid}.

3    \textit{Remarks:} The result of calling \texttt{what()} on the newly constructed object is implementation-defined.

\begin{verbatim}
bad\_typeid(const bad\_typeid&) throw();
bad\_typeid\& operator=(const bad\_typeid&) throw();
\end{verbatim}

4    \textit{Effects:} Copies an object of class \texttt{bad\_typeid}.

\begin{verbatim}
virtual const char\* what() const throw();
\end{verbatim}

5    \textit{Returns:} An implementation-defined NTBS.

6    \textit{Remarks:} The message may be a null-terminated multibyte string (17.3.2.1.3.2), suitable for conversion and display as a \texttt{wstring} (21.2, 22.2.1.4)

\section*{18.7 Exception handling \hfill [lib.support.exception]}

The header \texttt{<exception>} defines several types and functions related to the handling of exceptions in a C++ program.
Header `<exception>` synopsis

```cpp
namespace std {
    class exception;
    class bad_exception;

    typedef void (*unexpected_handler)();
    unexpected_handler set_unexpected(unexpected_handler f) throw();
    void unexpected();

    typedef void (*terminate_handler)();
    terminate_handler set_terminate(terminate_handler f) throw();
    void terminate();

    bool uncaught_exception() throw();
}
```

See also: 15.5.

18.7.1 Class `exception`

```cpp
namespace std {
    class exception {
        public:
            exception() throw();
            exception(const exception&) throw();
            exception& operator=(const exception&) throw();
            virtual ~exception() throw();
            virtual const char* what() const throw();
    };
}
```

1 The class `exception` defines the base class for the types of objects thrown as exceptions by C++ Standard library components, and certain expressions, to report errors detected during program execution.

```cpp
exception() throw();
```

2 **Effects:** Constructs an object of class `exception`.

3 **Remarks:** Does not throw any exceptions.

```cpp
exception(const exception&) throw();
exception& operator=(const exception&) throw();
```

4 **Effects:** Copies an exception object.

5 **Remarks:** The effects of calling `what()` after assignment are implementation-defined.

```cpp
virtual ~exception() throw();
```

6 **Effects:** Destroys an object of class `exception`.

7 **Remarks:** Does not throw any exceptions.
virtual const char* what() const throw();

Returns: An implementation-defined NTBS.

Remarks: The message may be a null-terminated multibyte string (17.3.2.1.3.2), suitable for conversion and display as a wstring (21.2, 22.2.1.4). The return value remains valid until the exception object from which it is obtained is destroyed or a non-const member function of the exception object is called.

18.7.2 Violating exception-specifications [lib.exception.unexpected]

18.7.2.1 Class bad_exception [lib.bad.exception]

namespace std {
    class bad_exception : public exception {
        public:
            bad_exception() throw();
            bad_exception(const bad_exception&) throw();
            bad_exception& operator=(const bad_exception&) throw();
            virtual const char* what() const throw();
    };
}

The class bad_exception defines the type of objects thrown as described in (15.5.2).

bad_exception() throw();

Effects: Constructs an object of class bad_exception.

Remarks: The result of calling what() on the newly constructed object is implementation-defined.

bad_exception(const bad_exception&) throw();
bad_exception& operator=(const bad_exception&) throw();

Effects: Copies an object of class bad_exception.

virtual const char* what() const throw();

Returns: An implementation-defined NTBS.

Remarks: The message may be a null-terminated multibyte string (17.3.2.1.3.2), suitable for conversion and display as a wstring (21.2, 22.2.1.4).

18.7.2.2 Type unexpected_handler [lib.unexpected.handler]

typedef void (*unexpected_handler)();

The type of a handler function to be called by unexpected() when a function attempts to throw an exception not listed in its exception-specification.

Required behavior: An unexpected_handler shall not return. See also 15.5.2.

Default behavior: The implementation’s default unexpected_handler calls terminate().

Draft
18.7 Exception handling

18.7.2.3 set_unexpected

unexpected_handler set_unexpected(unexpected_handler f) throw();

Effects: Establishes the function designated by f as the current unexpected_handler.
Requires: f shall not be a null pointer.
Returns: The previous unexpected_handler.

18.7.2.4 unexpected

void unexpected();

Called by the implementation when a function exits via an exception not allowed by its exception-specification (15.5.2). May also be called directly by the program.
Effects: Calls the unexpected_handler function in effect immediately after evaluating the throw-expression (18.7.2.2), if called by the implementation, or calls the current unexpected_handler, if called by the program.

18.7.3 Abnormal termination

18.7.3.1 Type terminate_handler

typedef void (*terminate_handler)();

The type of a handler function to be called by terminate() when terminating exception processing.
Required behavior: A terminate_handler shall terminate execution of the program without returning to the caller.
Default behavior: The implementation’s default terminate_handler calls abort().

18.7.3.2 set_terminate

terminate_handler set_terminate(terminate_handler f) throw();

Effects: Establishes the function designated by f as the current handler function for terminating exception processing.
Requires: f shall not be a null pointer.
Returns: The previous terminate_handler.

18.7.3.3 terminate

void terminate();
1 Called by the implementation when exception handling must be abandoned for any of several reasons (15.5.1). May also be called directly by the program.

Effects: Calls the terminate_handler function in effect immediately after evaluating the throw-expression (18.7.3.1), if called by the implementation, or calls the current terminate_handler function, if called by the program.

18.7.4 uncaught_exception

bool uncaught_exception() throw();

1 Returns: true after completing evaluation of a throw-expression until either completing initialization of the exception-declaration in the matching handler or entering unexpected() due to the throw; or after entering terminate() for any reason other than an explicit call to terminate(). [Note: This includes stack unwinding (15.2). — end note]

2 Remarks: When uncaught_exception() is true, throwing an exception can result in a call of terminate() (15.5.1).

18.8 Other runtime support

Headers <stdarg> (variable arguments), <csetjmp> (nonlocal jumps), <ctime> (system clock clock(), time()), <csignal> (signal handling), <cstdlib> (runtime environment getenv(), system()), and <cstdbool> (_ _ bool_ _true_false_are_defined.

Table 20: Header <stdarg> synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td>va_arg va_end va_start va_copy</td>
</tr>
<tr>
<td>Type:</td>
<td>va_list</td>
</tr>
</tbody>
</table>

Table 21: Header <csetjmp> synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td>setjmp</td>
</tr>
<tr>
<td>Type:</td>
<td>jmp_buf</td>
</tr>
<tr>
<td>Function:</td>
<td>longjmp</td>
</tr>
</tbody>
</table>

Table 22: Header <ctime> synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td>CLOCKS_PER_SEC</td>
</tr>
<tr>
<td>Type:</td>
<td>clock_t</td>
</tr>
<tr>
<td>Function:</td>
<td>clock</td>
</tr>
</tbody>
</table>
The contents of these headers are the same as the Standard C library headers `<stdlib.h>`, `<setjmp.h>`, `<time.h>`, `<signal.h>`, and `<stdio.h>` respectively, with the following changes:

1. The restrictions that ISO C places on the second parameter to the `va_start()` macro in header `<stdarg.h>` are different in this International Standard. The parameter `parmN` is the identifier of the rightmost parameter in the variable parameter list of the function definition (the one just before the ...). [223] If the parameter `parmN` is declared with a function, array, or reference type, or with a type that is not compatible with the type that results when passing an argument for which there is no parameter, the behavior is undefined.

See also: ISO C subclause 4.8.1.1.

2. The function signature `longjmp(jmp_buf jbuf, int val)` has more restricted behavior in this International Standard. If any automatic objects would be destroyed by a thrown exception transferring control to another (destination) point in the program, then a call to `longjmp(jbuf, val)` at the throw point that transfers control to the same (destination) point has undefined behavior.

See also: ISO C subclause 7.10.4, 7.8, 7.6, 7.12.

TR1: The header `<cstdbool>` and the header `<stdbool.h>` shall not define macros named `bool`, `true`, and `false`.

3. The common subset of the C and C++ languages consists of all declarations, definitions, and expressions that may appear in a well formed C++ program and also in a conforming C program. A POF (“plain old function”) is a function that uses only features from this common subset, and that does not directly or indirectly use any function that is not a POF. All signal handlers shall have C linkage. A POF that could be used as a signal handler in a conforming C program does not produce undefined behavior when used as a signal handler in a C++ program. The behavior of any other function used as a signal handler in a C++ program is implementation-defined. [224]

Note that `va_start` is required to work as specified even if unary operator `&` is overloaded for the type of `parmN`.

In particular, a signal handler using exception handling is very likely to have problems.

Table 23: Header `<csignal>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td>SIGABRT SIGILL SIGSEGV SIG_DFL SIG_IGN SIGFPE SIGINT SIGTERM SIG_ERR</td>
</tr>
<tr>
<td>Type:</td>
<td>sig_atomic_t</td>
</tr>
<tr>
<td>Functions:</td>
<td>raise signal</td>
</tr>
</tbody>
</table>

Table 24: Header `<cstdlib>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions:</td>
<td>getenv system</td>
</tr>
</tbody>
</table>

Table 25: Header `<cstdbool>` synopsis

<table>
<thead>
<tr>
<th>Macro:</th>
<th>__bool_true_false_are_defined</th>
</tr>
</thead>
</table>

Draft
Chapter 19  Diagnostics library  [lib.diagnostics]

This clause describes components that C++ programs may use to detect and report error conditions.

The following subclauses describe components for reporting several kinds of exceptional conditions, documenting program assertions, and a global variable for error number codes, as summarized in Table 26.

Table 26: Diagnostics library summary

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.1 Exception classes</td>
<td>&lt;stdexcept&gt;</td>
</tr>
<tr>
<td>19.2 Assertions</td>
<td>&lt;cassert&gt;</td>
</tr>
<tr>
<td>19.3 Error numbers</td>
<td>&lt;cerrno&gt;</td>
</tr>
</tbody>
</table>

19.1 Exception classes  [lib.std.exceptions]

The Standard C++ library provides classes to be used to report certain errors (17.4.4.8) in C++ programs. In the error model reflected in these classes, errors are divided into two broad categories: logic errors and runtime errors.

The distinguishing characteristic of logic errors is that they are due to errors in the internal logic of the program. In theory, they are preventable.

By contrast, runtime errors are due to events beyond the scope of the program. They cannot be easily predicted in advance. The header <stdexcept> defines several types of predefined exceptions for reporting errors in a C++ program. These exceptions are related by inheritance.

Header <stdexcept> synopsis

namespace std {
  class logic_error;
  class domain_error;
  class invalid_argument;
  class length_error;
  class out_of_range;
  class runtime_error;
  class range_error;
  class overflow_error;
  class underflow_error;
}

19.1.1 Class logic_error  [lib.logic.error]
namespace std {

    class logic_error : public exception {
    public:
        explicit logic_error(const string& what_arg);
    }
}

The class logic_error defines the type of objects thrown as exceptions to report errors presumably detectable before the program executes, such as violations of logical preconditions or class invariants.

logic_error(const string& what_arg);

Effects: Constructs an object of class logic_error.

Postcondition: strcmp(what(), what_arg.c_str()) == 0.

19.1.2 Class domain_error [lib.domain.error]

namespace std {

    class domain_error : public logic_error {
    public:
        explicit domain_error(const string& what_arg);
    }
}

The class domain_error defines the type of objects thrown as exceptions by the implementation to report domain errors.

domain_error(const string& what_arg);

Effects: Constructs an object of class domain_error.

Postcondition: strcmp(what(), what_arg.c_str()) == 0.

19.1.3 Class invalid_argument [lib.invalid.argument]

namespace std {

    class invalid_argument : public logic_error {
    public:
        explicit invalid_argument(const string& what_arg);
    }
}

The class invalid_argument defines the type of objects thrown as exceptions to report an invalid argument.

invalid_argument(const string& what_arg);

Effects: Constructs an object of class invalid_argument.

Postcondition: strcmp(what(), what_arg.c_str()) == 0.
19.1.4 **Class length_error**

```cpp
namespace std {
    class length_error : public logic_error {
        public:
            explicit length_error(const string& what_arg);
    };
}
```

The class `length_error` defines the type of objects thrown as exceptions to report an attempt to produce an object whose length exceeds its maximum allowable size.

```cpp
length_error(const string& what_arg);
```

*Effects:* Constructs an object of class `length_error`.

*Postcondition:* `strcmp(what(), what_arg.c_str()) == 0`.

19.1.5 **Class out_of_range**

```cpp
namespace std {
    class out_of_range : public logic_error {
        public:
            explicit out_of_range(const string& what_arg);
    };
}
```

The class `out_of_range` defines the type of objects thrown as exceptions to report an argument value not in its expected range.

```cpp
out_of_range(const string& what_arg);
```

*Effects:* Constructs an object of class `out_of_range`.

*Postcondition:* `strcmp(what(), what_arg.c_str()) == 0`.

19.1.6 **Class runtime_error**

```cpp
namespace std {
    class runtime_error : public exception {
        public:
            explicit runtime_error(const string& what_arg);
    };
}
```

The class `runtime_error` defines the type of objects thrown as exceptions to report errors presumably detectable only when the program executes.

```cpp
runtime_error(const string& what_arg);
```
Effects: Constructs an object of class `runtime_error`.
Postcondition: `strcmp(what(), what_arg.c_str()) == 0`.

19.1.7 Class `range_error` [lib.range.error]

```cpp	namespace std {
    class range_error : public runtime_error {
        public:
            explicit range_error(const string& what_arg);
    };
}
```

The class `range_error` defines the type of objects thrown as exceptions to report range errors in internal computations.

`range_error(const string& what_arg);`

Effects: Constructs an object of class `range_error`.
Postcondition: `strcmp(what(), what_arg.c_str()) == 0`.

19.1.8 Class `overflow_error` [lib.overflow.error]

```cpp	namespace std {
    class overflow_error : public runtime_error {
        public:
            explicit overflow_error(const string& what_arg);
    };
}
```

The class `overflow_error` defines the type of objects thrown as exceptions to report an arithmetic overflow error.

`overflow_error(const string& what_arg);`

Effects: Constructs an object of class `overflow_error`.
Postcondition: `strcmp(what(), what_arg.c_str()) == 0`.

19.1.9 Class `underflow_error` [lib.underflow.error]

```cpp	namespace std {
    class underflow_error : public runtime_error {
        public:
            explicit underflow_error(const string& what_arg);
    };
}
```

The class `underflow_error` defines the type of objects thrown as exceptions to report an arithmetic underflow error.

`underflow_error(const string& what_arg);`
2 Effects: Constructs an object of class `underflow_error`.
3 Postcondition: `strcmp(what(), what_arg.c_str()) == 0`.

### 19.2 Assertions

Provides macros for documenting C++ program assertions, and for disabling the assertion checks.

Header `<cassert>` (Table 27):

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td><code>assert</code></td>
</tr>
</tbody>
</table>

2 The contents are the same as the Standard C library header `<assert.h>`.  

SEE ALSO: ISO C subclause 7.2.

### 19.3 Error numbers

Header `<cerrno>` (Table 28):

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td><code>EDOM EILSEQ ERANGE errno</code></td>
</tr>
</tbody>
</table>

2 The contents are the same as the Standard C library header `<errno.h>`, except that `errno` shall be defined as a macro.  

SEE ALSO: ISO C subclause 7.1.4, 7.2, Amendment 1 subclause 4.3.
Chapter 20  General utilities library  [lib.utilities]

1 This clause describes components used by other elements of the Standard C++ library. These components may also be used by C++ programs.

2 The following clauses describe utility and allocator requirements, utility components, tuples, type traits templates, function objects, dynamic memory management utilities, and date/time utilities, as summarized in Table 29.

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.1 Requirements</td>
<td></td>
</tr>
<tr>
<td>20.2 Utility components</td>
<td>&lt;utility&gt;</td>
</tr>
<tr>
<td>20.3 Tuples</td>
<td>&lt;tuple&gt;</td>
</tr>
<tr>
<td>20.4 Type traits</td>
<td>&lt;type_traits&gt;</td>
</tr>
<tr>
<td>20.5 Function objects</td>
<td>&lt;functional&gt;</td>
</tr>
<tr>
<td>20.6 Memory</td>
<td>&lt;memory&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cstdlib&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cstring&gt;</td>
</tr>
<tr>
<td>20.7 Date and time</td>
<td>&lt;ctime&gt;</td>
</tr>
</tbody>
</table>

20.1 Requirements  [lib.utility.requirements]

1 20.1 describes requirements on template arguments. 20.1.1 through 20.1.4 describe requirements on types used to instantiate templates. 20.1.6 describes the requirements on storage allocators.

20.1.1 Equality comparison  [lib.equalitycomparable]

1 In Table 30, T is a type to be supplied by a C++ program instantiating a template, a, b, and c are values of type const T.

20.1.2 Less than comparison  [lib.lessthancomparable]

1 In the following Table 31, T is a type to be supplied by a C++ program instantiating a template, a and b are values of type T.

20.1.3 Copy construction  [lib.copyconstructible]

1 In the following Table 32, T is a type to be supplied by a C++ program instantiating a template, t is a value of type T,
Table 30: EqualityComparable requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>requirement</th>
</tr>
</thead>
</table>
| a == b     | convertible to bool | == is an equivalence relation, that is, it satisfies the following properties:  
  — For all a, a == a.  
  — If a == b, then b == a.  
  — If a == b and b == c, then a == c. |

Table 31: LessThanComparable requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>a &lt; b</td>
<td>convertible to bool</td>
<td>&lt; is a strict weak ordering relation (25.3)</td>
</tr>
</tbody>
</table>

and u is a value of type const T.

20.1.4 Swapping

In the following Table 33, T is a non-const type to be supplied by a C++ program instantiating a template, and t and u are values of type T.

The Swappable requirement is met by satisfying one or more of the following conditions:

1. T is Swappable if T satisfies the CopyConstructible requirements (20.1.3) and the Assignable requirements (23.1);
2. T is Swappable if a namespace scope function named swap exists in the same namespace as the definition of T, such that the expression swap(t, u) is valid and has the semantics described in Table 33.

20.1.5 Default construction

The default constructor is not required. Certain container class member function signatures specify the default constructor as a default argument. T() shall be a well-defined expression (8.5) if one of those signatures is called using the default argument (8.3.6).

20.1.6 Allocator requirements

The library describes a standard set of requirements for allocators, which are objects that encapsulate the information
Table 33: Swappable requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>post-condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>swap(t, u)</td>
<td>void</td>
<td>t has the value originally held by u, and u has the value originally held by t</td>
</tr>
</tbody>
</table>

about an allocation model. This information includes the knowledge of pointer types, the type of their difference, the type of the size of objects in this allocation model, as well as the memory allocation and deallocation primitives for it. All of the containers (clause 23) are parameterized in terms of allocators.

Table 34 describes the requirements on types manipulated through allocators. All the operations on the allocators are expected to be amortized constant time. Table 35 describes the requirements on allocator types.

Table 34: Descriptive variable definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>T, U</td>
<td>any non-const, non-reference type</td>
</tr>
<tr>
<td>X</td>
<td>an Allocator class for type T</td>
</tr>
<tr>
<td>Y</td>
<td>the corresponding Allocator class for type U</td>
</tr>
<tr>
<td>t</td>
<td>a value of type const. T&amp;</td>
</tr>
<tr>
<td>a, a1, a2</td>
<td>values of type X&amp;</td>
</tr>
<tr>
<td>b</td>
<td>a value of type Y</td>
</tr>
<tr>
<td>p</td>
<td>a value of type X::pointer, obtained by calling a1.allocate, where a1 == a</td>
</tr>
<tr>
<td>q</td>
<td>a value of type X::const_pointer obtained by conversion from a value p.</td>
</tr>
<tr>
<td>r</td>
<td>a value of type X::reference obtained by the expression *p.</td>
</tr>
<tr>
<td>s</td>
<td>a value of type X::const_reference obtained by the expression *q or by conversion from a value r.</td>
</tr>
<tr>
<td>u</td>
<td>a value of type Y::const_pointer obtained by calling Y::allocate, or else 0.</td>
</tr>
<tr>
<td>n</td>
<td>a value of type X::size_type.</td>
</tr>
</tbody>
</table>
Table 35: Allocator requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
</tr>
</thead>
<tbody>
<tr>
<td>X::pointer</td>
<td>Pointer to T.</td>
<td></td>
</tr>
<tr>
<td>X::const_pointer</td>
<td>Pointer to const T.</td>
<td></td>
</tr>
<tr>
<td>X::reference</td>
<td>T &amp;</td>
<td></td>
</tr>
<tr>
<td>X::const_reference</td>
<td>T const&amp;</td>
<td></td>
</tr>
<tr>
<td>X::value_type</td>
<td>Identical to T</td>
<td></td>
</tr>
<tr>
<td>X::size_type</td>
<td>unsigned integral type</td>
<td>a type that can represent the size of the largest object in the allocation model.</td>
</tr>
<tr>
<td>X::difference_type</td>
<td>signed integral type</td>
<td>a type that can represent the difference between any two pointers in the allocation model.</td>
</tr>
<tr>
<td>typename X::template rebind&lt;U&gt;::other</td>
<td>Y</td>
<td>For all U (including T), Y::template rebind&lt;T&gt;::other is X.</td>
</tr>
<tr>
<td>a.address(r)</td>
<td>X::pointer</td>
<td></td>
</tr>
<tr>
<td>a.address(s)</td>
<td>X::const_pointer</td>
<td></td>
</tr>
<tr>
<td>a.allocate(n)</td>
<td>X::pointer</td>
<td>Memory is allocated for n objects of type T but objects are not constructed. allocate may raise an appropriate exception. The result is a random access iterator. [ Note: If n == 0, the return value is unspecified. — end note ]</td>
</tr>
<tr>
<td>a.allocate(n,u)</td>
<td>X::pointer</td>
<td></td>
</tr>
<tr>
<td>a.deallocate(p,n)</td>
<td>(not used)</td>
<td>All n T objects in the area pointed to by p shall be destroyed prior to this call. n shall match the value passed to allocate to obtain this memory. Does not throw exceptions. [ Note: p shall not be null. — end note ]</td>
</tr>
<tr>
<td>a.max_size()</td>
<td>X::size_type</td>
<td>the largest value that can meaningfully be passed to X::allocate()</td>
</tr>
<tr>
<td>a1 == a2</td>
<td>bool</td>
<td>returns true iff storage allocated from each can be deallocated via the other.</td>
</tr>
<tr>
<td>a1 != a2</td>
<td>bool</td>
<td>same as !(a1 == a2)</td>
</tr>
<tr>
<td>X()</td>
<td>bool</td>
<td>creates a default instance. [ Note: a destructor is assumed. — end note ]</td>
</tr>
<tr>
<td>X a(b);</td>
<td>post: Y(a) == b</td>
<td></td>
</tr>
<tr>
<td>a.construct(p,t)</td>
<td>(not used)</td>
<td>Effect: ::new((void*)p) T(t)</td>
</tr>
<tr>
<td>a.destroy(p)</td>
<td>(not used)</td>
<td>Effect: ((T*)p)-&gt;~T()</td>
</tr>
</tbody>
</table>

3 The member class template rebind in the table above is effectively a typedef template: if the name Allocator is bound to SomeAllocator<T>, then Allocator::rebind<U>::other is the same type as SomeAllocator<U>.

4 Implementations of containers described in this International Standard are permitted to assume that their Allocator template parameter meets the following two additional requirements beyond those in Table 35.

\[ \text{Note:} \text{if } \text{sizeof(T)} \text{ is small. That is, there is no need for a container to maintain its own “free list”.} \]
All instances of a given allocator type are required to be interchangeable and always compare equal to each other.

The typedef members `pointer`, `const_pointer`, `size_type`, and `difference_type` are required to be `T*`, `T const*`, `std::size_t`, and `std::ptrdiff_t`, respectively.

Implementors are encouraged to supply libraries that can accept allocators that encapsulate more general memory models and that support non-equal instances. In such implementations, any requirements imposed on allocators by containers beyond those requirements that appear in Table 35, and the semantics of containers and algorithms when allocator instances compare non-equal, are implementation-defined.

### 20.2 Utility components

This subclause contains some basic function and class templates that are used throughout the rest of the library.

**Header `<utility>` synopsis**

```cpp
namespace std {
    // 20.2.1, operators:
    namespace rel_ops {
        template<class T> bool operator!=(const T&, const T&);
        template<class T> bool operator>(const T&, const T&);
        template<class T> bool operator<=(const T&, const T&);
        template<class T> bool operator>=(const T&, const T&);
    }

    // 20.2.2, pairs:
    template <class T1, class T2> struct pair;
    template <class T1, class T2>
    bool operator==(const pair<T1,T2>&, const pair<T1,T2>&);
    template <class T1, class T2>
    bool operator< (const pair<T1,T2>&, const pair<T1,T2>&);
    template <class T1, class T2>
    bool operator!=(const pair<T1,T2>&, const pair<T1,T2>&);
    template <class T1, class T2>
    bool operator> (const pair<T1,T2>&, const pair<T1,T2>&);
    template <class T1, class T2>
    bool operator>=(const pair<T1,T2>&, const pair<T1,T2>&);
    template <class T1, class T2>
    bool operator<=(const pair<T1,T2>&, const pair<T1,T2>&);
    template <class T1, class T2> pair<T1,T2> make_pair(T1, T2);
}

// TR1: // 20.2.2, tuple-like access to pair:
template <class T> class tuple_size;
template <int I, class T> class tuple_element;

    template <class T1, class T2> struct tuple_size<std::pair<T1, T2> >;
    template <class T1, class T2> struct tuple_element<0, std::pair<T1, T2> >;
    template <class T1, class T2> struct tuple_element<1, std::pair<T1, T2> >;

    template<int I, class T1, class T2> P& get(std::pair<T1, T2>&);
```
20.2 Utility components

    template<int I, class T1, class T2> const P& get(const std::pair<T1, T2>&);
}

20.2.1 Operators [lib.operators]

1 To avoid redundant definitions of operatort!= out of operatorequal and operators >, <=, and >= out of operatorequal, the library provides the following:

    template <class T> bool operatort!= (const T& x, const T& y);

2 Requires: Type T is EqualityComparable (20.1.1).

3 Returns: !(x == y).

    template <class T> bool operatort>(const T& x, const T& y);

4 Requires: Type T is LessThanComparable (20.1.2).

5 Returns: y < x.

    template <class T> bool operatort<= (const T& x, const T& y);

6 Requires: Type T is LessThanComparable (20.1.2).

7 Returns: !(y < x).

    template <class T> bool operatort>= (const T& x, const T& y);

8 Requires: Type T is LessThanComparable (20.1.2).

9 Returns: !(x < y).

10 In this library, whenever a declaration is provided for an operatort!=, operatort>, operatort>=, or operatort<=, and requirements and semantics are not explicitly provided, the requirements and semantics are as specified in this clause.

20.2.2 Pairs [lib.pairs]

1 The library provides a template for heterogeneous pairs of values. The library also provides a matching function template to simplify their construction and several templates that provide access to pair objects as if they were tuple objects (see 20.3.1.3 and 20.3.1.4).

    template <class T1, class T2>
    struct pair {
    typedef T1 first_type;
    typedef T2 second_type;

    T1 first;
    T2 second;
    pair();
    pair(const T1& x, const T2& y);
    template<class U, class V> pair(const pair<U, V>& p);
    };

Draft
pair();

Effects: Initializes its members as if implemented: pair() : first(), second() {}

pair(const T1& x, const T2& y);

Effects: The constructor initializes first with x and second with y.

template<class U, class V> pair(const pair<U, V>& p);

Effects: Initializes members from the corresponding members of the argument, performing implicit conversions as needed.

template<class T1, class T2>
void operator==(const pair<T1, T2>& x, const pair<T1, T2>& y);

Returns: x.first == y.first && x.second == y.second.

template<class T1, class T2>
bool operator<(const pair<T1, T2>& x, const pair<T1, T2>& y);

Returns: x.first < y.first || (!y.first < x.first) && x.second < y.second.

template<class T1, class T2>
pair<T1, T2> make_pair(T1 x, T2 y);

Returns: pair<T1, T2>(x, y).

Example: In place of:

```
return pair<int, double>(5, 3.1415926);
// explicit types
```

a C++ program may contain:

```
return make_pair(5, 3.1415926);
// types are deduced
```

— end example }
TR1: template<int I, class T1, class T2>
    const P& get(const pair<T1, T2>&);

Return type: If I == 0 then P is T1, if I == 1 then P is T2, and otherwise the program is ill-formed.

Returns: If I == 0 returns p.first, otherwise returns p.second.

20.3 TR1: Tuples [lib.tuple]

20.3 describes the tuple library that provides a tuple type as the class template tuple that can be instantiated with any number of arguments. An implementation can set an upper limit for the number of arguments. The minimum value for this implementation quantity is defined in Annex B. Each template argument specifies the type of an element in the tuple. Consequently, tuples are heterogeneous, fixed-size collections of values.

Header <tuple> synopsis

namespace std {
    // 20.3.1.1, class template tuple:
    template <class T1 = unspecified, class T2 = unspecified, ...,
              class TM = unspecified> class tuple;

    // 20.3.1.2, tuple creation functions:
    const unspecified ignore;
    template<class T1, class T2, ..., class TN>
        tuple<V1, V2, ..., VN> make_tuple(const T1&, const T2& , ..., const TN&);
    template<class T1, class T2, ..., class TN>
        tuple<T1&, T2&, ..., TN&> tie(T1&, T2& , ..., TN&);

    // 20.3.1.3, tuple helper classes:
    template <class T> class tuple_size;
    template <int I, class T1, class T2, ..., class TN>
        RJ get(tuple<T1, T2, ..., TN>&);
    template <int I, class T1, class T2, ..., class TN>
        PJ get(const tuple<T1, T2, ..., TN>&);

    // 20.3.1.4, element access:
    template <int I, class T1, class T2, ..., class TN>
        bool operator==(const tuple<T1, T2, ..., TN>&, const tuple<U1, U2, ..., UM>&);
    template<class T1, class T2, ..., class TM, class U1, class U2, ..., class UM>
        bool operator<(const tuple<T1, T2, ..., TM>&, const tuple<U1, U2, ..., UM>&);

Draft
template<
class T1, class T2, ...,
class TM, class U1, class U2, ...
class UN>
bool operator!= (const tuple<T1, T2, ...,
TM>&, const tuple<U1, U2, ...
UN>&);

template<
class T1, class T2, ...,
class TM, class U1, class U2, ...
class UN>
bool operator> (const tuple<T1, T2, ...,
TM>&, const tuple<U1, U2, ...
UN>&);

template<
class T1, class T2, ...,
class TM, class U1, class U2, ...
class UN>
bool operator<= (const tuple<T1, T2, ...,
TM>&, const tuple<U1, U2, ...
UN>&);

template<
class T1, class T2, ...,
class TM, class U1, class U2, ...
class UN>
bool operator>= (const tuple<T1, T2, ...,
TM>&, const tuple<U1, U2, ...
UN>&);

} // namespace std

20.3.1 Class template tuple

M denotes the implementation-defined number of template type parameters to the tuple class template, and N denotes the number of template arguments specified in an instantiation.

[Example: Given the instantiation tuple<int, float, char>, N is 3. — end example]

template <class T1 = unspecified,
class T2 = unspecified,
...
class TM = unspecified>
class tuple
{
public:
tuple();
explicit tuple(P1, P2, ..., PN); // iff N > 0

tuple(const tuple&);
template <class U1, class U2, ..., class UN>
tuple(const tuple<U1, U2, ..., UN>&);
template <class U1, class U2>
tuple(const pair<U1, U2>&); // iff N == 2

tuple& operator=(const tuple&);
template <class U1, class U2, ..., class UN>
tuple& operator=(const tuple<U1, U2, ..., UN>&);
template <class U1, class U2>
tuple& operator=(const pair<U1, U2>&); // iff N == 2

};

20.3.1.1 Construction

tuple();

Requires: Each type Ti shall be default constructible.

Effects: Default initializes each element.
tuple(P1, P2, ..., PN);
3 where P_i is T_i if T_i is a reference type, or const T_i& otherwise.
4 Requires: Each type T_i shall be copy constructible.
5 Effects: Copy initializes each element with the value of the corresponding parameter.

tuple(const tuple& u);
6 Requires: Each type T_i shall be copy constructible.
7 Effects: Copy constructs each element of *this with the corresponding element of u.

template <class U1, class U2, ..., class UN> tuple(const tuple<U1, U2, ..., UN>& u);
8 Requires: Each type T_i shall be constructible from the corresponding type U_i.
9 Effects: Constructs each element of *this with the corresponding element of u.
10 \[ Note: In an implementation where one template definition serves for many different values for N, enable_if can be used to make the converting constructor and assignment operator exist only in the cases where the source and target have the same number of elements. Another way of achieving this is adding an extra integral template parameter which defaults to N (more precisely, a metafunction that computes N), and then defining the converting copy constructor and assignment only for tuples where the extra parameter in the source is N. — end note ]

template <class U1, class U2> tuple(const pair<U1, U2>& u);
11 Requires: T_1 shall be constructible from U_1, T_2 shall be constructible from U_2. N == 2.
12 Effects: Constructs the first element with u.first and the second element with u.second.

tuple& operator=(const tuple& u);
13 Requires: Each type T_i shall be assignable.
14 Effects: Assigns each element of u to the corresponding element of *this.
15 Returns: *this

template <class U1, class U2, ..., class UN>
16 tuple& operator=(const tuple<U1, U2, ..., UN>& u);
17 Requires: Each type T_i shall be assignable from the corresponding type U_i.
18 Effects: Assigns each element of u to the corresponding element of *this.
19 Returns: *this

template <class U1, class U2> tuple& operator=(const pair<U1, U2>& u);
20 Requires: T_1 shall be assignable from U_1, T_2 shall be assignable from U_2. N == 2.
21 Effects: Assigns u.first to the first element of *this and u.second to the second element of *this.
22 Returns: *this

Draft
[Note: There are rare conditions where the converting copy constructor is a better match than the element-wise construction, even though the user might intend differently. An example of this is if one is constructing a one-element tuple where the element type is another tuple type `T` and if the parameter passed to the constructor is not of type `T`, but rather a tuple type that is convertible to `T`. The effect of the converting copy construction is most likely the same as the effect of the element-wise construction would have been. However, it is possible to compare the “nesting depths” of the source and target tuples and decide to select the element-wise constructor if the source nesting depth is smaller than the target nesting-depth. This can be accomplished using an `enable_if` template or other tools for constrained templates. — end note ]

### 20.3.1.2 Tuple creation functions

```cpp
template<class T1, class T2, ..., class TN>
tuple<V1, V2, ..., VN> make_tuple(const T1& t1, const T2& t2, ..., const TN& tn);
```

where 

- `Vi` is `X&` if the cv-unqualified type `Ti` is a `reference_wrapper<X>`, otherwise `Vi` is `Ti`.

- The `make_tuple` function template shall be implemented for each different number of arguments from 0 to the maximum number of allowed tuple elements.

- **Returns:** `tuple<V1, V2, ..., VN>(t1, t2, ..., tn)`.

- Example:

```cpp```
```cpp
int i; float j;
make_tuple(i, ref(i), cref(j))
```

creates a tuple of type

```cpp```
```cpp
tuple<int&, int&, const float&>
```

— end example]

```cpp
template<class T1, class T2, ..., class TN>
tuple<T1&, T2&, ..., TN&> tie(T1& t1, T2& t2, ..., TN& tn);
```

- The `tie` function template shall be implemented for each different number of arguments from 0 to the maximum number of allowed tuple elements.

- **Returns:** `tuple<T1&, T2&, ..., TN&>(t1, t2, ..., tn)`. When an argument `t_i` is `ignore`, assigning any value to the corresponding tuple element has no effect.

- Example: `tie` functions allow one to create tuples that unpack tuples into variables. `ignore` can be used for elements that are not needed:

```cpp```
```cpp
int i; std::string s;
tie(i, ignore, s) = make_tuple(42, 3.14, "C++");
// i == 42, s == "C++"
```

— end example]
20.3 TR1: Tuples

20.3.1.3 Tuple helper classes

**tuple_size<T>::value**

1. Requires: T is an instantiation of class template tuple.
2. Type: integral constant expression.
3. Value: Number of elements in T.

**tuple_element<I, T>::type**

4. Requires: 0 ≤ I < N. The program is ill-formed if I is out of bounds.
5. Value: The type of the Ith element of T, where indexing is zero-based.

20.3.1.4 Element access

**template <int I, class T1, class T2, ..., class TN>
RJ get(tuple<T1, T2, ..., TN>& t);**

1. Requires: 0 ≤ I < N. The program is ill-formed if I is out of bounds.
2. Return type: RJ, where J=I+1. If TJ is a reference type, then RJ is TJ, otherwise RJ is TJ&.
3. Returns: A reference to the Ith element of t, where indexing is zero-based.

**template <int I, class T1, class T2, ..., class TN>
PJ get(const tuple<T1, T2, ..., TN>& t);**

4. Requires: 0 ≤ I < N. The program is ill-formed if I is out of bounds.
5. Return type: PJ, where J=I+1. If TJ is a reference type, then PJ is TJ, otherwise PJ is const TJ&.
6. Returns: A const reference to the Ith element of t, where indexing is zero-based.

[Note: Constness is shallow. If TJ is some reference type X&, the return type is X&, not const X&. However, if the element type is non-reference type T, the return type is const T&. This is consistent with how constness is defined to work for member variables of reference type. —end note.]

[Note: The reason get is a nonmember function is that if this functionality had been provided as a member function, invocations where the type depended on a template parameter would have required using the template keyword. —end note]

20.3.1.5 Relational operators

**template<class T1, class T2, ..., class TN, class U1, class U2, ..., class UN>
bool operator==(const tuple<T1, T2, ..., TN>& t, const tuple<U1, U2, ..., UN>& u);**

1. Requires: For all i, where 0 ≤ i < N, get<i>(t) == get<i>(u) is a valid expression returning a type that is convertible to bool.

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Returns: true iff get<i>(t) == get<i>(u) for all i. For any two zero-length tuples e and f, e == f returns true.

Effects: The elementary comparisons are performed in order from the zeroth index upwards. No comparisons or element accesses are performed after the first equality comparison that evaluates to false.

template<class T1, class T2, ..., class TN, class U1, class U2, ..., class UN>
bool operator<(const tuple<T1, T2, ..., TN>& t, const tuple<U1, U2, ..., UN>& u);

Requires: For all i, where 0 <= i < N, get<i>(t) < get<i>(u) is a valid expression returning a type that is convertible to bool.

Returns: The result of a lexicographical comparison between t and u. The result is defined as: (bool)(get<0>(t) < get<0>(u)) || (!((bool)(get<0>(u) < get<0>(t)) && t_tail < u_tail)), where r_tail for some tuple r is a tuple containing all but the first element of r. For any two zero-length tuples e and f, e < f returns false.

returns:

Template<class T1, class T2, ..., class TN, class U1, class U2, ..., class UN>
bool operator!=(const tuple<T1, T2, ..., TM>& t, const tuple<U1, U2, ..., UM>& u);

Returns: !(t == u).

Template<class T1, class T2, ..., class TN, class U1, class U2, ..., class UN>
bool operator<=(const tuple<T1, T2, ..., TN>& t, const tuple<U1, U2, ..., UN>& u);

Returns: !(u < t)

Template<class T1, class T2, ..., class TN, class U1, class U2, ..., class UN>
bool operator>=(const tuple<T1, T2, ..., TN>& t, const tuple<U1, U2, ..., UN>& u);

Returns: !(t < u)

Note: The above definitions for comparison operators do not require t_tail (or u_tail) to be constructed. It may not even be possible, as t and u are not required to be copy constructible. Also, all comparison operators are short circuited; they do not perform element accesses beyond what is required to determine the result of the comparison. —end note]
### Table 36: Type traits library summary

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.4.1 Requirements</td>
<td></td>
</tr>
<tr>
<td>20.4.5 Unary type traits</td>
<td>&lt;type_traits&gt;</td>
</tr>
<tr>
<td>20.4.6 Relationships between types</td>
<td>&lt;type_traits&gt;</td>
</tr>
<tr>
<td>20.4.7 Transformations between types</td>
<td>&lt;type_traits&gt;</td>
</tr>
</tbody>
</table>

with the arguments to the template integral_constant determined by the requirements for the particular property being described.

2 A **BinaryTypeTrait** is a template that describes a relationship between two types. It shall be a class template that takes two template type arguments and, optionally, additional arguments that help define the relationship being described. It shall be **DefaultConstructible** and derived, directly or indirectly, from an instance of the template integral_constant (20.4.3), with the arguments to the template integral_constant determined by the requirements for the particular relationship being described.

3 A **TransformationTypeTrait** is a template that modifies a property of a type. It shall be a class template that takes one template type argument and, optionally, additional arguments that help define the modification. It shall define a nested type named type, which shall be a synonym for the modified type.

### 20.4.2 Header <type_traits> synopsis

```
namespace std {
    // [20.4.3] helper class:
    template <class T, T v> struct integral_constant;
    typedef integral_constant<bool, true> true_type;
    typedef integral_constant<bool, false> false_type;

    // [20.4.5.1] primary type categories:
    template <class T> struct is_void;
    template <class T> struct is_integral;
    template <class T> struct is_floating_point;
    template <class T> struct is_array;
    template <class T> struct is_pointer;
    template <class T> struct is_reference;
    template <class T> struct is_member_object_pointer;
    template <class T> struct is_member_function_pointer;
    template <class T> struct is_enum;
    template <class T> struct is_union;
    template <class T> struct is_class;
    template <class T> struct is_function;

    // [20.4.5.2] composite type categories:
    template <class T> struct is_arithmetic;
    template <class T> struct is_fundamental;
    template <class T> struct is_object;
    template <class T> struct is_scalar;
    template <class T> struct is_compound;
```

Draft
template <class T> struct is_member_pointer;

// [20.4.5.3] type properties:
template <class T> struct is_const;
template <class T> struct is_volatile;
template <class T> struct is_pod;
template <class T> struct is_empty;
template <class T> struct is_polymorphic;
template <class T> struct is_abstract;
template <class T> struct has_trivial_constructor;
template <class T> struct has_trivial_copy;
template <class T> struct has_trivial_destructor;
template <class T> struct has_nothrow_constructor;
template <class T> struct has_nothrow_copy;
template <class T> struct has_nothrow_destructor;
template <class T> struct has_virtual_destructor;
template <class T> struct is_signed;
template <class T> struct is_unsigned;
template <class T> struct alignment_of;
template <class T> struct rank;
template <class T, unsigned I = 0> struct extent;

// [20.4.6] type relations:
template <class T, class U> struct is_same;
template <class Base, class Derived> struct is_base_of;
template <class From, class To> struct is_convertible;

// [20.4.7.1] const-volatile modifications:
template <class T> struct remove_const;
template <class T> struct remove_volatile;
template <class T> struct remove_cv;
template <class T> struct add_const;
template <class T> struct add_volatile;
template <class T> struct add_cv;

// [20.4.7.2] reference modifications:
template <class T> struct remove_reference;
template <class T> struct add_reference;

// [20.4.7.3] array modifications:
template <class T> struct remove_extent;
template <class T> struct remove_all_extents;

// [20.4.7.4] pointer modifications:
template <class T> struct remove_pointer;
template <class T> struct add_pointer;

// [20.4.8] other transformations:
template <std::size_t Len, std::size_t Align> struct aligned_storage;

Draft
20.4.3 Helper classes

```cpp
template <class T, T v>
struct integral_constant {
    static const T value = v;
    typedef T value_type;
    typedef integral_constant<T, v> type;
};
```

typedef integral_constant<bool, true> true_type;

typedef integral_constant<bool, false> false_type;

The class template `integral_constant` and its associated typedefs `true_type` and `false_type` are used as base classes to define the interface for various type traits.

20.4.4 General Requirements

1. Tables 37, 38, 39, and 41 define type predicates. Each type predicate `pred<T>` shall be a `UnaryTypeTrait (20.4.1)`, derived directly or indirectly from `true_type` if the corresponding condition is true, otherwise from `false_type`. Each type predicate `pred<T, U>` shall be a `BinaryTypeTrait (20.4.1)`, derived directly or indirectly from `true_type` if the corresponding condition is true, otherwise from `false_type`.

2. Table 40 defines various type queries. Each type query shall be a `UnaryTypeTrait (20.4.1)`, derived directly or indirectly from `integral_constant<std::size_t, value>`, where `value` is the value of the property being queried.

3. Tables 42, 43, 44, and 45 define type transformations. Each transformation shall be a `TransformationTrait (20.4.1)`.

4. Table 46 defines a template that can be instantiated to define a type with a specific alignment and size.

20.4.5 Unary Type Traits

1. This subclause contains templates that may be used to query the properties of a type at compile time.

2. For all of the class templates X declared in this clause, instantiating that template with a template-argument that is a class template specialization may result in the implicit instantiation of the template argument if and only if the semantics of X require that the argument must be a complete type.

20.4.5.1 Primary Type Categories

1. The primary type categories correspond to the descriptions given in section [basic.types] of the C++ standard.

2. For any given type T, the result of applying one of these templates to T and to `cv-qualified T` shall yield the same result.

3. The behavior of a program that adds specializations for any of the class templates defined in this clause is undefined.

[Note: For any given type T, exactly one of the primary type categories has a `value` member that evaluates to `true.` — end note]

Table 37: Primary Type Category Predicates

<table>
<thead>
<tr>
<th>Template</th>
<th>Condition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


```cpp
template <class T>
struct is_void;
T is void

template <class T>
struct is_integral;
T is an integral type
([basic.fundamental])

template <class T>
struct is_floating_point;
T is a floating point type
([basic.fundamental])

template <class T>
struct is_array;
T is an array type
([basic.compound])
Class template array
((23.2.1)) is not an array type.

template <class T>
struct is_pointer;
T is a pointer type
([basic.compound])
Includes function pointers,
but not pointers to members.

template <class T>
struct is_reference;
T is a reference type
([basic.fundamental])
Includes references to
functions.

template <class T>
struct is_member_object_pointer;
T is a pointer to data member

---

20.4.5.2 Composite type traits [lib.meta.unary.comp]

1 These templates provide convenient compositions of the primary type categories, corresponding to the descriptions given
in section [basic.types].

2 For any given type T, the result of applying one of these templates to T, and to cv-qualified T shall yield the same result.

3 The behavior of a program that adds specializations for any of the class templates defined in this clause is undefined.

Table 38: Composite Type Category Predicates

<table>
<thead>
<tr>
<th>Template</th>
<th>Condition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;class T&gt; struct is_arithmetic;</td>
<td>T is an arithmetic type</td>
<td>([basic.fundamental])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_fundamental;</td>
<td>T is a fundamental type</td>
<td>([basic.fundamental])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_object;</td>
<td>T is an object type</td>
<td>([basic.types])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_scalar;</td>
<td>T is a scalar type</td>
<td>([basic.types])</td>
</tr>
</tbody>
</table>
```

Draft
20.4 TR1: Metaprogramming and type traits

<table>
<thead>
<tr>
<th>Template</th>
<th>Condition</th>
<th>Preconditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;class T&gt; struct is_compound;</td>
<td>T is a compound type</td>
<td>([basic.compound])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_member_pointer;</td>
<td>T is a pointer to a member or member function</td>
<td></td>
</tr>
</tbody>
</table>

20.4.5.3 Type properties

These templates provide access to some of the more important properties of types.

1. It is unspecified whether the library defines any full or partial specialisations of any of these templates. A program may specialise any of these templates on a user-defined type, provided the semantics of the specialisation match those given for the template in its description.

Table 39: Type Property Predicates

<table>
<thead>
<tr>
<th>Template</th>
<th>Condition</th>
<th>Preconditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;class T&gt; struct is_const;</td>
<td>T is const-qualified</td>
<td>([basic.qualifier])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_volatile;</td>
<td>T is volatile-qualified</td>
<td>([basic.qualifier])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_pod;</td>
<td>T is a POD type</td>
<td>([basic.types])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_empty;</td>
<td>T is an empty class</td>
<td>([class])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_polymorphic;</td>
<td>T is a polymorphic class</td>
<td>([class.virtual])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct is_abstract;</td>
<td>T is an abstract class</td>
<td>([class.abstract])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct has_trivial_constructor;</td>
<td>The default constructor for T is trivial</td>
<td>([class.ctor])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct has_trivial_copy;</td>
<td>The copy constructor for T is trivial</td>
<td>([class.copy])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct has_trivial_assign;</td>
<td>The assignment operator for T is trivial</td>
<td>([class.copy])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct has_trivial_destructor;</td>
<td>The destructor for T is trivial</td>
<td>([class.dtor])</td>
</tr>
<tr>
<td>template &lt;class T&gt; struct has_nothrow_constructor;</td>
<td>The default constructor for T has an empty exception specification or can otherwise be deduced never to throw an exception</td>
<td>T shall be a complete type.</td>
</tr>
</tbody>
</table>
Table 40: Type Property Queries

<table>
<thead>
<tr>
<th>Template</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>template &lt;class T&gt; struct alignment_of;</code></td>
<td>An integer value representing the number of bytes of the alignment of objects of type T; an object of type T may be allocated at an address that is a multiple of its alignment ([basic.types]). Precondition: T shall be a complete type.</td>
</tr>
<tr>
<td><code>template &lt;class T&gt; struct rank;</code></td>
<td>An integer value representing the rank of objects of type T ([dcl.array]). [Note: The term “rank” here is used to describe the number of dimensions of an array type. — end note]</td>
</tr>
<tr>
<td><code>template &lt;class T, template &lt;unsigned I = 0&gt; struct extent;</code></td>
<td>An integer value representing the extent (dimension) of the T’th bound of objects of type T (8.3.4). If the type T is not an array type, has rank of less than I, or if I == 0 and T is of type “array of unknown bound of U,” then value shall evaluate to zero; otherwise value shall evaluate to the number of elements in the T’th array bound of T. [Note: The term “extent” here is used to describe the number of elements in an array type — end note]</td>
</tr>
</tbody>
</table>

3 [Example:

// the following assertions hold:
assert(rank<int>::value == 0);
assert(rank<int[2]>::value == 1);
assert(rank<int[]>::value == 2);

— end example ]

4 [Example:
20.4 Metaprogramming and type traits

General utilities library 444

// the following assertions hold:
assert(extent<int>::value == 0);
assert(extent<int[2]>::value == 2);
assert(extent<int[2][4]>::value == 2);
assert(extent<int[]>[4]>::value == 0);
assert((extent<int, 1>::value) == 0);
assert((extent<int[2], 1>::value) == 0);
assert((extent<int[2][4], 1>::value) == 4);
assert((extent<int[], 4>::value) == 4);

— end example ]

20.4.6 Relationships between types [lib.meta.rel]

Table 41: Type Relationship Predicates

<table>
<thead>
<tr>
<th>Template</th>
<th>Condition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;class T, class U&gt; struct is_same;</td>
<td>T and U name the same type</td>
<td></td>
</tr>
<tr>
<td>template &lt;class Base, class Derived&gt; struct is_base_of;</td>
<td>Base is a base class of Derived ([class.derived]) or Base and Derived name the same type</td>
<td>Preconditions: Base and Derived shall be complete types.</td>
</tr>
<tr>
<td>template &lt;class From, class To&gt; struct is_convertible;</td>
<td>An imaginary lvalue of type From is implicitly convertible to type To ([conv])</td>
<td>Special conversions involving string-literals and null-pointer constants are not considered ([conv.array], [conv.ptr], and [conv.mem]). No function-parameter adjustments ([dcl.fct]) are made to type To when determining whether From is convertible to To; this implies that if type To is a function type or an array type, then the condition is false. See below.</td>
</tr>
</tbody>
</table>

The expression is_convertible<From,To>::value is ill-formed if:

- Type From is an incomplete type ([basic.types]).
- Type To is an incomplete or abstract type ([basic.types]).
- The conversion is ambiguous. An example of an ambiguous conversion is a type From that has multiple base classes of type To ([class.member.lookup]).
- Type To is of class type and the conversion would invoke a non-public constructor of To ([class.access] and [class.conv.ctor]).
— Type From is of class type and the conversion would invoke a non-public conversion operator of From ([class.access] and [class.conv.fct]).

2 Except that:
   — When From is void and To is not void then value is false.
   — When To is void then value is true.

### 20.4.7 Transformations between types

This sub-clause contains templates that may be used to transform one type to another following some predefined rule.

Each of the templates in this header shall be a Transformation Trait (20.4.1).

#### 20.4.7.1 Const-volatile modifications

<table>
<thead>
<tr>
<th>Template</th>
<th>Comments</th>
</tr>
</thead>
</table>
| template <class T>
struct remove_const;
| The member typedef type shall be the same as T except that any top level const-qualifier has been removed. [Example: remove_const<const volatile int>::type evaluates to volatile int, whereas remove_const<const int*> is const int*. —end example] |
| template <class T>
struct remove_volatile;
| The member typedef type shall be the same as T except that any top level volatile-qualifier has been removed. [Example: remove_volatile<const volatile int>::type evaluates to const int, whereas remove_volatile<volatile int*> is volatile int*. —end example] |
| template <class T>
struct remove_cv;
| The member typedef type shall be the same as T except that any top level cv-qualifier has been removed. [Example: remove_cv<const volatile int>::type evaluates to int, whereas remove_cv<const volatile int*> is const volatile int*. —end example] |
| template <class T>
struct add_const;
| If T is a reference, function, or top level const-qualified type, then type shall be the same as T, otherwise T const. |
| template <class T>
struct add_volatile;
| If T is a reference, function, or top level volatile-qualified type, then type shall be the same as T, otherwise T volatile. |
| template <class T>
struct add_cv;
| The member typedef type shall be the same type as add_const<typename add_volatile<T>::type>::type. |

#### 20.4.7.2 Reference modifications

<table>
<thead>
<tr>
<th>Template</th>
<th>Comments</th>
</tr>
</thead>
</table>
| template <class T>
struct remove_reference;
| The member typedef type shall be the same as T, except any reference qualifier has been removed. |

Draft
20.4 TR1: Metaprogramming and type traits General utilities library 446

Template <class T>
struct add_reference;

If T is a reference type, then the member typedef type shall be T, otherwise T&.

20.4.7.3 Array modifications [lib.meta.trans.arr]

Table 44: Array modifications

<table>
<thead>
<tr>
<th>Template</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;class T&gt;</td>
<td>If T is “array of U”, the member typedef type shall be U, otherwise T. For multidimensional</td>
</tr>
<tr>
<td>struct remove_extent;</td>
<td>arrays, only the first array dimension is removed. For a type “array of const U”, the</td>
</tr>
<tr>
<td></td>
<td>resulting type is const U.</td>
</tr>
<tr>
<td>template &lt;class T&gt;</td>
<td>If T is “multi-dimensional array of U”, the resulting member typedef type is U, otherwise T.</td>
</tr>
<tr>
<td>struct remove_all_extents;</td>
<td></td>
</tr>
</tbody>
</table>

1 [Example

// the following assertions hold:
assert((is_same<remove_extent<int>::type, int>::value));
assert((is_same<remove_extent<int[2]>::type, int>::value));
assert((is_same<remove_extent<int[2][3]>::type, int[3]>::value));
assert((is_same<remove_extent<int[3]>::type, int[3]>::value));

— end example ]

2 [Example

// the following assertions hold:
assert((is_same<remove_all_extents<int>::type, int>::value));
assert((is_same<remove_all_extents<int[2]>::type, int>::value));
assert((is_same<remove_all_extents<int[2][3]>::type, int>::value));
assert((is_same<remove_all_extents<int[3]>::type, int>::value));

— end example ]

20.4.7.4 Pointer modifications [lib.meta.trans.ptr]

Table 45: Pointer modifications

<table>
<thead>
<tr>
<th>Template</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;class T&gt;</td>
<td>The member typedef type shall be the same as T, except any top level indirection has been</td>
</tr>
<tr>
<td>struct remove_pointer;</td>
<td>removed. Note: pointers to members are left unchanged by remove_pointer.</td>
</tr>
<tr>
<td></td>
<td>The member typedef type shall be the same as remove_reference&lt;T&gt;::type if T is a reference</td>
</tr>
<tr>
<td></td>
<td>type, otherwise T*.</td>
</tr>
</tbody>
</table>

20.4.8 Other transformations [lib.meta.trans.other]
Table 46: Other transformations

<table>
<thead>
<tr>
<th>Template</th>
<th>Condition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>template &lt;template &lt;std::size_t Len, std::size_t Align&gt; struct aligned_storage;</td>
<td>Len is nonzero. Align is equal to alignment_of&lt;T&gt;::value for some type T.</td>
<td>The member typedef type shall be a POD type suitable for use as uninitialized storage for any object whose size is at most Len and whose alignment is a divisor of Align.</td>
</tr>
</tbody>
</table>

1 [Note: a typical implementation would define type as:

```cpp
union type
{
    unsigned char __data[Len];
    Aligner __align;
};
```

where Aligner is the smallest POD type for which alignment_of<Aligner>::value is Align. — end note ]

20.4.9 Implementation requirements

1 The behaviour of all the class templates defined in <type_traits> shall conform to the specifications given, except where noted below.

2 [Note: The latitude granted to implementers in this clause is temporary, and is expected to be removed in future revisions of this document. — end note ]

3 If the implementation cannot differentiate between class and union types, then the class templates is_class and is_union shall be defined as follows:

```cpp
template <class T> struct is_class {};
template <class T> struct is_union {};
```

4 If the implementation cannot detect polymorphic types, then the class template is_polymorphic shall be defined as follows:

```cpp
template <class T> struct is_polymorphic {};
```

5 If the implementation cannot detect abstract types, then the class template is_abstract shall be defined as follows:

```cpp
template <class T> struct is_abstract {};
```

6 If the implementation cannot determine whether a type T has a virtual destructor, e.g. a pure library implementation with no compiler support, then has_virtual_destructor<T> shall be derived, directly or indirectly, from false_type (20.4.1).

7 It is unspecified under what circumstances, if any, is_empty<T>::value evaluates to true.

8 It is unspecified under what circumstances, if any, is_pod<T>::value evaluates to true, except that, for all types T:
20.5 Function objects

Function objects are objects with an \texttt{operator()} defined. In the places where one would expect to pass a pointer to a function to an algorithmic template (clause 25), the interface is specified to accept an object with an \texttt{operator()} defined. This not only makes algorithmic templates work with pointers to functions, but also enables them to work with arbitrary function objects.

\begin{verbatim}
namespace std {
    // 20.5.3, base:
    template <class Arg, class Result> struct unary_function;
    template <class Arg1, class Arg2, class Result> struct binary_function;

    // TR1: 20.5.4 result_of:
    template <class FunctionCallType> class result_of;

    // TR1: 20.5.5, reference_wrapper:
    template <class T> class reference_wrapper;

    template <class T> reference_wrapper<T> ref(T&);
    template <class T> reference_wrapper<const T> cref(const T&);

    template <class T> reference_wrapper<T> ref(reference_wrapper<T>);  
    template <class T> reference_wrapper<const T> cref(reference_wrapper<T>);

    // 20.5.6, arithmetic operations:
    template <class T> struct plus;
    template <class T> struct minus;
    template <class T> struct multiplies;
    template <class T> struct divides;
    template <class T> struct modulus;
    template <class T> struct negate;

    Draft
\end{verbatim}
template <class T> struct equal_to;
template <class T> struct not_equal_to;
template <class T> struct greater;
template <class T> struct less;
template <class T> struct greater_equal;
template <class T> struct less_equal;

// 20.5.8, logical operations:
template <class T> struct logical_and;
template <class T> struct logical_or;
template <class T> struct logical_not;

// 20.5.9, negators:
template <class Predicate> class unary_negate;
template <class Predicate>
  unary_negate<Predicate> not1(const Predicate&);
template <class Predicate> class binary_negate;
template <class Predicate>
  binary_negate<Predicate> not2(const Predicate&);

// 20.5.10, bind:
TR1: template<class T> struct is_bind_expression;
TR1: template<class T> struct is_placeholder;
TR1: template<class Fn, class T1, ..., class TN>
  unspecified bind(Fn, T1, ..., TN);
TR1: template<class R, class Fn, class T1, ..., class Tn>
  unspecified bind(Fn, T1, ..., Tn);

TR1: namespace placeholders {
  // M is the implementation-defined number of placeholders
  extern unspecified _1;
  extern unspecified _2;
  .
  .
  .
  extern unspecified _M;
}

// D.8, binders (deprecated):
template <class OperationFn> class binder1st;
template <class OperationFn, class T>
  binder1st<OperationFn> bind1st(const OperationFn&, const T&);
template <class OperationFn> class binder2nd;
template <class OperationFn, class T>
  binder2nd<OperationFn> bind2nd(const OperationFn&, const T&);

// 20.5.11, adaptors:
template <class Arg, class Result> class pointer_to_unary_function;
template <class Arg, class Result>
pointer_to_unary_function<Arg, Result> ptr_fun(Result (*)(Arg));

template <class Arg1, class Arg2, class Result>
class pointer_to_binary_function;

template <class Arg1, class Arg2, class Result>
pointer_to_binary_function<Arg1, Arg2, Result>
ptr_fun(Result (*)(Arg1, Arg2));

// 20.5.12, adaptors:
template<class S, class T> class mem_fun_t;
template<class S, class T, class A> class mem_fun1_t;
template<class S, class T>
mem_fun_t<S, T> mem_fun(S (T::*f)());
template<class S, class T, class A>
mem_fun1_t<S, T, A> mem_fun(S (T::*f)(A));
template<class S, class T> class mem_fun_ref_t;
template<class S, class T, class A> class mem_fun1_ref_t;
template<class S, class T>
mem_fun_ref_t<S, T> mem_fun_ref(S (T::*f)());
template<class S, class T, class A>
mem_fun1_ref_t<S, T, A> mem_fun_ref(S (T::*f)(A));

template <class S, class T> class const_mem_fun_t;
template <class S, class T, class A> class const_mem_fun1_t;
template <class S, class T>
const_mem_fun_t<S, T> mem_fun(S (T::*f)() const);
template <class S, class T, class A>
const_mem_fun1_t<S, T, A> mem_fun(S (T::*f)(A) const);
template <class S, class T> class const_mem_fun_ref_t;
template <class S, class T, class A> class const_mem_fun1_ref_t;
template <class S, class T>
const_mem_fun_ref_t<S, T> mem_fun_ref(S (T::*f)() const);
template <class S, class T, class A>
const_mem_fun1_ref_t<S, T, A> mem_fun_ref(S (T::*f)(A) const);

// TR1: 20.5.13, member function adaptors:
template<class R, class T> unspecified mem_fn(R T::*);

// TR1: 20.5.14 polymorphic function wrappers:
class bad_function_call;

template<class Function> class function;

template<class Function>
void swap(function<Function>&, function<Function>&);

template<class Function1, class Function2>
void operator==(const function<Function1>&, const function<Function2>&);
template<class Function1, class Function2>
void operator!=(const function<Function1>&, const function<Function2>&);
template <class Function>
  bool operator==(const function<Function>&, unspecified-null-pointer-type);
template <class Function>
  bool operator==(unspecified-null-pointer-type, const function<Function>&);
template <class Function>
  bool operator!=(const function<Function>&, unspecified-null-pointer-type);
template <class Function>
  bool operator!=(unspecified-null-pointer-type, const function<Function>&);

// TR1: 20.5.15, hash function base template:
template <class T> struct hash;

// Hash function specializations
template <> struct hash<bool>;
template <> struct hash<char>;
template <> struct hash<signed char>;
template <> struct hash<unsigned char>;
template <> struct hash<wchar_t>;
template <> struct hash<short>;
template <> struct hash<unsigned short>;
template <> struct hash<int>;
template <> struct hash<unsigned int>;
template <> struct hash<long>;
template <> struct hash<unsigned long>;
template <> struct hash<float>;
template <> struct hash<double>;
template <> struct hash<long double>;
template<class T> struct hash<T*>;
template <> struct hash<std::string>;
template <> struct hash<std::wstring>;
}

Example: If a C++ program wants to have a by-element addition of two vectors a and b containing double and put the result into a, it can do:
  transform(a.begin(), a.end(), b.begin(), a.begin(), plus<double>());
— end example ]

Example: To negate every element of a:
  transform(a.begin(), a.end(), a.begin(), negate<double>())
— end example ]

To enable adaptors and other components to manipulate function objects that take one or two arguments it is required that the function objects correspondingly provide typedefs argument_type and result_type for function objects that
take one argument and \texttt{first\_argument\_type}, \texttt{second\_argument\_type}, and \texttt{result\_type} for function objects that take two arguments.

\subsection*{20.5.1 TR1: Definitions \hfill [lib.func.def]}
1 The following definitions apply to this clause:
2 A \textit{call signature} is the name of a return type followed by a parenthesized comma-separated list of zero or more argument types.
3 A \textit{call wrapper} is an object of a call wrapper type.
4 A \textit{call wrapper type} is a type that holds a callable object and supports a call operation that forwards to that object.
5 A \textit{callable object} is an object of a callable type.
6 A \textit{callable type} is a pointer to function, a pointer to member function, a pointer to member data, or a class type whose objects can appear immediately to the left of a function call operator.
7 A \textit{target object} is the callable object held by a call wrapper object.

\subsection*{20.5.2 TR1: Requirements \hfill [lib.func.require]}
1 Define \texttt{INVOKE}(f, t1, t2, \ldots, tN) as follows:
   \begin{itemize}
   \item \((t1.*f)(t2, \ldots, tN)\) when \(f\) is a pointer to a member function of a class \(T\) and \(t1\) is an object of type \(T\) or a reference to an object of type \(T\) or a reference to an object of a type derived from \(T\);
   \item \(((\*t1).*f)(t2, \ldots, tN)\) when \(f\) is a pointer to a member function of a class \(T\) and \(t1\) is not one of the types described in the previous item;
   \item \(t1.*f\) when \(f\) is a pointer to member data of a class \(T\) and \(t1\) is an object of type \(T\) or a reference to an object of type \(T\) or a reference to an object of a type derived from \(T\);
   \item \((\*t1).*f\) when \(f\) is a pointer to member data of a class \(T\) and \(t1\) is not one of the types described in the previous item;
   \item \(f(t1, t2, \ldots, tN)\) in all other cases.
\end{itemize}
2 Define \texttt{INVOKE}(f, t1, t2, \ldots, tN, R) as \texttt{INVOKE}(f, t1, t2, \ldots, tN) implicitly converted to R.
3 If a call wrapper ([20.5.1]) has a \textit{weak result type} the type of its member type \texttt{result\_type} is based on the type \(T\) of the wrapper’s target object ([20.5.1]):
   \begin{itemize}
   \item if \(T\) is a function, reference to function, or pointer to function type, \texttt{result\_type} shall be a synonym for the return type of \(T\);
   \item if \(T\) is a pointer to member function, \texttt{result\_type} shall be a synonym for the return type of \(T\);
   \item if \(T\) is a class type with a member type \texttt{result\_type}, then \texttt{result\_type} shall be a synonym for \(T::\texttt{result\_type}\);
   \item otherwise \texttt{result\_type} shall not be defined.
\end{itemize}
4 Every call wrapper [20.5.1] shall be CopyConstructible. A \textit{simple call wrapper} is a call wrapper that is Assignable and whose copy constructor and assignment operator do not throw exceptions. A \textit{forwarding call wrapper} is a call
wrapper that can be called with an argument list \( t_1, t_2, \ldots, t_N \) where each \( t_i \) is an lvalue. The effect of calling a forwarding call wrapper with one or more arguments that are rvalues is implementation defined. [Note: in a typical implementation forwarding call wrappers have overloaded function call operators of the form

\[
\text{template} \langle \text{class } T_1, \text{class } T_2, \ldots, \text{class } T_N \rangle
\text{R operator() (}T_1&t_1, T_2&t_2, \ldots, T_N&t_N) \text{ cv-gual};
\]

—end note]

20.5.3 Base

The following classes are provided to simplify the typedefs of the argument and result types:

1

\[
\text{template } \langle \text{class } \text{Arg}, \text{class } \text{Result} \rangle
\text{struct unary_function } \{
\text{typedef Arg argument_type;}
\text{typedef Result result_type;}
\} ;
\]

\[
\text{template } \langle \text{class } \text{Arg1}, \text{class } \text{Arg2}, \text{class } \text{Result} \rangle
\text{struct binary_function } \{
\text{typedef Arg1 first_argument_type;}
\text{typedef Arg2 second_argument_type;}
\text{typedef Result result_type;}
\} ;
\]

20.5.4 TR1: Function object return types

\[
\text{namespace std } \{
\text{template } \langle \text{class } \text{FunctionCallTypes} \rangle \# F(T_1, T_2, \ldots, T_N)
\text{class result_of } \{
\text{public }:
\# \text{types}
\text{typedef see below type;}
\} ;
\# \text{namespace std}
\]

1 Given an rvalue \( \text{fn} \) of type \( \text{Fn} \) and values \( t_1, t_2, \ldots, t_N \) of types \( T_1, T_2, \ldots, T_N \), respectively, the type member is the result type of the expression \( \text{f}(t_1, t_2, \ldots, t_N) \). The values \( t_i \) are lvalues when the corresponding type \( T_i \) is a reference type, and rvalues otherwise.

2 The implementation may determine the type member via any means that produces the exact type of the expression \( \text{f}(t_1, t_2, \ldots, t_N) \) for the given types. [Note: The intent is that implementations are permitted to use special compiler hooks —end note]

3 If \( \text{Fn} \) is not a function object defined by the standard library, and if either the implementation cannot determine the type of the expression \( \text{fn}(t_1, t_2, \ldots, t_N) \) or the expression is ill-formed, the implementation shall use the following process to determine the type member:

1. If \( \text{Fn} \) is a function pointer or function reference type, \( \text{type} \) shall be the return type of the function type.
2. If Fn is a member function pointer type, type shall be the return type of the member function type.

3. If Fn is a possibly cv-qualified class type with a member type result_type, type shall be typename F::result_type.

4. If Fn is a possibly cv-qualified class type with no member named result_type or if typename F::result_type is not a type:
   (a) If N=0 (no arguments), type shall be void.
   (b) If N>0, type shall be typename Fn::template result<Fn(T1, T2, ..., TN)>::type.

5. Otherwise, the program is ill-formed.

20.5.5 TR1: Class template reference_wrapper

```
template <class T> class reference_wrapper
  : public unary_function<T1, R>    // see below
  : public binary_function<T1, T2, R> // see below
{
  public:
    // types
    typedef T type;
    typedef see below result_type; // Not always defined

    // construct/copy/destroy
    explicit reference_wrapper(T&);
    reference_wrapper(const reference_wrapper<T>& x);

    // assignment
    reference_wrapper& operator=(const reference_wrapper<T>& x);

    // access
    operator T& () const;
    T& get() const;

    // invocation
    template <class T1, class T2, ..., class TN>
    typename result_of<T(T1, T2, ..., TN)>::type
    operator() (T1&, T2&, ..., TN&) const;
};
```

1 reference_wrapper<T> is a CopyConstructible and Assignable wrapper around a reference to an object of type T.

2 reference_wrapper has a weak result type ([20.5.2]).

3 The template instantiation reference_wrapper<T> shall be derived from std::unary_function<T1, R> only if the type T is any of the following:
   — a function type or a pointer to function type taking one argument of type T1 and returning R
The template instantiation `reference_wrapper<T>` shall be derived from `std::binary_function<T1, T2, R>` only if the type `T` is any of the following:

- a function type or a pointer to function type taking two arguments of types `T1` and `T2` and returning `R`
- a pointer to member function with cv-qualifier `cv` and taking one argument of type `T2`; the type `T1` is `cv T*` and `R` is the return type of the pointer to member function
- a class type that is derived from `std::binary_function<T1, T2, R>`

### 20.5.5.1 reference_wrapper construct/copy/destroy

```cpp
explicit reference_wrapper(T& t);
```

**Effects:** Constructs a `reference_wrapper` object that stores a reference to `t`.

**Throws:** nothing.

```cpp
reference_wrapper(const reference_wrapper<T>& x);
```

**Effects:** Constructs a `reference_wrapper` object that stores a reference to `x.get()`.

**Throws:** nothing.

### 20.5.5.2 reference_wrapper assignment

```cpp
reference_wrapper& operator=(const reference_wrapper<T>& x);
```

**Postconditions:** `*this` stores a reference to `x.get()`.

**Throws:** Nothing.

### 20.5.5.3 reference_wrapper access

```cpp
operator T& () const;
```

**Returns:** The stored reference.

**Throws:** nothing.

```cpp
T& get() const;
```

**Returns:** The stored reference.

**Throws:** nothing.
20.5 Function objects

20.5.4 reference_wrapper invocation

```cpp
template <class T1, class T2, ..., class TN>
typename result_of<T(T1, T2, ..., TN)>::type operator()(T1& a1, T2& a2, ..., TN& aN) const;
```

1 Returns: `INVOKE(get(), a1, a2, ..., aN)` ([20.5.2])

2 Remark: `operator()` is described for exposition only. Implementations are not required to provide an actual `reference_wrapper::operator()`. Implementations are permitted to support `reference_wrapper` function invocation through multiple overloaded operators or through other means.

20.5.5 reference_wrapper helper functions

```cpp
template <class T> reference_wrapper<T> ref(T& t);
```

1 Returns: `reference_wrapper<T>(t)`

2 Throws: nothing.

```cpp
template <class T> reference_wrapper<T> ref(reference_wrapper<T>t);
```

3 Returns: `ref(t.get())`

4 Throws: nothing.

```cpp
template <class T> reference_wrapper<const T> cref(const T& t);
```

5 Returns: `reference_wrapper <const T>(t)`

6 Throws: nothing.

```cpp
template <class T> reference_wrapper<const T> cref(reference_wrapper<T> t);
```

7 Returns: `cref(t.get())`;

8 Throws: nothing.

20.5.6 Arithmetic operations

The library provides basic function object classes for all of the arithmetic operators in the language (5.6, 5.7).

```cpp
template <class T> struct plus : binary_function<T,T,T> {
    T operator()(const T& x, const T& y) const;
};
```

1 operator() returns `x + y`.

```cpp
template <class T> struct minus : binary_function<T,T,T> {
    T operator()(const T& x, const T& y) const;
};
```

3 operator() returns `x - y`.

Draft
template <class T> struct multiplies : binary_function<T,T,T> {
    T operator()(const T& x, const T& y) const;
};
operator() returns \( x \times y \).

template <class T> struct divides : binary_function<T,T,T> {
    T operator()(const T& x, const T& y) const;
};
operator() returns \( x \div y \).

template <class T> struct modulus : binary_function<T,T,T> {
    T operator()(const T& x, const T& y) const;
};
operator() returns \( x \mod y \).

template <class T> struct negate : unary_function<T,T> {
    T operator()(const T& x) const;
};
operator() returns \(-x\).

20.5.7 Comparisons

The library provides basic function object classes for all of the comparison operators in the language (5.9, 5.10).

template <class T> struct equal_to : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};
operator() returns \( x == y \).

template <class T> struct not_equal_to : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};
operator() returns \( x != y \).

template <class T> struct greater : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};
operator() returns \( x > y \).

template <class T> struct less : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};
operator() returns \( x < y \).

template <class T> struct greater_equal : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};
operator() returns \( x \geq y \).
bool operator()(const T& x, const T& y) const;
};

operator() returns \( x \geq y \).

template <class T> struct less_equal : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};

operator() returns \( x \leq y \).

For templates greater, less, greater_equal, and less_equal, the specializations for any pointer type yield a total order, even if the built-in operators \(<\), \(>, \leq, \geq\) do not.

### 20.5.8 Logical operations

The library provides basic function object classes for all of the logical operators in the language (5.14, 5.15, 5.3.1).

```cpp
template <class T> struct logical_and : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};

operator() returns \( x \&\& y \).

template <class T> struct logical_or : binary_function<T,T,bool> {
    bool operator()(const T& x, const T& y) const;
};

operator() returns \( x \|\| y \).

template <class T> struct logical_not : unary_function<T,bool> {
    bool operator()(const T& x) const;
};

operator() returns \!x.```

### 20.5.9 Negators

Negators not1 and not2 take a unary and a binary predicate, respectively, and return their complements (5.3.1).

```cpp
template <class Predicate>
    class unary_negate
    : public unary_function<
        typename Predicate::argument_type,
        bool>
    {
        public:
            explicit unary_negate(const Predicate& pred);
            bool operator()(const typename Predicate::argument_type& x) const;
    }

operator() returns \!pred(x).

template <class Predicate>
    unary_negate<Predicate> not1(const Predicate& pred);
```

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Returns: `unary_negate<Predicate>(pred)`.

```cpp
template <class Predicate>
class binary_negate
  : public binary_function<typename Predicate::first_argument_type,
    typename Predicate::second_argument_type, bool> {
public:
  explicit binary_negate(const Predicate& pred);
  bool operator()(const typename Predicate::first_argument_type& x,
      const typename Predicate::second_argument_type& y) const;
};
```

Returns: `binary_negate<Predicate>(pred)`.

20.5.10 TR1: Template function `bind` [lib.bind]

The template function `bind` returns an object that binds a function object passed as an argument to additional arguments.

Binders `bind1st` and `bind2nd` take a function object `ffn` of two arguments and a value `x` and return a function object of one argument constructed out of `ffn` with the first or second argument correspondingly bound to `x`.

20.5.10.1 TR1: Function object binders [lib.func.bind]

This subclause describes a uniform mechanism for binding arguments of function objects.

20.5.10.1.1 Class template `is_bind_expression` [lib.func.bind.isbind]

```cpp
namespace std {
  template<class T> struct is_bind_expression {
    static const bool value = see below;
  };
} // namespace std
```

`is_bind_expression` can be used to detect function objects generated by `bind`. `bind` uses `is_bind_expression` to detect subexpressions. Users may specialize this template to indicate that a type should be treated as a subexpression in a `bind` call.

```cpp
static const bool value;
```

true if `T` is a type returned from `bind`, false otherwise.

20.5.10.1.2 Class template `is_placeholder` [lib.func.bind.isplace]
namespace std {
    template<class T> struct is_placeholder {
        static const int value = see below;
    }
} // namespace std

is_placeholder can be used to detect the standard placeholders _1, _2, and so on. bind uses is_placeholder to detect placeholders. Users may specialize this template to indicate a placeholder type.

static const int value;

value is J if T is the type of std::tr1::placeholders::_, 0 otherwise.

20.5.10.1.3 Function template bind

template<class F, class T1, class T2, ...., class TN>
unspecified bind(F f, T1 t1, T2 t2, ..., TN tN);

1 Requires: F and Ti shall be CopyConstructible. INVOKE (f, w1, w2, ..., wN) ([20.5.2]) shall be a valid expression for some values w1, w2, ..., wN.

2 Returns: A forwarding call wrapper g with a weak result type ([20.5.2]). The effect of g(u1, u2, ..., uM) shall be INVOKE (f, v1, v2, ..., vN, result_of<F cv (V1, V2, ..., VN)>>::type), where cv represents the cv-qualifiers of g and the values and types of the bound arguments v1, v2, ..., vN are determined as specified below.

template<class R, class F, class T1, class T2, ...., class TN>
unspecified bind(F f, T1 t1, T2 t2, ..., TN tN);

3 Requires: F and Ti shall be CopyConstructible. INVOKE (f, w1, w2, ..., wN) shall be a valid expression for some values w1, w2, ..., wN.

4 Returns: A forwarding call wrapper g with a nested type result_type defined as a synonym for R. The effect of g(u1, u2, ..., uM) shall be INVOKE (f, v1, v2, ..., vN, R), where the values and types of the bound arguments v1, v2, ..., vN are determined as specified below.

5 The values of the bound arguments v1, v2, ..., vN and their corresponding types V1, V2, ..., VN depend on the type of the corresponding argument ti of type Ti in the call to bind and the cv-qualifiers cv of the call wrapper g as follows:

   — if ti is of type reference_wrapper<T> the argument is ti.get() and its type Vi is T&;
   — if the value of std::tr1::is_bind_expression<Ti>::value is true the argument is ti(u1, u2, ..., uM) and its type Vi is result_of<Ti cv (U1&, U2&, ..., UM&)>::type;
   — if the value j of std::tr1::is_placeholder<Ti>::value is not zero the argument is uj and its type Vi is Uj&;
   — otherwise the value is ti and its type Vi is Ti cv &.
20.5.10.1.4 Placeholders

namespace std {
namespace placeholders {
    // M is the implementation-defined number of placeholders
    extern unspecified _1;
    extern unspecified _2;
    .
    .
    extern unspecified _M;
} // namespace std

All placeholder types shall be DefaultConstructible and CopyConstructible, and their default constructors and copy constructors shall not throw exceptions. It is implementation defined whether placeholder types are Assignable. Assignable placeholders’ copy assignment operators shall not throw exceptions.

20.5.11 Adaptors for pointers to functions

To allow pointers to (unary and binary) functions to work with function adaptors the library provides:

```cpp
template <class Arg, class Result>
class pointer_to_unary_function : public unary_function<Arg, Result> {
    public:
    explicit pointer_to_unary_function(Result (*)(Arg));
    Result operator()(Arg x) const;
};
```

operator() returns \( f(x) \).

```cpp
template <class Arg, class Result>
pointer_to_unary_function<Arg, Result> ptr_fun(Result (*)(Arg));
```

Returns: pointer_to_unary_function<Arg, Result>\( f \).

```cpp
template <class Arg1, class Arg2, class Result>
class pointer_to_binary_function : public binary_function<Arg1,Arg2,Result> {
    public:
    explicit pointer_to_binary_function(Result (*)(Arg1, Arg2));
    Result operator()(Arg1 x, Arg2 y) const;
};
```

operator() returns \( f(x,y) \).

```cpp
template <class Arg1, class Arg2, class Result>
pointer_to_binary_function<Arg1,Arg2,Result>
ptr_fun(Result (*)(Arg1, Arg2));
```

Returns: pointer_to_binary_function<Arg1,Arg2,Result>\( f \).

[Example:
```cpp
int compare(const char*, const char*);
replace_if(v.begin(), v.end(),
    not1(bind2nd(ptr_fun(compare), "abc")), "def");

replaces each abc with def in sequence v. — end example ]

20.5.12 Adaptors for pointers to members [lib.member.pointer.adaptors]

The purpose of the following is to provide the same facilities for pointer to members as those provided for pointers to functions in 20.5.11.

template <class S, class T> class mem_fun_t
    : public unary_function<T*, S> {
public:
    explicit mem_fun_t(S (T::*p)());
    S operator()(T* p) const;
};

mem_fun_t calls the member function it is initialized with given a pointer argument.

template <class S, class T, class A> class mem_fun1_t
    : public binary_function<T*, A, S> {
public:
    explicit mem_fun1_t(S (T::*p)(A));
    S operator()(T* p, A x) const;
};

mem_fun1_t calls the member function it is initialized with given a pointer argument and an additional argument of the appropriate type.

template<class S, class T> mem_fun_t<S,T> mem_fun(S (T::*f)());
template<class S, class T, class A> mem_fun1_t<S,T,A> mem_fun(S (T::*f)(A));

templatex(S (T::*f) returns an object through which X::f can be called given a pointer to an X followed by the argument required for f (if any).

template <class S, class T> class mem_fun_ref_t
    : public unary_function<T, S> {
public:
    explicit mem_fun_ref_t(S (T::*p)());
    S operator()(T& p) const;
};

mem_fun_ref_t calls the member function it is initialized with given a reference argument.

template <class S, class T, class A> class mem_fun1_ref_t
    : public binary_function<T, A, S> {
public:
    explicit mem_fun1_ref_t(S (T::*p)(A));
};
```
mem_fun1_ref_t calls the member function it is initialized with given a reference argument and an additional argument of the appropriate type.

template<class S, class T> mem_fun1_ref_t<S,T> mem_fun(S (T::*f)(A) const);

mem_fun1_ref_t calls the member function it is initialized with given a pointer argument and an additional argument of the appropriate type.

template<class S, class T, class A> const_mem_fun1_t<S,T,A> mem_fun(S (T::*f)(A) const);

const_mem_fun1_t calls the member function it is initialized with given a pointer argument.

template <class S, class T, class A> class const_mem_fun1_t
: public binary_function<const T*, A, S> {
  public:
    explicit const_mem_fun1_t(S (T::*p)(A) const);
    S operator()(const T* p, A x) const;
};

mem_fun calls the member function it is initialized with given a pointer argument.

template <class S, class T> class mem_fun_t
: public unary_function<const T*, S> {
  public:
    explicit mem_fun_t(S (T::*p)() const);
    S operator()() const;
};

const_mem_fun_t calls the member function it is initialized with given a pointer argument.

template <class S, class T> class const_mem_fun_t
: public unary_function<const T*, S> {
  public:
    explicit const_mem_fun_t(S (T::*p)() const);
    S operator()(const T* p) const;
};

mem_fun (&X::f) returns an object through which X::f can be called given a reference to an X followed by the argument required for f (if any).

template <class S, class T> class const_mem_fun_ref_t
: public unary_function<T, S> {
  public:
    explicit const_mem_fun_ref_t(S (T::*p)() const);
    S operator()() const;
};

call_mem_fun calls the member function it is initialized with given a reference argument.

template <class S, class T, class A> class call_mem_fun_t
: public binary_function<T, A, S> {
  public:
    explicit call_mem_fun_t(S (T::*p)(A) const);
    S operator()(T* p, A x) const;
};

const_mem_fun t calls the member function it is initialized with given a pointer argument.

template <class S, class T, class A> class const_mem_fun_t
: public unary_function<T*, S> {
  public:
    explicit const_mem_fun_t(S (T::*p)() const);
    S operator()(const T* p) const;
};

mem_fun calls the member function it is initialized with given a pointer argument.

template <class S, class T> class mem_fun_t
: public unary_function<const T*, S> {
  public:
    explicit mem_fun_t(S (T::*p)() const);
    S operator()() const;
};

Draft
20.5 Function objects

explicit const_mem_fun1_ref_t(S (T::*p)(A) const);
S operator()(const T& p, A x) const;
};

const_mem_fun1_ref_t calls the member function it is initialized with given a reference argument and an additional argument of the appropriate type.

template<class S, class T> const_mem_fun_ref_t<S,T>
    mem_fun_ref(S (T::*f)() const);

template<class S, class T, class A> const_mem_fun1_ref_t<S,T,A>
    mem_fun_ref(S (T::*f)(A) const);

mem_fun_ref(&X::f) returns an object through which X::f can be called given a reference to an X followed by the argument required for f (if any).

20.5.13 TR1: Function template mem_fn

template<class R, class T>
    unspecified mem_fn(R T::* pm);

Returns: A simple call wrapper ([20.5.1]) fn such that the expression fn(t, a2, ..., aN) is equivalent to INVOKE (pm, t, a2, ..., aN) ([20.5.2]). fn shall have a nested type result_type that is a synonym for the return type of pm when pm is a pointer to member function.

The simple call wrapper shall be derived from std::unary_function<cv T*, Ret> when pm is a pointer to member function with cv-qualifier cv and taking no arguments, where Ret is pm’s return type.

The simple call wrapper shall be derived from std::binary_function<cv T*, T1, Ret> when pm is a pointer to member function with cv-qualifier cv and taking one argument of type T1, where Ret is pm’s return type.

Throws: Nothing.

Remarks: Implementations may implement mem_fn as a set of overloaded function templates.

20.5.14 TR1: Polymorphic function wrappers

This subclause describes a polymorphic wrapper class that encapsulates arbitrary function objects.

20.5.14.1 Class bad_function_call

An exception of type bad_function_call is thrown by function::operator() ([20.5.14.2.4]) when the function wrapper object has no target.

namespace std {
    class bad_function_call : public std::exception
    {
        public:
            // 20.5.14.1.1, constructor:
            bad_function_call();
        }
    } // namespace std

Draft
20.5.14.1 bad_function_call constructor

bad_function_call();

Effects: constructs a bad_function_call object.

20.5.14.2 Class template function

namespace std {

    // Function type $R \ (T_1, T_2, \ldots, T_N)$, $0 \leq N \leq N_{\text{max}}$
    template<class Function>
    class function
    {
    public:
        typedef $R$ result_type;

        // 20.5.14.2.1, construct/copy/destroy:
        explicit function();
        function(unspecified-null-pointer-type);
        function(const function&);
        template<class F> function(F);
        function& operator=(const function&);
        function& operator=(unspecified-null-pointer-type);
        template<class F> function& operator=(F);
        template<class F> function& operator=(reference_wrapper<F>);
        ~function();

        // 20.5.14.2.2, function modifiers:
        void swap(const function&);

        // 20.5.14.2.3, function capacity:
        operator unspecified-bool-type() const;

        // 20.5.14.2.4, function invocation:
        $R$ operator()(T1, T2, \ldots, TN) const;

        // 20.5.14.2.5, function target access:
        const std::type_info& target_type() const;
        template<typename T> T* target();
        template<typename T> const T* target() const;

    private:
        // 20.5.14.2.6, undefined operators:
        template<class Function2> bool operator==((const function<Function2>&));
        template<class Function2> bool operator!=(const function<Function2>&);
    };

    // Draft
// 20.5.14.2.7. Null pointer comparisons:
template <class Function>
  bool operator==(const function<Function>&, unspecified-null-pointer-type);

template <class Function>
  bool operator==(unspecified-null-pointer-type, const function<Function>&);

template <class Function>
  bool operator!=(const function<Function>&, unspecified-null-pointer-type);

template <class Function>
  bool operator!=(unspecified-null-pointer-type, const function<Function>&);

// 20.5.14.2.8. specialized algorithms:
template<class Function> void swap(function<Function>&, function<Function>&);
} // namespace std

The function class template provides polymorphic wrappers that generalize the notion of a function pointer. Wrappers can store, copy, and call arbitrary callable objects ([20.5.1]), given a call signature ([20.5.1]), allowing functions to be first-class objects.

A function object \( f \) of type \( F \) is Callable for argument types \( T_1, T_2, \ldots, T_N \) and a return type \( R \), if, given lvalues \( t_1, t_2, \ldots, t_N \) of types \( T_1, T_2, \ldots, T_N \), respectively, \( \text{INVOKE}(f, t_1, t_2, \ldots, t_N) \) is well-formed ([20.5.2]) and, if \( R \) is not void, convertible to \( R \).

The function class template is a call wrapper ([20.5.1]) whose call signature ([20.5.1]) is \( R(T_1, T_2, \ldots, T_N) \).

#### 20.5.14.2.1 function construct/copy/destroy [lib.func.wrap.func.con]

```cpp
explicit function();
Postconditions: !*this.
Throws: nothing.

function(unspecified-null-pointer-type);
Postconditions: !*this.
Throws: nothing.

function(const function& f);
Postconditions: !*this if !f; otherwise, *this targets a copy of \( f \).\'s target().
Throws: shall not throw exceptions if \( f \)'s target is a function pointer or a function object passed via reference_-

```
Postconditions: !*this if any of the following hold:
   — f is a NULL function pointer.
   — f is a NULL member function pointer.
   — F is an instance of the function class template, and !f

Otherwise, *this targets a copy of f if f is not a pointer to member function, and targets a copy of mem_fn(f) if f is a pointer to member function.

Throws: shall not throw exceptions when f is a function pointer or a reference_wrapper<T> for some T. Otherwise, may throw bad_alloc or any exception thrown by F’s copy constructor.

function& operator=(const function& f);
   Effects: function(f).swap(*this);
   Returns: *this

function& operator=(unspecified-null-pointer-type);
   Effects: If *this != NULL, destroys the target of this.
   Postconditions: !(*this).
   Returns: *this

template<class F> function& operator=(F f);
   Effects: function(f).swap(*this);
   Returns: *this

template<class F> function& operator=(reference_wrapper<F> f);
   Effects: function(f).swap(*this);
   Returns: *this
   Throws: nothing.

~function();
   Effects: If *this != NULL, destroys the target of this.

20.5.14.2.2 function modifiers

void swap(function& other);
   Effects: interchanges the targets of *this and other.
   Throws: nothing.
### 20.5.14.2.3 Function capacity

**operator unspecified-bool-type() const**

1. **Returns:** if *this has a target, returns a value that will evaluate `true` in a boolean context; otherwise, returns a value that will evaluate `false` in a boolean context. The value type returned shall not be convertible to `int`.
2. **Throws:** nothing.
3. **Note:** This conversion can be used in contexts where a `bool` is expected (e.g., an `if` condition); however, implicit conversions (e.g., to `int`) that can occur with `bool` are not allowed, eliminating some sources of user error. One possible implementation choice for this type is pointer-to-member. —end note

### 20.5.14.2.4 Function invocation

**R operator()(T1 t1, T2 t2, ..., TN tN) const**

1. **Effects:** `INVOKE(f, t1, t2, ..., tN, R)` ([20.5.2]), where `f` is the target object ([20.5.1]) of *this.
2. **Returns:** nothing, if `R` is `void`, otherwise the return value of `INVOKE(f, t1, t2, ..., tN, R)`.
3. **Throws:** `bad_function_call` if !*this; otherwise, any exception thrown by the wrapped function object.

### 20.5.14.2.5 Function target access

**const std::type_info& target_type() const**

1. **Returns:** If *this has a target of type `T`, `typeid(T)`; otherwise, `typeid(void)`.
2. **Throws:** nothing.

```
template<typename T> T* target();
template<typename T> const T* target() const;
```

3. **Requires:** `T` is a function object type that is Callable ([20.5.14.2]) for parameter types `T1`, `T2`, ..., `TN` and return type `R`.
4. **Returns:** If `type()` == `typeid(T)`, a pointer to the stored function target; otherwise a null pointer.
5. **Throws:** nothing.

### 20.5.14.2.6 Undefined operators

**template<class Function2> bool operator==(const function<Function2>&);**
**template<class Function2> bool operator!=(const function<Function2>&);**

1. These member functions shall be left undefined.
2. **Note:** the boolean-like conversion opens a loophole whereby two function instances can be compared via `==` or `!=`. These undefined void operators close the loophole and ensure a compile-time error. —end note
20.5.14.2.7 null pointer comparison operators

```
template <class Function>
    bool operator==(const function<Function>& f,
                   unspecified-null-pointer-type);

template <class Function>
    bool operator==(unspecified-null-pointer-type,
                   const function<Function>& f);

Returns: !f.
Throws: nothing.
```

```
template <class Function>
    bool operator!=(const function<Function>& f,
                   unspecified-null-pointer-type);

template <class Function>
    bool operator!=(unspecified-null-pointer-type,
                   const function<Function>& f);

Returns: (bool) f.
Throws: nothing.
```

20.5.14.2.8 specialized algorithms

```
template <class Function>
    void swap(function<Function>& f1, function<Function>& f2);

Effects: f1.swap(f2);
```

20.5.15 TR1: Class template hash

The unordered associative containers defined in clause 23.4 use specializations of hash as the default hash function. This class template is only required to be instantiable for integer types (3.9.1), floating point types (3.9.1), pointer types (8.3.1), and std::string and std::wstring.

```
template <class T>
    struct hash : public std::unary_function<T, std::size_t>
    {
        std::size_t operator()(T val) const;
    }
```

The return value of operator() is unspecified, except that equal arguments shall yield the same result. operator() shall not throw exceptions.

20.6 Memory

```
namespace std {
    // 20.6.1, the default allocator:
    template <class T> class allocator;

    Draft
```
template <> class allocator<void>;
template <class T, class U>
bool operator==(const allocator<T>&, const allocator<U>&) throw();
template <class T, class U>
bool operator!=(const allocator<T>&, const allocator<U>&) throw();

// 20.6.2, raw storage iterator:
template <class OutputIterator, class T> class raw_storage_iterator;

// 20.6.3, temporary buffers:
template <class T>
pair<T*,ptrdiff_t> get Temporary_buffer(ptrdiff_t n);
template <class T>
void return Temporary_buffer(T* p);

// 20.6.4, specialized algorithms:
template <class InputIterator, class ForwardIterator>
ForwardIterator uninitialized_copy(InputIterator first, InputIterator last, ForwardIterator result);
template <class ForwardIterator, class T>
void uninitialized_fill(ForwardIterator first, ForwardIterator last, const T& x);
template <class ForwardIterator, class Size, class T>
void uninitialized_fill_n(ForwardIterator first, Size n, const T& x);

// 20.6.5, pointers:
template<class X> class auto_ptr;

// 20.6.6.1, Class bad_weak_ptr:
class bad_weak_ptr;

// 20.6.6.2, Class template shared_ptr:
template<class T> class shared_ptr;

// 20.6.6.2.6, shared_ptr comparisons:
template<class T, class U>
bool operator==(shared_ptr<T> const& a, shared_ptr<U> const& b);
template<class T, class U>
bool operator!=(shared_ptr<T> const& a, shared_ptr<U> const& b);
template<class T, class U>
bool operator<(shared_ptr<T> const& a, shared_ptr<U> const& b);

// 20.6.6.2.8, shared_ptr specialized algorithms:
template<class T> void swap(shared_ptr<T>& a, shared_ptr<T>& b);

// 20.6.6.2.9, shared_ptr casts:
template<class T, class U>
shared_ptr<T> static_pointer_cast(shared_ptr<U> const& r);
template<class T, class U>
shared_ptr<T> dynamic_pointer_cast(shared_ptr<U> const& r);
template<class T, class U>
    shared_ptr<T> const_pointer_cast(shared_ptr<U> const& r);

// 20.6.6.2.7, shared_ptr I/O:
template<class E, class T, class Y>
    basic_ostream<E, T>& operator<<(basic_ostream<E, T>& os, shared_ptr<Y> const& p);

// 20.6.6.2.10, shared_ptr get_deleter:
template<class D, class T> D* get_deleter(shared_ptr<T> const& p);

// 20.6.6.3, Class template weak_ptr:
template<class T> class weak_ptr;

// 20.6.6.3.6, weak_ptr comparison:
template<class T, class U> bool operator<(weak_ptr<T> const& a, weak_ptr<U> const& b);

// 20.6.6.3.7, weak_ptr specialized algorithms:
template<class T> void swap(weak_ptr<T>& a, weak_ptr<T>& b);

// 20.6.6.4, Class enable_shared_from_this:
template<class T> class enable_shared_from_this;

20.6.1 The default allocator
[lib.default.allocator]

namespace std {
    template <class T> class allocator;

    // specialize for void:
template <> class allocator<void> {
        public:
            typedef void* pointer;
            typedef const void* const_pointer;
            // reference-to-void members are impossible.
            typedef void value_type;
            template <class U> struct rebind { typedef allocator<U> other; }; 
    };

template <class T> class allocator {
    public:
        typedef size_t size_type;
        typedef ptrdiff_t difference_type;
        typedef T* pointer;
        typedef const T* const_pointer;
        typedef T& reference;
        typedef const T& const_reference;
        typedef T value_type;
        template <class U> struct rebind { typedef allocator<U> other; }; 
    }

    allocator() throw();
}

Draft
20.6 Memory

General utilities library

allocator(const allocator&) throw();
template <class U> allocator(const allocator<U>&) throw();
~allocator() throw();

pointer address(reference x) const;
const_pointer address(const_reference x) const;

pointer allocate(
    size_type, allocator<void>::const_pointer hint = 0);
void deallocate(pointer p, size_type n);
size_type max_size() const throw();
void construct(pointer p, const T& val);
void destroy(pointer p);
}

20.6.1.1 allocator members

pointer address(reference x) const;
Returns: &x.

const_pointer address(const_reference x) const;
Returns: &x.

pointer allocate(size_type n, allocator<void>::const_pointer hint=0);
Remarks: Uses ::operator new(std::size_t) (18.5.1).
Requires: hint either 0 or previously obtained from member allocate and not yet passed to member deallocate. The value hint may be used by an implementation to help improve performance\(^{227}\).
Returns: a pointer to the initial element of an array of storage of size n * sizeof(T), aligned appropriately for objects of type T.
Remark: the storage is obtained by calling ::operator new(std::size_t), but it is unspecified when or how often this function is called. The use of hint is unspecified, but intended as an aid to locality if an implementation so desires.
Throws: bad_alloc if the storage cannot be obtained.

void deallocate(pointer p, size_type n);
Requires: p shall be a pointer value obtained from allocate(). n shall equal the value passed as the first argument to the invocation of allocate which returned p.
Effects: deallocates the storage referenced by p.
Remarks: Uses ::operator delete(void*) (18.5.1), but it is unspecified when this function is called.

\(^{227}\) In a container member function, the address of an adjacent element is often a good choice to pass for this argument.
size_type max_size() const throw();

Returns: the largest value $N$ for which the call allocate($N$, 0) might succeed.

void construct(pointer p, const_reference val);

Effects: ::new((void *)p) T(val)

void destroy(pointer p);

Effects: p->~T()

20.6.1.2 allocator globals [lib.allocator.globals]

template <class T1, class T2>
  bool operator==(const allocator<T1>&, const allocator<T2>&) throw();

Returns: true.

template <class T1, class T2>
  bool operator!=(const allocator<T1>&, const allocator<T2>&) throw();

Returns: false.

20.6.2 Raw storage iterator [lib.storage.iterator]

raw_storage_iterator is provided to enable algorithms to store their results into uninitialized memory. The formal template parameter OutputIterator is required to have its operator* return an object for which operator& is defined and returns a pointer to T, and is also required to satisfy the requirements of an output iterator (24.1.2).

namespace std {
  template <class OutputIterator, class T>
  class raw_storage_iterator
    : public iterator<output_iterator_tag,void,void,void,void> {
  public:
    explicit raw_storage_iterator(OutputIterator x);

    raw_storage_iterator<OutputIterator,T>& operator*();
    raw_storage_iterator<OutputIterator,T>& operator=(const T& element);
    raw_storage_iterator<OutputIterator,T>& operator++();
    raw_storage_iterator<OutputIterator,T> operator++(int);
  }
}

raw_storage_iterator(OutputIterator x);

Effects: Initializes the iterator to point to the same value to which x points.

raw_storage_iterator<OutputIterator,T>& operator*();

Returns: *this
raw_storage_iterator<OutputIterator,T>& operator=(const T& element);

Effects: Constructs a value from element at the location to which the iterator points.
Returns: A reference to the iterator.

raw_storage_iterator<OutputIterator,T>& operator++();

Effects: Pre-increment: advances the iterator and returns a reference to the updated iterator.

raw_storage_iterator<OutputIterator,T> operator++(int);

Effects: Post-increment: advances the iterator and returns the old value of the iterator.

### 20.6.3 Temporary buffers

```cpp
template <class T>
pair<T*, ptrdiff_t> get_temporary_buffer(ptrdiff_t n);
```

Effects: Obtains a pointer to storage sufficient to store up to n adjacent T objects.
Returns: A pair containing the buffer’s address and capacity (in the units of sizeof(T)), or a pair of 0 values if no storage can be obtained or if n <= 0.

```cpp
template <class T> void return_temporary_buffer(T* p);
```

Effects: Deallocates the buffer to which p points.
Requires: The buffer shall have been previously allocated by get_temporary_buffer.

### 20.6.4 Specialized algorithms

All the iterators that are used as formal template parameters in the following algorithms are required to have their operator* return an object for which operator& is defined and returns a pointer to T. In the algorithm uninitialized_copy, the formal template parameter InputIterator is required to satisfy the requirements of an input iterator (24.1.1).

In all of the following algorithms, the formal template parameter ForwardIterator is required to satisfy the requirements of a forward iterator (24.1.3) and also to satisfy the requirements of a mutable iterator (24.1), and is required to have the property that no exceptions are thrown from increment, assignment, comparison, or dereference of valid iterators. In the following algorithms, if an exception is thrown there are no effects.

#### 20.6.4.1 uninitialized_copy

```cpp
template <class InputIterator, class ForwardIterator>
ForwardIterator
uninitialized_copy(InputIterator first, InputIterator last,
ForwardIterator result);
```

Effects:
```cpp
for (; first != last; ++result, ++first)
new (static_cast<void*>(&*result))
typename iterator_traits<ForwardIterator>::value_type(*first);
```
20.6.4.2 uninitialized_fill

```cpp
template <class ForwardIterator, class T>
void uninitialized_fill(ForwardIterator first, ForwardIterator last, const T& x);
```

1 Effects:

```cpp
for (; first != last; ++first)
new (static_cast<void*>(&*first))
typename iterator_traits<ForwardIterator>::value_type(x);
```

20.6.4.3 uninitialized_fill_n

```cpp
template <class ForwardIterator, class Size, class T>
void uninitialized_fill_n(ForwardIterator first, Size n, const T& x);
```

1 Effects:

```cpp
for (; n--; ++first)
new (static_cast<void*>(&*first))
typename iterator_traits<ForwardIterator>::value_type(x);
```

20.6.5 Class template auto_ptr

Template auto_ptr stores a pointer to an object obtained via new and deletes that object when it itself is destroyed (such as when leaving block scope 6.7).

Template auto_ptr_ref holds a reference to an auto_ptr. It is used by the auto_ptr conversions to allow auto_ptr objects to be passed to and returned from functions.

```cpp
namespace std {
    template <class Y> struct auto_ptr_ref {};

    template<class X> class auto_ptr {
public:
    typedef X element_type;

    // 20.6.5.1 construct/copy/destroy:
    explicit auto_ptr(X* p = 0) throw();
    auto_ptr(auto_ptr&) throw();
    template<class Y> auto_ptr(auto_ptr<Y>&) throw();
    auto_ptr& operator=(auto_ptr&) throw();
    template<class Y> auto_ptr& operator=(auto_ptr<Y>&) throw();
    auto_ptr& operator=(auto_ptr_ref<X> r) throw();
    ~auto_ptr() throw();

    Draft
// 20.6.5.2 members:
X& operator*() const throw();
X* operator->() const throw();
X* get() const throw();
X* release() throw();
void reset(X* p =0) throw();

// 20.6.5.3 conversions:
auto_ptr(auto_ptr_ref<X>) throw();
template<class Y> operator auto_ptr_ref<Y>() throw();
template<class Y> operator auto_ptr<Y>() throw();
}

The auto_ptr provides a semantics of strict ownership. An auto_ptr owns the object it holds a pointer to. Copying an auto_ptr copies the pointer and transfers ownership to the destination. If more than one auto_ptr owns the same object at the same time the behavior of the program is undefined. [Note: The uses of auto_ptr include providing temporary exception-safety for dynamically allocated memory, passing ownership of dynamically allocated memory to a function, and returning dynamically allocated memory from a function. auto_ptr does not meet the CopyConstructible and Assignable requirements for Standard Library container elements and thus instantiating a Standard Library container with an auto_ptr results in undefined behavior. — end note]

20.6.5.1 auto_ptr constructors

explicit auto_ptr(X* p =0) throw();

    Postconditions: *this holds the pointer p.

auto_ptr(auto_ptr& a) throw();

    Effects: Calls a.release().

    Postconditions: *this holds the pointer returned from a.release().

template<class Y> auto_ptr(auto_ptr<X>& a) throw();

    Requires: Y* can be implicitly converted to X*.

    Effects: Calls a.release().

    Postconditions: *this holds the pointer returned from a.release().

auto_ptr& operator=(auto_ptr& a) throw();

    Requires: The expression delete get() is well formed.

    Effects: reset(a.release()).

    Returns: *this.

template<class Y> auto_ptr& operator=(auto_ptr<X>& a) throw();

    Requires: Y* can be implicitly converted to X*. The expression delete get() is well formed.
20.6.5.2 auto_ptr members

X& operator*() const throw();
  Requires: get() != 0
  Returns: *get()

X* operator->() const throw();
  Returns: get()

X* get() const throw();
  Returns: The pointer *this holds.

X* release() throw();
  Returns: get()
  Postcondition: *this holds the null pointer.

void reset(X* p=0) throw();
  Effects: If get() != p then delete get().
  Postconditions: *this holds the pointer p.

20.6.5.3 auto_ptr conversions

auto_ptr(auto_ptr_ref<X> r) throw();
  Effects: Calls p.release() for the auto_ptr p that r holds.
  Postconditions: *this holds the pointer returned from release().

template<class Y> operator auto_ptr_ref<Y>() throw();
  Returns: An auto_ptr_ref<Y> that holds *this.

template<class Y> operator auto_ptr<Y>() throw();
  Effects: Calls release().
  Returns: An auto_ptr<Y> that holds the pointer returned from release().
auto_ptr& operator=(auto_ptr_ref<X> r) throw()

Effects: Calls reset(p.release()) for the auto_ptr p that r holds a reference to.

Returns: *this

20.6.6 TR1: Smart pointers

20.6.6.1 Class bad_weak_ptr

namespace std {
    class bad_weak_ptr: public std::exception {
    public:
        bad_weak_ptr();
    } // namespace std

An exception of type bad_weak_ptr is thrown by the shared_ptr constructor taking a weak_ptr.

bad_weak_ptr();

Postconditions: what() returns "bad_weak_ptr".

Throws: nothing.

20.6.6.2 Class template shared_ptr

The shared_ptr class template stores a pointer, usually obtained via new. shared_ptr implements semantics of shared ownership: the last remaining owner of the pointer is responsible for destroying the object, or otherwise releasing the resources associated with the stored pointer.

namespace std {
    template<class T> class shared_ptr {
        public:
            typedef T element_type;

            // 20.6.6.2.1, constructors:
            shared_ptr();
            template<class Y> explicit shared_ptr(Y* p);
            template<class Y, class D> shared_ptr(Y* p, D d);
            shared_ptr(shared_ptr const& r);
            template<class Y> shared_ptr(shared_ptr<Y> const& r);
            template<class Y> explicit shared_ptr(weak_ptr<Y> const& r);
            template<class Y> explicit shared_ptr(auto_ptr<Y>& r);

            // 20.6.6.2.2, destructor:
            ~shared_ptr();

            // 20.6.6.2.3, assignment:
shared_ptr& operator=(shared_ptr const& r);
template<class Y> shared_ptr& operator=(shared_ptr<Y> const& r);
template<class Y> shared_ptr& operator=(auto_ptr<Y>& r);

// 20.6.6.2.4, modifiers:
void swap(shared_ptr& r);
void reset();
template<class Y> void reset(Y* p);
template<class Y, class D> void reset(Y* p, D d);

// 20.6.6.2.5, observers:
T* get() const;
T& operator*() const;
T* operator->() const;
long use_count() const;
bool unique() const;
operator unspecified_bool_type() const;
};

// 20.6.6.2.6, shared_ptr comparisons:
template<class T, class U>
bool operator==(shared_ptr<T> const& a, shared_ptr<U> const& b);
template<class T, class U>
bool operator!=(shared_ptr<T> const& a, shared_ptr<U> const& b);
template<class T, class U>
bool operator<(shared_ptr<T> const& a, shared_ptr<U> const& b);

// 20.6.6.2.7, shared_ptr I/O:
template<class E, class T, class Y>
basic_ostream<E, T>& operator<<(basic_ostream<E, T>& os, shared_ptr<Y> const& p);

// 20.6.6.2.8, shared_ptr specialized algorithms:
template<class T> void swap(shared_ptr<T>& a, shared_ptr<T>& b);

// 20.6.6.2.9, shared_ptr casts:
template<class T, class U>
shared_ptr<T> static_pointer_cast(shared_ptr<U> const& r);
template<class T, class U>
shared_ptr<T> dynamic_pointer_cast(shared_ptr<U> const& r);
template<class T, class U>
shared_ptr<T> const_pointer_cast(shared_ptr<U> const& r);

// 20.6.6.2.10, shared_ptr get_deleter:
template<class D, class T> D* get_deleter(shared_ptr<T> const& p);
} // namespace std

Specializations of shared_ptr shall be CopyConstructible, Assignable, and LessThanComparable, allowing their use in standard containers. Specializations of shared_ptr shall be convertible to bool, allowing their use in boolean expressions and declarations in conditions. The template parameter T of shared_ptr may be an incomplete type.
[Example:

```cpp
if(shared_ptr<X> px = dynamic_pointer_cast<X>(py))
{
    // do something with px
}
```

—end example.]

### 20.6.6.2.1 shared_ptr constructors

**shared_ptr();**

```cpp
Effects: Constructs an empty shared_ptr object.
```

**Postconditions:** `use_count() == 0 && get() == 0`.

**Throws:** nothing.

**template<class Y> explicit shared_ptr(Y* p);**

```cpp
Requires: p shall be convertible to T*. Y shall be a complete type. The expression `delete p` shall be well-formed, shall have well defined behavior, and shall not throw exceptions.
```

**Effects:** Constructs a shared_ptr object that owns the pointer p.

**Postconditions:** `use_count() == 1 && get() == p`.

**Throws:** `bad_alloc`, or an implementation-defined exception when a resource other than memory could not be obtained.

**Exception safety:** If an exception is thrown, `delete p` is called.

**template<class Y, class D> shared_ptr(Y* p, D d);**

```cpp
Requires: p shall be convertible to T*. D shall be CopyConstructible. The copy constructor and destructor of D shall not throw exceptions. The expression `d(p)` shall be well-formed, shall have well defined behavior, and shall not throw exceptions.
```

**Effects:** Constructs a shared_ptr object that owns the pointer p and the deleter d.

**Postconditions:** `use_count() == 1 && get() == p`.

**Throws:** `bad_alloc`, or an implementation-defined exception when a resource other than memory could not be obtained.

**Exception safety:** If an exception is thrown, `d(p)` is called.

**shared_ptr(shared_ptr const& r);**

**template<class Y> shared_ptr(shared_ptr<Y> const& r);**

**Requires:** For the second constructor Y* shall be convertible to T*.

**Effects:** If r is empty, constructs an empty shared_ptr object; otherwise, constructs a shared_ptr object that shares ownership with r.
Postconditions: $get() == r.get()$ && $use\_count() == r.use\_count()$.

Throws: nothing.

```cpp
template<class Y> explicit shared_ptr(weak_ptr<y> const& r);
```

Requires: $Y*$ shall be convertible to $T*$.

Effects: Constructs a shared_ptr object that shares ownership with $r$ and stores a copy of the pointer stored in $r$.

Postconditions: $use\_count() == r.use\_count()$.

Throws: bad_weak_ptr when $r.expired()$.

Exception safety: If an exception is thrown, the constructor has no effect.

```cpp
template<class Y> shared_ptr(auto_ptr<y>& r);
```

Requires: $r.release()$ shall be convertible to $T*$.

Effects: Constructs a shared_ptr object that stores and owns $r.release()$.

Postconditions: $use\_count() == 1$ && $r.get() == 0$.

Throws: bad_alloc, or an implementation-defined exception when a resource other than memory could not be obtained.

Exception safety: If an exception is thrown, the constructor has no effect.

### 20.6.6.2.2 shared_ptr destructor

```
~shared_ptr();
```

Effects:
- If *this is empty, there are no side effects.
- If *this shares ownership with another shared_ptr instance (use_count() > 1), decrements that instance’s use count.
- Otherwise, if *this owns a pointer p and a deleter d, d(p) is called.
- Otherwise, *this owns a pointer p, and delete p is called.

Throws: nothing.

### 20.6.6.2.3 shared_ptr assignment

```
shared_ptr& operator=(shared_ptr const& r);
```

```cpp
template<class Y> shared_ptr& operator=(shared_ptr<y> const& r);
template<class Y> shared_ptr& operator=(auto_ptr<y>& r);
```
20.6 Memory

Effects: Equivalent to `shared_ptr(r).swap(*this)`.

Returns: `*this`.

[Note: The use count updates caused by the temporary object construction and destruction are not observable side effects, so the implementation may meet the effects (and the implied guarantees) via different means, without creating a temporary. In particular, in the example:

```cpp
shared_ptr<int> p(new int);
shared_ptr<void> q(p);
p = p;
q = p;
```

both assignments may be no-ops. –end note]

20.6.6.2.4 shared_ptr modifiers

`void swap(shared_ptr& r);`

Effects: Exchanges the contents of `*this` and `r`.

Throws: nothing.

`void reset();`

Effects: Equivalent to `shared_ptr().swap(*this)`.

`template<class Y> void reset(Y* p);`

Effects: Equivalent to `shared_ptr(p).swap(*this)`.

`template<class Y, class D> void reset(Y* p, D d);`

Effects: Equivalent to `shared_ptr(p, d).swap(*this)`.

20.6.6.2.5 shared_ptr observers

`T* get() const;`

Returns: the stored pointer. Returns a null pointer if `*this` is empty.

Throws: nothing.

`T& operator*() const;`

Requires: `get() != 0`.

Returns: `*get()`.

Throws: nothing.

Remarks: When `T` is `void`, attempting to instantiate this member function renders the program ill-formed. [Note: Instantiating `shared_ptr<void>` does not necessarily result in instantiating this member function. –end note]


T* operator->() const;

Requires: get() != 0.

Returns: get().

Throws: nothing.

long use_count() const;

Returns: the number of shared_ptr objects, *this included, that share ownership with *this, or 0 when *this is empty.

Throws: nothing.

[ Note: use_count() is not necessarily efficient. Use only for debugging and testing purposes, not for production code. — end note ]

bool unique() const;

Returns: use_count() == 1.

Throws: nothing.

[ Note: unique() may be faster than use_count(). If you are using unique() to implement copy on write, do not rely on a specific value when get() == 0. — end note ]

operator unspecified-bool-type() const;

Returns: an unspecified value that, when used in boolean contexts, is equivalent to get() != 0.

Throws: nothing.

[ Note: This conversion operator allows shared_ptr objects to be used in boolean contexts. [ Example: if (p && p->valid()) —end example. ] One possible choice for the return type is a pointer to member function, which avoids many of the implicit conversion pitfalls of a bool or void* return type. — end note ]

20.6.6.2.6 shared_ptr comparison

[lib.util.smartptr.shared.cmp]

template<class T, class U> bool operator==(shared_ptr<T> const& a, shared_ptr<U> const& b);

Returns: a.get() == b.get().

Throws: nothing.

template<class T, class U> bool operator!=(shared_ptr<T> const& a, shared_ptr<U> const& b);

Returns: a.get() != b.get().

Throws: nothing.

template<class T, class U> bool operator<(shared_ptr<T> const& a, shared_ptr<U> const& b);

Returns: an unspecified value such that

— operator< is a strict weak ordering as described in [lib.alg.sorting]:

Draft
— under the equivalence relation defined by operator<, !(a < b) && !(b < a), two shared_ptr instances are equivalent if and only if they share ownership or are both empty.

6 Throws: nothing.

7 [ Note: Defining a comparison operator allows shared_ptr objects to be used as keys in associative containers. — end note ]

20.6.6.2.7 shared_ptr I/O

[lib.util.smartptr.shared.io]

```
template<class E, class T, class Y>
basic_ostream<E, T>& operator<<(basic_ostream<E, T>& os, shared_ptr<Y> const& p);
```

1 Effects: os << p.get();

2 Returns: os.

20.6.6.2.8 shared_ptr specialized algorithms

[lib.util.smartptr.shared.spec]

```
template<class T> void swap(shared_ptr<T>& a, shared_ptr<T>& b);
```

1 Effects: Equivalent to a.swap(b).

2 Throws: nothing.

20.6.6.2.9 shared_ptr casts

[lib.util.smartptr.shared.cast]

```
template<class T, class U> shared_ptr<T> static_pointer_cast(shared_ptr<U> const& r);
```

1 Requires: The expression static_cast<T*>(r.get()) shall be well-formed.

2 Returns: If r is empty, an empty shared_ptr<T>; otherwise, a shared_ptr<T> object that stores static_cast<T*>(r.get()) and shares ownership with r.

3 Throws: nothing.

4 [ Note: The seemingly equivalent expression shared_ptr<T>(static_cast<T*>(r.get())) will eventually result in undefined behavior, attempting to delete the same object twice. — end note ]

```
template<class T, class U> shared_ptr<T> dynamic_pointer_cast(shared_ptr<U> const& r);
```

5 Requires: The expression dynamic_cast<T*>(r.get()) shall be well-formed and shall have well defined behavior.

6 Returns:

— When dynamic_cast<T*>(r.get()) returns a nonzero value, a shared_ptr<T> object that stores a copy of it and shares ownership with r;

— Otherwise, an empty shared_ptr<T> object.
20.6.6.2.10 \texttt{get\_deleter} \hfill [lib.util.smartptr.getdeleter]

\begin{verbatim}
template<class D, class T> D* get_deleter(shared_ptr<T> const& p);
\end{verbatim}

\begin{verbatim}
Returns: If \textit{p} owns a deleter \textit{d} of type \textit{cv-unqualified} \texttt{D}, returns \&\texttt{d}; otherwise returns 0.
\end{verbatim}

\begin{verbatim}
Throws: nothing.
\end{verbatim}

20.6.6.3 Class template \texttt{weak\_ptr} \hfill [lib.util.smartptr.weak]

The \texttt{weak\_ptr} class template stores a weak reference to an object that is already managed by a \texttt{shared\_ptr}. To access the object, a \texttt{weak\_ptr} can be converted to a \texttt{shared\_ptr} using the member function \texttt{lock}.

\begin{verbatim}
namespace std {
    template<class T> class weak_ptr {
        public:
            typedef T element_type;

            // constructors
            weak_ptr();
            template<class Y> weak_ptr(shared_ptr<Y> const& r);
            weak_ptr(weak_ptr const& r);
            template<class Y> weak_ptr(weak_ptr<Y> const& r);

            // destructor
            ~weak_ptr();

            // assignment
            weak_ptr& operator=(weak_ptr const& r);
            template<class Y> weak_ptr& operator=(weak_ptr<Y> const& r);
            template<class Y> weak_ptr& operator=(shared_ptr<Y> const& r);

            // modifiers

        };
    };
\end{verbatim}

Draft
void swap(weak_ptr& r);
void reset();

// observers
long use_count() const;
bool expired() const;
shared_ptr<T> lock() const;
};

// comparison
template<class T, class U> bool operator<(weak_ptr<T> const& a, weak_ptr<U> const& b);

// specialized algorithms
template<class T> void swap(weak_ptr<T>& a, weak_ptr<T>& b);
} // namespace std

Specializations of weak_ptr shall be CopyConstructible, Assignable, and LessThanComparable, allowing their use in standard containers. The template parameter T of weak_ptr may be an incomplete type.

### 20.6.6.3.1 weak_ptr constructors

```cpp
weak_ptr();
```

**Effects:** Constructs an empty weak_ptr object.

**Postconditions:** use_count() == 0.

**Throws:** nothing.

```cpp
template<class Y> weak_ptr(shared_ptr<Y> const& r);
weak_ptr(weak_ptr const& r);
template<class Y> weak_ptr(weak_ptr<Y> const& r);
```

**Requires:** For the second and third constructors, Y* shall be convertible to T*.

**Effects:** If r is empty, constructs an empty weak_ptr object; otherwise, constructs a weak_ptr object that shares ownership with r and stores a copy of the pointer stored in r.

**Postconditions:** use_count() == r.use_count().

**Throws:** nothing.

### 20.6.6.3.2 weak_ptr destructor

```cpp
~weak_ptr();
```

**Effects:** Destroys this weak_ptr object but has no effect on the object its stored pointer points to.

**Throws:** nothing.
20.6.6.3.3 weak_ptr assignment

weak_ptr& operator=(weak_ptr const& r);
template<class Y> weak_ptr& operator=(weak_ptr<Y> const& r);
template<class Y> weak_ptr& operator=(shared_ptr<Y> const& r);

Effects: Equivalent to weak_ptr(r).swap(*this).

Throws: nothing.

Remarks: The implementation may meet the effects (and the implied guarantees) via different means, without creating a temporary.

20.6.6.3.4 weak_ptr modifiers

void swap(weak_ptr& r);

Effects: Exchanges the contents of *this and r.

Throws: nothing.

void reset();

Effects: Equivalent to weak_ptr().swap(*this).

20.6.6.3.5 weak_ptr observers

long use_count() const;

Returns: 0 if *this is empty; otherwise, the number of shared_ptr instances that share ownership with *this.

Throws: nothing.

[Note: use_count() is not necessarily efficient. Use only for debugging and testing purposes, not for production code. — end note]

bool expired() const;

Returns: use_count() == 0.

Throws: nothing.

[Note: expired() may be faster than use_count(). — end note]

shared_ptr<T> lock() const;

Returns: expired() ? shared_ptr<T>(): shared_ptr<T>(*this).

Throws: nothing.
20.6.6.3.6 weak_ptr comparison

```cpp
template<class T, class U> bool operator<(weak_ptr<T> const& a, weak_ptr<U> const& b);
```

1. **Returns**: an unspecified value such that
   - operator< is a strict weak ordering as described in [lib.alg.sorting];
   - under the equivalence relation defined by operator<, !(a < b) && !(b < a), two weak_ptr instances are equivalent if and only if they share ownership or are both empty.

2. **Throws**: nothing.

3. **Note**: Allows weak_ptr objects to be used as keys in associative containers. — end note

20.6.6.3.7 weak_ptr specialized algorithms

```cpp
template<class T> void swap(weak_ptr<T>& a, weak_ptr<T>& b)
```

1. **Effects**: Equivalent to a.swap(b).

2. **Throws**: nothing.

20.6.6.4 Class template enable_shared_from_this

A class T can inherit from enable_shared_from_this<T> to inherit the shared_from_this member functions that obtain a shared_ptr instance pointing to *this.

```cpp
struct X: public enable_shared_from_this<X>
{
};
```

```cpp
int main()
{
    shared_ptr<X> p(new X);
    shared_ptr<X> q = p->shared_from_this();
    assert(p == q);
    assert(!(p < q) && !(q < p)); // p and q share ownership
}
```

—end example.

```cpp
namespace std {
    template<class T> class enable_shared_from_this {
        protected:
            enable_shared_from_this();
            enable_shared_from_this(enable_shared_from_this const&);
            enable_shared_from_this& operator=(enable_shared_from_this const&);
        ~enable_shared_from_this();
        public:
            Draft
```

The template parameter \( T \) of `enable_shared_from_this` may be an incomplete type.

```cpp
enable_shared_from_this();
enable_shared_from_this(enable_shared_from_this<T> const&);
```

*Effects:* Constructs an `enable_shared_from_this<T>` object.

*Throws:* nothing.

```cpp
~enable_shared_from_this();
```

*Effects:* Destroys \(*this\).

*Throws:* nothing.

The template parameter \( T \) of `enable_shared_from_this` may be an incomplete type.

```cpp
shared_ptr<T> shared_from_this();
shared_ptr<T const> shared_from_this() const;
```

*Requires:* `enable_shared_from_this<T>` shall be an accessible base class of \( T \). \(*this\) shall be a subobject of an object \( t \) of type \( T \). There shall be at least one `shared_ptr` instance \( p \) that `owns \&t`.

*Returns:* A `shared_ptr<T>` object \( r \) that shares ownership with \( p \).

*Postconditions:* \( r\.get() == this \).

*[Note:* a possible implementation is shown below:]

```cpp
template<class T> class enable_shared_from_this
{
private:
    weak_ptr<T> __weak_this;

protected:
    enable_shared_from_this() {}
    enable_shared_from_this(enable_shared_from_this const &) {}
    enable_shared_from_this& operator=(enable_shared_from_this const &) { return *this; }
    ~enable_shared_from_this() {}

public:
    shared_ptr<T> shared_from_this() { return shared_ptr<T>(__weak_this); }
    shared_ptr<T const> shared_from_this() const { return shared_ptr<T const>(__weak_this); }
};
```

Draft
The shared_ptr constructors that create unique pointers can detect the presence of an enable_shared_from_this base and assign the newly created shared_ptr to its __weak_this member. — end note]

20.6.7 C Library [lib.c.malloc]

Header <cstdlib> (Table 47):

Table 47: Header <cstdlib> synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions:</td>
<td>calloc malloc</td>
</tr>
<tr>
<td>free realloc</td>
<td></td>
</tr>
</tbody>
</table>

The contents are the same as the Standard C library header <stdlib.h>, with the following changes:

1. The functions calloc(), malloc(), and realloc() do not attempt to allocate storage by calling ::operator new() (18.5).

2. The function free() does not attempt to deallocate storage by calling ::operator delete().

SEE ALSO: ISO C clause 7.11.2.

Header <cstring> (Table 48):

Table 48: Header <cstring> synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td>NULL</td>
</tr>
<tr>
<td>Type:</td>
<td>size_t</td>
</tr>
<tr>
<td>Functions:</td>
<td>memchr memcmp</td>
</tr>
<tr>
<td>memcpy memmove memset</td>
<td></td>
</tr>
</tbody>
</table>

The contents are the same as the Standard C library header <string.h>, with the change to memchr() specified in 21.4.

SEE ALSO: ISO C clause 7.11.2.

20.7 Date and time [lib.date.time]

Header <ctime> (Table 49):

The contents are the same as the Standard C library header <time.h>. 228)

SEE ALSO: ISO C clause 7.12, Amendment 1 clause 4.6.4.

228) TR1: strftime supports the C99 conversion specifiers C, D, E, F, g, G, h, r, R, t, T, u, V, and z, and the modifiers E and 0.

Draft
Table 49: Header `<ctime>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros</td>
<td>NULL, CLocks_PER_SEC</td>
</tr>
<tr>
<td>Types</td>
<td>size_t, clock_t, time_t</td>
</tr>
<tr>
<td>Struct</td>
<td>tm</td>
</tr>
<tr>
<td>Functions</td>
<td>asctime, clock, difftime, localtime, strftime, ctime, gmtime, mktime, time</td>
</tr>
</tbody>
</table>
Chapter 21  Strings library

This clause describes components for manipulating sequences of “characters,” where characters may be of any POD type. In this clause such types are called char-like types, and objects of char-like types are called char-like objects or simply “characters.”

The following subclauses describe a character traits class, a string class, and null-terminated sequence utilities, as summarized in Table 50:

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.1 Character traits</td>
<td>&lt;string&gt;</td>
</tr>
<tr>
<td>21.2 String classes</td>
<td>&lt;string&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cctype&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cwctype&gt;</td>
</tr>
<tr>
<td>21.4 Null-terminated sequence utilities</td>
<td>&lt;cstring&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cwchar&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cstdlib&gt;</td>
</tr>
</tbody>
</table>

21.1 Character traits

This subclause defines requirements on classes representing character traits, and defines a class template char_traits<charT>, along with two specializations, char_traits<char> and char_traits<wchar_t>, that satisfy those requirements.

Most classes specified in clauses 21.2 and 27 need a set of related types and functions to complete the definition of their semantics. These types and functions are provided as a set of member typedefs and functions in the template parameter ‘traits’ used by each such template. This subclause defines the semantics guaranteed by these members.

To specialize those templates to generate a string or iostream class to handle a particular character container type CharT, that and its related character traits class Traits are passed as a pair of parameters to the string or iostream template as formal parameters charT and traits. Traits::char_type shall be the same as CharT.

This subclause specifies a struct template, char_traits<charT>, and two explicit specializations of it, char_traits<char> and char_traits<wchar_t>, all of which appear in the header <string> and satisfy the requirements below.

21.1.1 Character traits requirements

In Table 51, X denotes a Traits class defining types and functions for the character container type CharT; c and d denote
values of type CharT; p and q denote values of type const CharT*; s denotes a value of type CharT*; n, i and j denote values of type std::size_t; e and f denote values of type X::int_type; pos denotes a value of type X::pos_type; state denotes a value of type X::state_type; and r denotes an lvalue of type CharT. Operations on Traits shall not throw exceptions.

### Table 51: Traits requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>X::char_type</td>
<td>charT</td>
<td>(described in 21.1.2)</td>
<td>compile-time</td>
</tr>
<tr>
<td>X::int_type</td>
<td>(described in 21.1.2)</td>
<td>compile-time</td>
<td></td>
</tr>
<tr>
<td>X::off_type</td>
<td>(described in 21.1.2)</td>
<td>compile-time</td>
<td></td>
</tr>
<tr>
<td>X::pos_type</td>
<td>(described in 21.1.2)</td>
<td>compile-time</td>
<td></td>
</tr>
<tr>
<td>X::state_type</td>
<td>(described in 21.1.2)</td>
<td>compile-time</td>
<td></td>
</tr>
<tr>
<td>X::eq(c,d)</td>
<td>bool</td>
<td>yields: whether c is to be treated as equal to d.</td>
<td>constant</td>
</tr>
<tr>
<td>X::lt(c,d)</td>
<td>bool</td>
<td>yields: whether c is to be treated as less than d.</td>
<td>constant</td>
</tr>
<tr>
<td>X::compare(p,q,n)</td>
<td>int</td>
<td>yields: 0 if for each i in [0,n), X::eq(p[i],q[i]) is true; else, a negative value if, for some j in [0,n), X::lt(p[j],q[j]) is true and for each i in [0,j) X::eq(p[i],q[i]) is true; else a positive value.</td>
<td>linear</td>
</tr>
<tr>
<td>X::length(p)</td>
<td>std::size_t</td>
<td>yields: the smallest i such that X::eq(p[i],charT()) is true.</td>
<td>linear</td>
</tr>
<tr>
<td>X::find(p,n,c)</td>
<td>const X::char_type*</td>
<td>yields: the smallest q in [p,p+n) such that X::eq(*q,c) is true, zero otherwise.</td>
<td>linear</td>
</tr>
<tr>
<td>X::move(s,p,n)</td>
<td>X::char_type*</td>
<td>for each i in [0,n), performs X::assign(s[i],p[i]). Copies correctly even where the ranges [p,p+n) and [s,s+n) overlap. yields: s.</td>
<td>linear</td>
</tr>
<tr>
<td>X::copy(s,p,n)</td>
<td>X::char_type*</td>
<td>pre: p not in [s,s+n). yields: s. for each i in [0,n), performs X::assign(s[i],p[i]).</td>
<td>linear</td>
</tr>
<tr>
<td>X::assign(r,d)</td>
<td>(not used)</td>
<td>assigns r=d.</td>
<td>constant</td>
</tr>
<tr>
<td>X::assign(s,n,c)</td>
<td>X::char_type*</td>
<td>for each i in [0,n), performs X::assign(s[i],c). yields: s.</td>
<td>linear</td>
</tr>
<tr>
<td>expression</td>
<td>return type</td>
<td>assertion/note pre/post condition</td>
<td>complexity</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------</td>
<td>----------------------------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td><code>X::not_eof(e)</code></td>
<td><code>int_type</code></td>
<td>yields: if <code>X::eq_int_type(e,X::eof())</code> is false, otherwise a value <code>f</code> such that <code>X::eq_int_type(f,X::eof())</code> is false.</td>
<td>constant</td>
</tr>
<tr>
<td><code>X::to_char_type(e)</code></td>
<td><code>X::char_type</code></td>
<td>yields: if for some <code>c</code>, <code>X::eq_int_type(e,X::to_int_type(c))</code> is true, <code>c</code>; else some unspecified value.</td>
<td>constant</td>
</tr>
<tr>
<td><code>X::to_int_type(c)</code></td>
<td><code>X::int_type</code></td>
<td>yields: some value <code>e</code>, constrained by the definitions of <code>to_char_type</code> and <code>eq_int_type</code>.</td>
<td>constant</td>
</tr>
<tr>
<td><code>X::eq_int_type(e,f)</code></td>
<td><code>bool</code></td>
<td>yields: for all <code>c</code> and <code>d</code>, <code>X::eq(c,d)</code> is equal to <code>X::eq_int_type(X::to_int_type(c), X::to_int_type(d))</code>; otherwise, yields true if <code>e</code> and <code>f</code> are both copies of <code>X::eof()</code>; otherwise, yields false if one of <code>e</code> and <code>f</code> is a copy of <code>X::eof()</code> and the other is not; otherwise the value is unspecified.</td>
<td>constant</td>
</tr>
<tr>
<td><code>X::eof()</code></td>
<td><code>X::int_type</code></td>
<td>yields: a value <code>e</code> such that <code>X::eq_int_type(e,X::to_int_type(c))</code> is false for all values <code>c</code>.</td>
<td>constant</td>
</tr>
</tbody>
</table>

2 The struct template

    template<class charT> struct char_traits;

shall be provided in the header `<string>` as a basis for explicit specializations.

3 In the following subclauses, the token `charT` represents the parameter of the traits template.

### 21.1.2 traits typedefs

    typedef CHAR_T char_type;

The type `char_type` is used to refer to the character container type in the implementation of the library classes defined in 21.2 and clause 27.

    typedef INT_T int_type;

Draft
21.1 Character traits

Requires: For a certain character container type char_type, a related container type INT_T shall be a type or class which can represent all of the valid characters converted from the corresponding char_type values, as well as an end-of-file value, eof(). The type int_type represents a character container type which can hold end-of-file to be used as a return type of the iostream class member functions. ²²⁹)

typedef OFF_T off_type;
typedef POS_T pos_type;

Requires: Requirements for off_type and pos_type are described in 27.1.2.

typedef STATE_T state_type;

Requires: state_type shall meet the requirements of Assignable (23.1), CopyConstructible (20.1.3), and DefaultConstructible (20.1.5) types.

21.1.3 char_traits specializations

namespace std {
    template<> struct char_traits<char>;
    template<> struct char_traits<wchar_t>;
}

The header <string> declares two structs that are specializations of the template struct char_traits.

The struct char_traits<char> is the char type specialization of the template struct char_traits, which contains all of the types and functions necessary to ensure the behavior of the classes in 21.2 and clause 27.

The types and static member functions are described in detail in 21.1.1.

21.1.3.1 struct char_traits<char>

namespace std {
    template<>
    struct char_traits<char> {
        typedef char char_type;
        typedef int int_type;
        typedef streamoff off_type;
        typedef streampos pos_type;
        typedef mbstate_t state_type;

        static void assign(char_type& c1, const char_type& c2);
        static bool eq(const char_type& c1, const char_type& c2);
        static bool lt(const char_type& c1, const char_type& c2);
        static int compare(const char_type* s1, const char_type* s2, size_t n);
        static size_t length(const char_type* s);
        static const char_type* find(const char_type* s, size_t n,
                                    const char_type&amp; a);
        static char_type* move(char_type* s1, const char_type* s2, size_t n);
    }

²²⁹) If eof() can be held in char_type then some iostreams operations may give surprising results.
static char_type* copy(char_type* s1, const char_type* s2, size_t n);
static char_type* assign(char_type* s, size_t n, char_type a);
static int_type not_eof(const int_type& c);
static char_type to_char_type(const int_type& c);
static int_type to_int_type(const char_type& c);
static bool eq_int_type(const int_type& c1, const int_type& c2);
static int_type eof();
}

The header `<string>` (21.2) declares a specialization of the template struct char_traits for char. It is for narrow-oriented iostream classes.

The defined types for int_type, pos_type, off_type, and state_type are int, streampos, streamoff, and mbstate_t respectively.

The type streampos is an implementation-defined type that satisfies the requirements for POS_T in 21.1.2.

The type streamoff is an implementation-defined type that satisfies the requirements for OFF_T in 21.1.2.

The type mbstate_t is defined in `<cwchar>` and can represent any of the conversion states possible to occur in an implementation-defined set of supported multibyte character encoding rules.

The two-argument member assign is defined identically to the built-in operator =. The two-argument members eq and lt are defined identically to the built-in operators == and < for type unsigned char.

The member eof() returns EOF.

21.1.3.2 struct char_traits<wchar_t>  

namespace std {
    template<>
    struct char_traits<wchar_t> {
        typedef wchar_t char_type;
        typedef wint_t int_type;
        typedef streamoff off_type;
        typedef wstreampos pos_type;
        typedef mbstate_t state_type;

        static void assign(char_type& c1, const char_type& c2);
        static bool eq(const char_type& c1, const char_type& c2);
        static bool lt(const char_type& c1, const char_type& c2);
        static int compare(const char_type* s1, const char_type* s2, size_t n);
        static size_t length(const char_type* s);
        static const char_type* find(const char_type* s, size_t n,
                                      const char_type& a);
        static char_type* move(char_type* s1, const char_type* s2, size_t n);
        static char_type* copy(char_type* s1, const char_type* s2, size_t n);
        static char_type* assign(char_type* s, size_t n, char_type a);
    };
}

Draft
static int_type not_eof(const int_type& c);
static char_type to_char_type(const int_type& c);
static int_type to_int_type(const char_type& c);
static bool eq_int_type(const int_type& c1, const int_type& c2);
static int_type eof();
};

The header <string> (21.2) declares a specialization of the template struct char_traits for wchar_t. It is for wide-oriented iostream classes.

The defined types for int_type, pos_type, and state_type are wint_t, wstreampos, and mbstate_t respectively.

The type wstreampos is an implementation-defined type that satisfies the requirements for POS_T in 21.1.2.

[Note: This paragraph is intentionally empty. —end note]

The type mbstate_t is defined in <cwchar> and can represent any of the conversion states possible to occur in an implementation-defined set of supported multibyte character encoding rules.

The two-argument members assign, eq, and lt are defined identically to the built-in operators =, ==, and < respectively.

The member eof() returns WEOF.

21.2 String classes

The header <string> defines a basic string class template and its traits that can handle all char-like (clause 21) template arguments with several function signatures for manipulating varying-length sequences of char-like objects.

The header <string> also defines two specific template classes string and wstring and their special traits.

Header <string> synopsis

namespace std {

// 21.1. character traits:
  template<class charT>
    struct char_traits;
  template <> struct char_traits<char>;
  template <> struct char_traits<wchar_t>;

  // 21.3. basic_string:
  template<class charT, class traits = char_traits<charT>,
    class Allocator = allocator<charT> >
    class basic_string;

  template<class charT, class traits, class Allocator>
    basic_string<
      charT, traits, Allocator>
      operator+(const basic_string<
        charT, traits, Allocator>& lhs,
      const basic_string<
        charT, traits, Allocator>& rhs);

  template<class charT, class traits, class Allocator>
    basic_string<
      charT, traits, Allocator>
      operator+(const charT* lhs,
      const basic_string<
        charT, traits, Allocator>& rhs);

};

Draft
template<class charT, class traits, class Allocator>
  basic_string<charT, traits, Allocator> 
  operator+(charT lhs, const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  basic_string<charT, traits, Allocator> 
  operator+(const basic_string<charT, traits, Allocator>& lhs, 
            const charT* rhs);

template<class charT, class traits, class Allocator>
  basic_string<charT, traits, Allocator> 
  operator+(const basic_string<charT, traits, Allocator>& lhs, 
            charT rhs);

template<class charT, class traits, class Allocator>
  bool operator==(const basic_string<charT, traits, Allocator>& lhs, 
                  const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator==(const charT* lhs, 
                  const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator==(const basic_string<charT, traits, Allocator>& lhs, 
                  const charT* rhs);

template<class charT, class traits, class Allocator>
  bool operator!=(const basic_string<charT, traits, Allocator>& lhs, 
                  const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator!=(const charT* lhs, 
                  const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator!=(const basic_string<charT, traits, Allocator>& lhs, 
                  const charT* rhs);

template<class charT, class traits, class Allocator>
  bool operator<(const basic_string<charT, traits, Allocator>& lhs, 
                 const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator<(const charT* lhs, 
                 const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator<(const basic_string<charT, traits, Allocator>& lhs, 
                 const charT* rhs);

template<class charT, class traits, class Allocator>
  bool operator>(const basic_string<charT, traits, Allocator>& lhs, 
                 const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator>(const charT* lhs, 
                 const basic_string<charT, traits, Allocator>& rhs);

template<class charT, class traits, class Allocator>
  bool operator>(const basic_string<charT, traits, Allocator>& lhs, 
                 const charT* rhs);
21.3 Class template basic_string

For a char-like type charT, the class template basic_string describes objects that can store a sequence consisting of a varying number of arbitrary char-like objects (clause 21). The first element of the sequence is at position zero. Such a sequence is also called a “string” if the given char-like type is clear from context. In the rest of this clause, charT

typedef basic_string<char> string;
typedef basic_string<wchar_t> wstring;
denotes such a given char-like type. Storage for the string is allocated and freed as necessary by the member functions of class basic_string, via the Allocator class passed as template parameter. Allocator::value_type shall be the same as charT.

2 The class template basic_string conforms to the requirements of a Sequence, as specified in (23.1.1). Additionally, because the iterators supported by basic_string are random access iterators (24.1.5), basic_string conforms to the requirements of a Reversible Container, as specified in (23.1).

3 In all cases, size() <= capacity().

4 The functions described in this clause can report two kinds of errors, each associated with a distinct exception:
   — a length error is associated with exceptions of type length_error (19.1.4);
   — an out-of-range error is associated with exceptions of type out_of_range (19.1.5).

5 For any string operation, if as a result of the operation, size() would exceed max_size() then the operation throws length_error.

6 References, pointers, and iterators referring to the elements of a basic_string sequence may be invalidated by the following uses of that basic_string object:
   — As an argument to non-member functions swap() (21.3.7.8), operator>>() (21.3.7.9), and getline() (21.3.7.9).
   — As an argument to basic_string::swap().
   — Calling data() and c_str() member functions.
   — Calling non-const member functions, except operator [], at, begin, rbegin, end, and rend.
   — Following construction or any of the above uses, except the forms of insert and erase that return iterators, the first call to non-const member functions operator [], at, begin, rbegin, end, or rend.

7 [ Note: These rules are formulated to allow, but not require, a reference counted implementation. A reference counted implementation must have the same semantics as a non-reference counted implementation. [ Example:

   string s1("abc");

   string::iterator i = s1.begin();
   string s2 = s1;

   *i = 'a'; // Must modify only s1

   — end example ] — end note ]

namespace std {
   template<class charT, class traits = char_traits<charT>,
            class Allocator = allocator<charT> >
   class basic_string {
      public:
         // types:
         typedef traits traits;
         typedef typename traits::char_type value_type;
         typedef Allocator allocator_type;

         Draft
typedef typename Allocator::size_type size_type;
typedef typename Allocator::difference_type difference_type;

typedef typename Allocator::reference reference;
typedef typename Allocator::const_reference const_reference;
typedef typename Allocator::pointer pointer;
typedef typename Allocator::const_pointer const_pointer;

typedef implementation-defined iterator;    // See 23.1

typedef implementation-defined const_iterator; // See 23.1

typedef std::reverse_iterator<iterator> reverse_iterator;
typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

static const size_type npos = -1;

// 21.3.1 construct/copy/destroy:
explicit basic_string(const Allocator& a = Allocator());
basic_string(const basic_string& str);
basic_string(const basic_string& str, size_type pos, size_type n = npos,
            const Allocator& a = Allocator());
basic_string(const charT* s,
            size_type n, const Allocator& a = Allocator());
basic_string(const charT* s, const Allocator& a = Allocator());
basic_string(size_type n, charT c, const Allocator& a = Allocator());
template<class InputIterator>
    basic_string(InputIterator begin, InputIterator end,
            const Allocator& a = Allocator());
~basic_string();
basic_string& operator=(const basic_string& str);
basic_string& operator=(const charT* s);
basic_string& operator=(charT c);

// 21.3.2 iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;

reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;

const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// 21.3.3 capacity:
size_type size() const;
size_type length() const;
size_type max_size() const;
void resize(size_type n, charT c);
void resize(size_type n);
size_type capacity() const;
void reserve(size_type res_arg = 0);
void clear();
bool empty() const;

// 21.3.4 element access:
const_reference operator[](size_type pos) const;
reference operator[](size_type pos);
const_reference at(size_type n) const;
reference at(size_type n);

// 21.3.5 modifiers:
basic_string& operator+=(const basic_string& str);
basic_string& operator+=(const charT* s);
basic_string& operator+=(charT c);
basic_string& append(const basic_string& str);
basic_string& append(const basic_string& str, size_type pos, size_type n);
basic_string& append(const charT* s, size_type n);
basic_string& append(const charT* s);
basic_string& append(size_type n, charT c);
template<class InputIterator>
  basic_string& append(InputIterator first, InputIterator last);
void push_back(charT c);

basic_string& assign(const basic_string& str);
basic_string& assign(const basic_string& str, size_type pos, size_type n);
basic_string& assign(const charT* s, size_type n);
basic_string& assign(const charT* s);
basic_string& assign(size_type n, charT c);
template<class InputIterator>
  basic_string& assign(InputIterator first, InputIterator last);

basic_string& insert(size_type pos1, const basic_string& str);
basic_string& insert(size_type pos1, const basic_string& str, size_type pos2, size_type n);
basic_string& insert(size_type pos, const charT* s, size_type n);
basic_string& insert(size_type pos, const charT* s);
basic_string& insert(size_type pos, size_type n, charT c);
iterator insert(iterator p, charT c);
void insert(iterator p, size_type n, charT c);
template<class InputIterator>
  void insert(iterator p, InputIterator first, InputIterator last);

basic_string& erase(size_type pos = 0, size_type n = npos);
iterator erase(iterator position);
iterator erase(iterator first, iterator last);

basic_string& replace(size_type pos1, size_type n1,  
const basic_string& str);

basic_string& replace(size_type pos1, size_type n1,  
const basic_string& str,  
size_type pos2, size_type n2);

basic_string& replace(size_type pos, size_type n1, const charT* s,  
size_type n2);

basic_string& replace(size_type pos, size_type n1, const basic_string& str);

basic_string& replace(size_type pos, size_type n1, const charT* s);

basic_string& replace(size_type pos, size_type n1, size_type n2,  
charT c);

basic_string& replace(iterator i1, iterator i2,  
const basic_string& str);

basic_string& replace(iterator i1, iterator i2, const charT* s,  
size_type n);

basic_string& replace(iterator i1, iterator i2, const charT* s);

basic_string& replace(iterator i1, iterator i2,  
size_type n, charT c);

template<class InputIterator>  
basic_string& replace(iterator i1, iterator i2,  
InputIterator j1, InputIterator j2);

size_type copy(charT* s, size_type n, size_type pos = 0) const;
void swap(basic_string& str);

// 21.3.6 string operations:

const charT* c_str() const;  // explicit
const charT* data() const;
allocator_type get_allocator() const;

size_type find (const basic_string& str, size_type pos = 0) const;
size_type find (const charT* s, size_type n) const;
size_type find (const charT* s, size_type pos = 0) const;
size_type find (charT c, size_type pos = 0) const;
size_type rfind(const basic_string& str, size_type pos = npos) const;
size_type rfind(const charT* s, size_type pos, size_type n) const;
size_type rfind(const charT* s, size_type pos = npos) const;
size_type rfind(charT c, size_type pos = npos) const;

size_type find_first_of(const basic_string& str,  
size_type pos = 0) const;
size_type find_first_of(const charT* s,  
size_type pos, size_type n) const;
size_type find_first_of(const charT* s, size_type pos = 0) const;
size_type find_first_of(charT c, size_type pos = 0) const;
size_type find_last_of (const basic_string& str,  
size_type pos = npos) const;
size_type find_last_of (const charT* s,  
size_type pos = npos) const;
size_type pos, size_type n) const;
size_type find_last_of (const charT* s, size_type pos = npos) const;
size_type find_last_of (charT c, size_type pos = npos) const;

size_type find_first_not_of(const basic_string& str, 
    size_type pos = 0) const;
size_type find_first_not_of(const charT* s, size_type pos, 
    size_type n) const;
size_type find_first_not_of(const charT* s, size_type pos = 0) const;
size_type find_last_not_of (const basic_string& str, 
    size_type pos = npos) const;
size_type find_last_not_of (const charT* s, size_type pos, 
    size_type n) const;
size_type find_last_not_of (const charT* s, 
    size_type pos = npos) const;
size_type find_last_not_of (charT c, size_type pos = npos) const;

basic_string substr(size_type pos = 0, size_type n = npos) const;
int compare(const basic_string& str) const;
int compare(size_type pos1, size_type n1, 
    const basic_string& str) const;
int compare(size_type pos1, size_type n1, 
    const basic_string& str, 
    size_type pos2, size_type n2) const;
int compare(const charT* s) const;
int compare(size_type pos1, size_type n1, 
    const charT* s) const;
int compare(size_type pos1, size_type n1, 
    const charT* s, size_type n2) const;

};
}

21.3.1 basic_string constructors [lib.string.cons]

In all basic_string constructors, a copy of the Allocator argument is used for any memory allocation performed by the constructor or member functions during the lifetime of the object.

explicit basic_string(const Allocator& a = Allocator());

Effects: Constructs an object of class basic_string. The postconditions of this function are indicated in Table 52.

basic_string(const basic_string<charT,traits,Allocator>& str);

basic_string(const basic_string<charT,traits,Allocator>& str, 
    size_type pos, size_type n = npos, 
    const Allocator& a = Allocator());
21.3 Class template basic_string

Table 52: basic_string(const Allocator&) effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>data()</td>
<td>a non-null pointer that is copyable and can have 0 added to it</td>
</tr>
<tr>
<td>size()</td>
<td>0</td>
</tr>
<tr>
<td>capacity()</td>
<td>an unspecified value</td>
</tr>
</tbody>
</table>

Requires: pos \(\leq\) str.size()

Throws: out_of_range if pos > str.size().

Effects: Constructs an object of class basic_string and determines the effective length \(rlen\) of the initial string value as the smaller of \(n\) and \(str\).size() - pos, as indicated in Table 53. In the first form, the Allocator value used is copied from str.get_allocator().

Table 53: basic_string(basic_string, size_type, size_type, const Allocator&) effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>data()</td>
<td>points at the first element of an allocated copy of (rlen) consecutive elements of the string controlled by str beginning at position pos</td>
</tr>
<tr>
<td>size()</td>
<td>(rlen)</td>
</tr>
<tr>
<td>capacity()</td>
<td>a value at least as large as size()</td>
</tr>
</tbody>
</table>

basic_string(const charT* s, size_type n,
const Allocator& a = Allocator());

Requires: s shall not be a null pointer and \(n < npos\).

[Note: This paragraph is intentionally empty. — end note]

Effects: Constructs an object of class basic_string and determines its initial string value from the array of charT of length \(n\) whose first element is designated by \(s\), as indicated in Table 54.

Table 54: basic_string(const charT*, size_type, const Allocator&) effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>data()</td>
<td>points at the first element of an allocated copy of the array whose first element is pointed at by (s)</td>
</tr>
<tr>
<td>size()</td>
<td>(n)</td>
</tr>
<tr>
<td>capacity()</td>
<td>a value at least as large as size()</td>
</tr>
</tbody>
</table>

basic_string(const charT* s, const Allocator& a = Allocator());

Requires: s shall not be a null pointer.

Effects: Constructs an object of class basic_string and determines its initial string value from the array of charT of length traits::length(s) whose first element is designated by \(s\), as indicated in Table 55.
Table 55: `basic_string(const charT*, const Allocator&)` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>data()</td>
<td>points at the first element of an allocated copy of the array whose first element is pointed at by s</td>
</tr>
<tr>
<td>size()</td>
<td>traits::length(s)</td>
</tr>
<tr>
<td>capacity()</td>
<td>a value at least as large as size()</td>
</tr>
</tbody>
</table>

Remarks: Uses traits::length().

`basic_string(size_type n, charT c, const Allocator& a = Allocator());`

Requires: n < npos

[Note: This paragraph is intentionally empty. — end note]

Effects: Constructs an object of class `basic_string` and determines its initial string value by repeating the char-like object c for all n elements, as indicated in Table 56:

Table 56: `basic_string(size_t, charT, const Allocator&)` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>data()</td>
<td>points at the first element of an allocated array of n elements, each storing the initial value c</td>
</tr>
<tr>
<td>size()</td>
<td>n</td>
</tr>
<tr>
<td>capacity()</td>
<td>a value at least as large as size()</td>
</tr>
</tbody>
</table>

Template<class InputIterator>

`basic_string(InputIterator begin, InputIterator end, const Allocator& a = Allocator());`

Effects: If `InputIterator` is an integral type, equivalent to

`basic_string(static_cast<size_type>(begin), static_cast<value_type>(end), a)`

Otherwise constructs a string from the values in the range `[begin, end)`, as indicated in the Sequence Requirements table (see 23.1.1).

`basic_string<charT,traits,Allocator>& operator=(const basic_string<charT,traits,Allocator>& str);`

Effects: If `*this` and `str` are not the same object, modifies `*this` as shown in Table 57:

Returns: `*this`

`basic_string<charT,traits,Allocator>& operator=(const charT* s);`
Table 57: `operator=(const basic_string<charT, traits, Allocator>&)` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>data()</td>
<td>points at the first element of an allocated copy of the array whose first element is pointed at by <code>str.data()</code></td>
</tr>
<tr>
<td>size()</td>
<td><code>str.size()</code></td>
</tr>
<tr>
<td>capacity()</td>
<td>a value at least as large as <code>size()</code></td>
</tr>
</tbody>
</table>

```
20  Returns: *this = basic_string<charT, traits, Allocator>(s).
21  Remarks: Uses traits::length().

basic_string<charT, traits, Allocator>& operator=(charT c);

22  Returns: *this = basic_string<charT, traits, Allocator>(1, c).
```

### 21.3.2 basic_string iterator support

```
iterator begin();
const_iterator begin() const;

1  Returns: an iterator referring to the first character in the string.

iterator end();
const_iterator end() const;

2  Returns: an iterator which is the past-the-end value.

reverse_iterator rbegin();
const_reverse_iterator rbegin() const;

3  Returns: an iterator which is semantically equivalent to reverse_iterator(end()).

reverse_iterator rend();
const_reverse_iterator rend() const;

4  Returns: an iterator which is semantically equivalent to reverse_iterator(begin()).
```

### 21.3.3 basic_string capacity

```
size_type size() const;

1  Returns: a count of the number of char-like objects currently in the string.

size_type length() const;

2  Returns: size().

size_type max_size() const;
```

Draft
Returns: The maximum size of the string.

Remark: See Container requirements table (23.1).

void resize(size_type n, charT c);

Requires: n <= max_size()

Throws: length_error if n > max_size().

Effects: Alters the length of the string designated by *this as follows:

— If n <= size(), the function replaces the string designated by *this with a string of length n whose elements are a copy of the initial elements of the original string designated by *this.

— If n > size(), the function replaces the string designated by *this with a string of length n whose first size() elements are a copy of the original string designated by *this, and whose remaining elements are all initialized to c.

void resize(size_type n);

Effects: resize(n, charT()).

size_type capacity() const;

Returns: the size of the allocated storage in the string.

void reserve(size_type res_arg=0);

The member function reserve() is a directive that informs a basic_string object of a planned change in size, so that it can manage the storage allocation accordingly.

Effects: After reserve(), capacity() is greater or equal to the argument of reserve. [Note: Calling reserve() with a res_arg argument less than capacity() is in effect a non-binding shrink request. A call with res_arg <= size() is in effect a non-binding shrink-to-fit request. — end note]

Throws: length_error if res_arg > max_size().

void clear();

Effects: Behaves as if the function calls:

erase(begin(), end());

bool empty() const;

Returns: size() == 0.

21.3.4 basic_string element access

const_reference operator[](size_type pos) const;
reference operator[](size_type pos);

reserve() uses Allocator::allocate() which may throw an appropriate exception.

Draft
21.3 Class template basic_string

Returns: If \( \text{pos} < \text{size()} \), returns \(*\text{begin()} + \text{pos}\). Otherwise, if \( \text{pos} = \text{size()} \), the const version returns \( \text{charT()} \). Otherwise, the behavior is undefined.

\[
\text{const\_reference at(size\_type pos) const;}
\text{reference at(size\_type pos);}\]

2 Requires: \( \text{pos} < \text{size()} \)

3 Throws: out\_of\_range if \( \text{pos} \geq \text{size()} \).

4 Returns: \( \text{operator[]} \text{(pos)} \).

21.3.5 basic_string modifiers

21.3.5.1 basic_string::operator+=

\[
\text{basic\_string<charT, traits, Allocator>& operator+=(const basic\_string<charT, traits, Allocator>& str);}\]

1 Returns: append\( \text{(str)} \).

\[
\text{basic\_string<charT, traits, Allocator>& operator+=(const charT* s);}\]

2 Returns: \( \text{*this += basic\_string<charT, traits, Allocator>(s)} \).

3 Remarks: Uses \text{traits::length()}.

\[
\text{basic\_string<charT, traits, Allocator>& operator+=(charT c);}\]

4 Returns: \( \text{*this += basic\_string<charT, traits, Allocator>(1, c)} \).

21.3.5.2 basic_string::append

\[
\text{basic\_string<charT, traits, Allocator>& append(const basic\_string<charT, traits>& str);}\]

1 Returns: append\( \text{(str}, 0, \text{npos)} \).

\[
\text{basic\_string<charT, traits, Allocator>& append(const basic\_string<charT, traits>& str, size\_type pos, size\_type n);}\]

2 Requires: \( \text{pos} <= \text{str.size()} \)

3 Throws: out\_of\_range if \( \text{pos} > \text{str.size()} \).

4 Effects: Determines the effective length \( rlen \) of the string to append as the smaller of \( n \) and \( \text{str.size()} - \text{pos} \). The function then throws \text{length\_error} if \( \text{size()} >= \text{npos} - rlen \).

Otherwise, the function replaces the string controlled by \text{*this} with a string of length \text{size()} + \( rlen \) whose first \text{size()} elements are a copy of the original string controlled by \text{*this} and whose remaining elements are a copy of the initial elements of the string controlled by \text{str} beginning at position \text{pos}.

5 Returns: \text{*this}.
basic_string<charT,traits,Allocator>&
append(const charT* s, size_type n);

Returns: append(basic_string<charT,traits,Allocator>(s,n)).

basic_string<charT,traits,Allocator>&
append(const charT* s);

Returns: append(basic_string<charT,traits,Allocator>(s)).

Remarks: Uses traits::length().

basic_string<charT,traits,Allocator>&
append(size_type n, charT c);

Returns: append(basic_string<charT,traits,Allocator>(n,c)).

template<class InputIterator>
basic_string&
append(InputIterator first, InputIterator last);

Returns: append(basic_string<charT,traits,Allocator>(first,last)).

void push_back(charT c)
Effects: Equivalent to append(static_cast<size_type>(1), c).

21.3.5.3 basic_string::assign

basic_string<charT,traits,Allocator>&
assign(const basic_string<charT,traits>&& str);

Returns: assign(str, 0, npos).

basic_string<charT,traits,Allocator>&
assign(const basic_string<charT,traits>& str, size_type pos,
size_type n);

Requires: pos <= str.size()
Throws: out_of_range if pos > str.size().

Effects: Determines the effective length rlen of the string to assign as the smaller of n and str.size() - pos.
The function then replaces the string controlled by *this with a string of length rlen whose elements are a copy of
the string controlled by str beginning at position pos.

Returns: *this.

basic_string<charT,traits,Allocator>&
assign(const charT* s, size_type n);

Returns: assign(basic_string<charT,traits,Allocator>(s,n)).

basic_string<charT,traits,Allocator>&
assign(const charT* s);
21.3 Class template `basic_string`  

Strings library

- **Returns:** assign(basic_string<charT, traits, Allocator>(s)).
- **Remarks:** Uses traits::length().

```cpp
basic_string<charT, traits, Allocator>& assign(size_type n, charT c);
```

- **Returns:** assign(basic_string<charT, traits, Allocator>(n, c)).

```cpp
template<class InputIterator>
basic_string& assign(InputIterator first, InputIterator last);
```

- **Returns:** assign(basic_string<charT, traits, Allocator>(first, last)).

### 21.3.5.4 `basic_string::insert`  [lib.string::insert]

- **Returns:** insert(pos1, str, 0, npos).

```cpp
basic_string<charT, traits, Allocator>&
insert(size_type pos1,  
    const basic_string<charT, traits, Allocator>& str);
```

- **Requires:** pos1 <= size() and pos2 <= str.size()
- **Throws:** out_of_range if pos1 > size() or pos2 > str.size().
- **Effects:** Determines the effective length rlen of the string to insert as the smaller of n and str.size() - pos2. Then throws length_error if size() >= npos - rlen.

Otherwise, the function replaces the string controlled by *this with a string of length size() + rlen whose first pos1 elements are a copy of the initial elements of the original string controlled by *this, whose next rlen elements are a copy of the elements of the string controlled by str beginning at position pos2, and whose remaining elements are a copy of the remaining elements of the original string controlled by *this.

- **Returns:** *this.

```cpp
basic_string<charT, traits, Allocator>&
insert(size_type pos, const charT* s, size_type n);
```

- **Returns:** insert(pos, basic_string<charT, traits, Allocator>(s, n)).

```cpp
basic_string<charT, traits, Allocator>&
insert(size_type pos, const charT* s);
```

- **Returns:** insert(pos, basic_string<charT, traits, Allocator>(s)).
- **Remarks:** Uses traits::length().

Draft
basic_string<
   charT,traits,Allocator>&
   insert(size_type pos, size_type n, charT c);

   Returns: insert(pos,basic_string<
       charT,traits,Allocator>(n,c)).

   iterator insert(iterator p, charT c);

   Requires: p is a valid iterator on *this.
   Effects: inserts a copy of c before the character referred to by p.
   Returns: an iterator which refers to the copy of the inserted character.

   void insert(iterator p, size_type n, charT c);

   Requires: p is a valid iterator on *this.
   Effects: inserts n copies of c before the character referred to by p.

   template<class InputIterator>
   void insert(iterator p, InputIterator first, InputIterator last);

   Requires: p is a valid iterator on *this. [first, last) is a valid range.
   Effects: Equivalent to insert(p - begin(), basic_string(first, last)).

21.3.5.5 basic_string::erase

   basic_string<
       charT,traits,Allocator>&
   erase(size_type pos = 0, size_type n = npos);

   Requires: pos <= size()
   Throws: out_of_range if pos > size().
   Effects: Determines the effective length xlen of the string to be removed as the smaller of n and size() - pos.
   The function then replaces the string controlled by *this with a string of length size() - xlen whose first pos elements are a copy of the initial elements of the original string controlled by *this, and whose remaining elements are a copy of the elements of the original string controlled by *this beginning at position pos + xlen.
   Returns: *this.

   iterator erase(iterator p);

   Effects: removes the character referred to by p.
   Returns: an iterator which points to the element immediately following p prior to the element being erased. If no such element exists, end() is returned.

   iterator erase(iterator first, iterator last);

   Requires: first and last are valid iterators on *this, defining a range [first, last).
   Effects: removes the characters in the range [first, last).
Returns: an iterator which points to the element pointed to by \textit{last} prior to the other elements being erased. If no such element exists, \textit{end()} is returned.

21.3.5.6 \texttt{basic\_string::replace} \hfill [lib.string::replace]

\begin{verbatim}
basic_string& replace(size_type pos1, size_type n1, const basic_string& str);

Returns: replace(pos1, n1, str, 0, npos).

basic_string& replace(size_type pos1, size_type n1, const basic_string& str, size_type pos2, size_type n2);

Requires: pos1 \leq size() \&\& pos2 \leq str.size().

Throws: out\_of\_range if pos1 > size() or pos2 > str.size(), or length\_error if the length of the resulting string would exceed max\_size() (see below).

Effects: Determines the effective length \textit{xlen} of the string to be removed as the smaller of \textit{n1} and \textit{size()} - \textit{pos1}. Also determines the effective length \textit{rlen} of the string to be inserted as the smaller of \textit{n2} and \textit{str.size()} - \textit{pos2}. If \textit{size()} - \textit{xlen} \geq max\_size() - \textit{rlen}, throws length\_error. Otherwise, the function replaces the string controlled by \texttt{*this} with a string of length \textit{size()} - \textit{xlen} whose first \textit{xlen} elements are a copy of the initial elements of the original string controlled by \texttt{*this}, whose next \textit{rlen} elements are a copy of the initial elements of the string controlled by \texttt{str} beginning at position \textit{pos2}, and whose remaining elements are a copy of the elements of the original string controlled by \texttt{*this} beginning at position \textit{pos1} + \textit{xlen}.

Returns: \texttt{*this}.

basic_string& replace(size_type pos, size_type n1, const char* s, size_type n2);

Returns: replace(pos, n1, (unsigned char*)s, n2).

basic_string& replace(size_type pos, size_type n1, const char* s);

Returns: replace(pos, n1, (unsigned char*)s).

Remarks: Uses \texttt{traits::length()}.

basic_string& replace(size_type pos, size_type n1, size_type n2, char c);

Returns: replace(pos, n1, (unsigned char*)s, n2, c).

basic_string& replace(iterator i1, iterator i2, const basic_string& str);
\end{verbatim}
10  * Requires: The iterators *i1 and *i2 are valid iterators on *this, defining a range [*i1,*i2*).
11  * Effects: Replaces the string controlled by *this with a string of length size() - (*i2 - *i1) + str.size() whose first begin() - *i1 elements are a copy of the initial elements of the original string controlled by *this, whose next str.size() elements are a copy of the string controlled by str, and whose remaining elements are a copy of the elements of the original string controlled by *this beginning at position *i2.
12  *
13  * Returns: *this.
14  *
15  * Remarks: After the call, the length of the string will be changed by: str.size() - (*i2 - *i1).

class replace(iterator *i1, iterator *i2, const charT* s, size_type n);
14  * Returns: replace(*i1,*i2,basic_string(s,n)).
15  *
16  * Remarks: Length change: n - (*i2 - *i1).

class replace(iterator *i1, iterator *i2, const charT* s);
16  * Returns: replace(*i1,*i2,basic_string(s)).
17  *
18  * Remarks: Length change: traits::length(s) - (*i2 - *i1).
Uses traits::length().

class replace(iterator *i1, iterator *i2, size_type n, charT c);
18  * Returns: replace(*i1,*i2,basic_string(n,c)).
19  *
20  * Remarks: Length change: n - (*i2 - *i1).

template<class InputIterator>
21  class replace(iterator *i1, iterator *i2,
22             InputIterator j1, InputIterator j2);
23  * Returns: replace(*i1,*i2,basic_string(j1,j2)).
24  *
25  * Remarks: Length change: *j2 - j1 - (*i2 - *i1).

21.3.5.7  basic_string::copy

size_type copy(charT* s, size_type n, size_type pos = 0) const;
1  * Requires: pos <= size()
2  *
2  * Throws: out_of_range if pos > size().
3  *
3  * Effects: Determines the effective length rlen of the string to copy as the smaller of n and size() - pos. s shall designate an array of at least rlen elements.

The function then replaces the string designated by *s with a string of length rlen whose elements are a copy of the string controlled by *this beginning at position pos.
The function does not append a null object to the string designated by s.

Returns: rlen.

### 21.3.5.8 basic_string::swap

```c
void swap(basic_string<charT,traits,Allocator>& s);
```

**Effects:** Swaps the contents of the two strings.

**Requires:** Nothing.

**Postcondition:** *this contains the characters that were in s, s contains the characters that were in *this.

**Complexity:** constant time.

### 21.3.6 basic_string string operations

```c
const charT* c_str() const;
```

**Returns:** A pointer to the initial element of an array of length size() + 1 whose first size() elements equal the corresponding elements of the string controlled by *this and whose last element is a null character specified by charT().

**Requires:** The program shall not alter any of the values stored in the array. Nor shall the program treat the returned value as a valid pointer value after any subsequent call to a non-const member function of the class basic_string that designates the same object as this.

```c
const charT* data() const;
```

**Returns:** If size() is nonzero, the member returns a pointer to the initial element of an array whose first size() elements equal the corresponding elements of the string controlled by *this. If size() is zero, the member returns a non-null pointer that is copyable and can have zero added to it.

**Requires:** The program shall not alter any of the values stored in the character array. Nor shall the program treat the returned value as a valid pointer value after any subsequent call to a non-const member function of basic_string that designates the same object as this.

```c
allocator_type get_allocator() const;
```

**Returns:** a copy of the Allocator object used to construct the string.

### 21.3.6.1 basic_string::find

```c
size_type find(const basic_string<charT,traits,Allocator>& str, size_type pos = 0) const;
```

**Effects:** Determines the lowest position xpos, if possible, such that both of the following conditions obtain:

- \( pos \leq xpos \) and \( xpos + str.size() \leq size() \).
— traits::eq(at(xpos + I), str.at(I)) for all elements I of the string controlled by str.

2 Returns: xpos if the function can determine such a value for xpos. Otherwise, returns npos.

3 Remarks: Uses traits::eq().

size_type find(const charT* s, size_type pos, size_type n) const;

4 Returns: find(basic_string<charT,traits,Allocator>(s,n),pos).

size_type find(const charT* s, size_type pos = 0) const;

5 Returns: find(basic_string<charT,traits,Allocator>(s),pos).

6 Remarks: Uses traits::length().

size_type find(charT c, size_type pos = 0) const;

7 Returns: find(basic_string<charT,traits,Allocator>(1,c),pos).

21.3.6.2 basic_string::rfind

size_type rfind(const basic_string<charT,traits,Allocator>& str,
    size_type pos = npos) const;

1 Effects: Determines the highest position xpos, if possible, such that both of the following conditions obtain:
   — xpos <= pos and xpos + str.size() <= size();
   — traits::eq(at(xpos + I), str.at(I)) for all elements I of the string controlled by str.

2 Returns: xpos if the function can determine such a value for xpos. Otherwise, returns npos.

3 Remarks: Uses traits::eq().

size_type rfind(const charT* s, size_type pos, size_type n) const;

4 Returns: rfind(basic_string<charT,traits,Allocator>(s,n),pos).

size_type rfind(const charT* s, size_type pos = npos) const;

5 Returns: rfind(basic_string<charT,traits,Allocator>(s),pos).

6 Remarks: Uses traits::length().

size_type rfind(charT c, size_type pos = npos) const;

7 Returns: rfind(basic_string<charT,traits,Allocator>(1,c),pos).

21.3.6.3 basic_string::find_first_of

size_type find_first_of(const basic_string<charT,traits,Allocator>& str,
    size_type pos = 0) const;

Draft
**21.3 Class template basic_string** Strings library 518

**21.3.6.4 basic_string::find_last_of**

```
size_type
find_last_of(const charT* s, size_type pos, size_type n) const;
```

**Effects:** Determines the highest position `xpos`, if possible, such that both of the following conditions obtain:

- `pos <= xpos` and `xpos < size();`
- `traits::eq(at(xpos), str.at(I))` for some element `I` of the string controlled by `str`.

**Returns:** `xpos` if the function can determine such a value for `xpos`. Otherwise, returns `npos`.

**Remarks:** Uses `traits::eq()`. 

```
size_type
find_last_of(const basic_string<charT, traits, Allocator>& str, size_type pos = npos) const;
```

**Effects:** Determines the highest position `xpos`, if possible, such that both of the following conditions obtain:

- `xpos <= pos` and `xpos < size();`
- `traits::eq(at(xpos), str.at(I))` for some element `I` of the string controlled by `str`.

**Returns:** `xpos` if the function can determine such a value for `xpos`. Otherwise, returns `npos`.

**Remarks:** Uses `traits::eq()`. 

```
size_type
find_last_of(const charT* s, size_type pos = 0) const;
```

**Returns:** `find_last_of(basic_string<charT, traits, Allocator>(s), pos)`. 

```
size_type
find_last_of(const charT* s, size_type pos = npos) const;
```

**Returns:** `find_last_of(basic_string<charT, traits, Allocator>(s), pos)`. 

```
size_type
find_last_of(charT c, size_type pos = npos) const;
```

**Returns:** `find_last_of(basic_string<charT, traits, Allocator>(1, c), pos)`. 

Draft
21.3.6.5 basic_string::find_first_not_of

size_type find_first_not_of(const basic_string<charT,traits,Allocator>& str, size_type pos = 0) const;

Effects: Determines the lowest position xpos, if possible, such that both of the following conditions obtain:
— pos <= xpos and xpos < size();
— traits::eq(at(xpos), str.at(I)) for no element I of the string controlled by str.

Returns: xpos if the function can determine such a value for xpos. Otherwise, returns npos.

Remarks: Uses traits::eq().

size_type find_first_not_of(const charT* s, size_type pos, size_type n) const;

Returns: find_first_not_of(basic_string<charT,traits,Allocator>(s,n),pos).

size_type find_first_not_of(const charT* s, size_type pos = 0) const;

Returns: find_first_not_of(basic_string<charT,traits,Allocator>(s),pos).

Remarks: Uses traits::length().

size_type find_first_not_of(charT c, size_type pos = 0) const;

Returns: find_first_not_of(basic_string<charT,traits,Allocator>(1,c),pos).

21.3.6.6 basic_string::find_last_not_of

size_type find_last_not_of(const basic_string<charT,traits,Allocator>& str, size_type pos = npos) const;

Effects: Determines the highest position xpos, if possible, such that both of the following conditions obtain:
— xpos <= pos and xpos < size();
— traits::eq(at(xpos), str.at(I)) for no element I of the string controlled by str.

Returns: xpos if the function can determine such a value for xpos. Otherwise, returns npos.

Remarks: Uses traits::eq().

size_type find_last_not_of(const charT* s, size_type pos, size_type n) const;

Returns: find_last_not_of(basic_string<charT,traits,Allocator>(s,n),pos).

size_type find_last_not_of(const charT* s, size_type pos = npos) const;
21.3 Class template basic_string

Returns: find_last_not_of(basic_string<charT,traits,Allocator>(s),pos).

Remarks: Uses traits::length().

size_type find_last_not_of(charT c, size_type pos = npos) const;

Returns: find_last_not_of(basic_string<charT,traits,Allocator>(1,c),pos).

21.3.6.7 basic_string::substr

basic_string<charT,traits,Allocator>
substr(size_type pos = 0, size_type n = npos) const;

Requires: pos <= size()

Throws: out_of_range if pos > size().

Effects: Determines the effective length rlen of the string to copy as the smaller of n and size() - pos.

Returns: basic_string<charT,traits,Allocator>(data()+pos,rlen).

21.3.6.8 basic_string::compare

int compare(const basic_string<charT,traits,Allocator>& str) const

Effects: Determines the effective length rlen of the strings to compare as the smallest of size() and str.size(). The function then compares the two strings by calling traits::compare(data(), str.data(), rlen).

Returns: the nonzero result if the result of the comparison is nonzero. Otherwise, returns a value as indicated in Table 58.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Return Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>size() &lt; str.size()</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>size() == str.size()</td>
<td>0</td>
</tr>
<tr>
<td>size() &gt; str.size()</td>
<td>&gt; 0</td>
</tr>
</tbody>
</table>

int compare(size_type pos1, size_type n1,
            const basic_string<charT,traits,Allocator>& str) const;

Returns:

basic_string<charT,traits,Allocator>(*this,pos1,n1).compare(str).

int compare(size_type pos1, size_type n1,
            const basic_string<charT,traits,Allocator>& str,
            size_type pos2, size_type n2 ) const;

Returns:
basic_string<charT,traits,Allocator>(*this,pos1,n1).compare(basic_string<charT,traits,Allocator>(str,pos2,n2)).

int compare(const charT *s) const;

5 Returns: this->compare(basic_string<charT,traits,Allocator>(s)).

int compare(size_type pos, size_type n1, const charT *s) const;

6 Returns:

basic_string<charT,traits,Allocator>(*this,pos,n1).compare(basic_string<charT,traits,Allocator>(s))

int compare(size_type pos, size_type n1, const charT *s, size_type n2) const;

7 Returns:

basic_string<charT,traits,Allocator>(*this,pos,n1).compare(basic_string<charT,traits,Allocator>(s,n2))

21.3.7 basic_string non-member functions [lib.string::op+]

21.3.7.1 operator+ [lib.string.nonmembers]

template<class charT, class traits, class Allocator>
basic_string<charT,traits,Allocator>
operator+(const basic_string<charT,traits,Allocator>& lhs, const basic_string<charT,traits,Allocator>& rhs);

1 Returns: basic_string<charT,traits,Allocator>(lhs).append(rhs)

template<class charT, class traits, class Allocator>
basic_string<charT,traits,Allocator>
operator+(const charT* lhs, const basic_string<charT,traits,Allocator>& rhs);

2 Returns: basic_string<charT,traits,Allocator>(lhs) + rhs.

3 Remarks: Uses traits::length().

template<class charT, class traits, class Allocator>
basic_string<charT,traits,Allocator>
operator+(charT lhs, const basic_string<charT,traits,Allocator>& rhs);

4 Returns: basic_string<charT,traits,Allocator>(1,lhs) + rhs.

template<class charT, class traits, class Allocator>
basic_string<charT,traits,Allocator>
21.3 Class template `basic_string`

```
operator+(const basic_string<charT,traits,Allocator>& lhs,
          const charT* rhs);

Returns: lhs + basic_string<charT,traits,Allocator>(rhs).

Remarks: Uses traits::length().
```

```
template<class charT, class traits, class Allocator>
  basic_string<charT,traits,Allocator>
  operator+(const basic_string<charT,traits,Allocator>& lhs,
            charT* rhs);

Returns: lhs + basic_string<charT,traits,Allocator>(1,rhs).
```

21.3.7.2 `operator==`

```
operator==(const basic_string<charT,traits,Allocator>& lhs,
           const basic_string<charT,traits,Allocator>& rhs);
```

```
Returns: lhs.compare(rhs) == 0.
```

```
template<class charT, class traits, class Allocator>
  bool operator==(const charT* lhs,
                 const basic_string<charT,traits,Allocator>& rhs);

Returns: basic_string<charT,traits,Allocator>(lhs) == rhs.
```

```
template<class charT, class traits, class Allocator>
  bool operator==(const basic_string<charT,traits,Allocator>& lhs,
                 const charT* rhs);

Returns: lhs == basic_string<charT,traits,Allocator>(rhs).

Remarks: Uses traits::length().
```

21.3.7.3 `operator!=`

```
operator!=(const basic_string<charT,traits,Allocator>& lhs,
           const basic_string<charT,traits,Allocator>& rhs);
```

```
Returns: !(lhs == rhs).
```

```
template<class charT, class traits, class Allocator>
  bool operator!=(const charT* lhs,
                 const basic_string<charT,traits,Allocator>& rhs);

Returns: basic_string<charT,traits,Allocator>(lhs) != rhs.
```

```
template<class charT, class traits, class Allocator>
  bool operator!=(const basic_string<charT,traits,Allocator>& lhs,
                 const charT* rhs);
```

Draft
const charT* rhs);

3  Returns: lhs != basic_string<charT,traits,Allocator>(rhs).

4  Remarks: Uses traits::length().

### 21.3.7.4 operator<

[lib.string::op<]

template<class charT, class traits, class Allocator>
bool operator< (const basic_string<charT,traits,Allocator>& lhs,
               const basic_string<charT,traits,Allocator>& rhs);

1  Returns: lhs.compare(rhs) < 0.

template<class charT, class traits, class Allocator>
bool operator< (const charT* lhs,
               const basic_string<charT,traits,Allocator>& rhs);

2  Returns: basic_string<charT,traits,Allocator>(lhs) < rhs.

template<class charT, class traits, class Allocator>
bool operator< (const basic_string<charT,traits,Allocator>& lhs,
               const charT* rhs);

3  Returns: lhs < basic_string<charT,traits,Allocator>(rhs).

### 21.3.7.5 operator>

[lib.string::op>]

template<class charT, class traits, class Allocator>
bool operator> (const basic_string<charT,traits,Allocator>& lhs,
               const basic_string<charT,traits,Allocator>& rhs);

1  Returns: lhs.compare(rhs) > 0.

template<class charT, class traits, class Allocator>
bool operator> (const charT* lhs,
               const basic_string<charT,traits,Allocator>& rhs);

2  Returns: basic_string<charT,traits,Allocator>(lhs) > rhs.

template<class charT, class traits, class Allocator>
bool operator> (const basic_string<charT,traits,Allocator>& lhs,
               const charT* rhs);

3  Returns: lhs > basic_string<charT,traits,Allocator>(rhs).

### 21.3.7.6 operator<=

[lib.string::op<=]

template<class charT, class traits, class Allocator>
bool operator<=(const basic_string<charT,traits,Allocator>& lhs,
                 const basic_string<charT,traits,Allocator>& rhs);

Draft
21.3 Class template `basic_string`

**Returns:** \( \text{lhs}.\text{compare}(\text{rhs}) \leq 0 \).

```cpp
template<class charT, class traits, class Allocator>
bool operator<=(const char* lhs, const basic_string<charT, traits, Allocator>& rhs);
```

**Returns:** \( \text{basic_string}\langle\text{charT},\text{traits},\text{Allocator}\rangle(\text{lhs}) \leq \text{rhs} \).

```cpp
template<class charT, class traits, class Allocator>
bool operator<=(const basic_string<charT, traits, Allocator>& lhs, const charT* rhs);
```

**Returns:** \( \text{lhs} \leq \text{basic_string}\langle\text{charT},\text{traits},\text{Allocator}\rangle(\text{rhs}) \).

### 21.3.7.7 `operator>=`

```cpp
template<class charT, class traits, class Allocator>
bool operator>=(const basic_string<charT, traits, Allocator>& lhs, const basic_string<charT, traits, Allocator>& rhs);
```

**Returns:** \( \text{lhs}.\text{compare}(\text{rhs}) \geq 0 \).

```cpp
template<class charT, class traits, class Allocator>
bool operator>=(const char* lhs, const basic_string<charT, traits, Allocator>& rhs);
```

**Returns:** \( \text{basic_string}\langle\text{charT},\text{traits},\text{Allocator}\rangle(\text{lhs}) \geq \text{rhs} \).

```cpp
template<class charT, class traits, class Allocator>
bool operator>=(const basic_string<charT, traits, Allocator>& lhs, const charT* rhs);
```

**Returns:** \( \text{lhs} \geq \text{basic_string}\langle\text{charT},\text{traits},\text{Allocator}\rangle(\text{rhs}) \).

### 21.3.7.8 `swap`

```cpp
template<class charT, class traits, class Allocator>
void swap(basic_string<charT, traits, Allocator>& lhs, basic_string<charT, traits, Allocator>& rhs);
```

**Effects:** \( \text{lhs}.\text{swap}(\text{rhs}) \);

### 21.3.7.9 Inserters and extractors

```cpp
template<class charT, class traits, class Allocator>
basic_istream<charT, traits>& operator>>(basic_istream<charT, traits>& is, basic_string<charT, traits, Allocator>& str);
```

Draft
Effects: Behaves as a formatted input function (27.6.1.2.1). After constructing a sentry object, if the sentry converts to true, calls \texttt{str.erase()} and then extracts characters from \texttt{is} and appends them to \texttt{str} as if by calling \texttt{str.append(1, c)}. If \texttt{is.width()} is greater than zero, the maximum number \( n \) of characters appended is \texttt{is.width()}; otherwise \( n \) is \texttt{str.max_size()}. Characters are extracted and appended until any of the following occurs:

- \( n \) characters are stored;
- end-of-file occurs on the input sequence;
- \texttt{isspace(c, is.getloc())} is true for the next available input character \( c \).

After the last character (if any) is extracted, \texttt{is.width(0)} is called and the sentry object \( k \) is destroyed.

If the function extracts no characters, it calls \texttt{is.setstate(ios::failbit)}, which may throw \texttt{ios_base::failure} (27.4.4.3).

Returns: \( \texttt{is} \)

\begin{verbatim}
template<class charT, class traits, class Allocator>
basic_ostream<charT, traits>&
operator<<((basic_ostream<charT, traits>&& os,
const basic_string<charT,traits,Allocator>&& str);
\end{verbatim}

Effects: Begins by constructing a sentry object \( k \) as if \( k \) were constructed by \texttt{typename basic_ostream< charT, traits>::sentry k(os)}. If \texttt{bool(k)} is true, determines padding as described in 22.2.2.2.2, then inserts the resulting sequence of characters \( \text{seq} \) as if by calling \texttt{os.rdbuf()->sputn(seq, n)}, where \( n \) is the larger of \texttt{os.width()} and \texttt{str.size()}; then calls \texttt{os.width(0)}. If the call to \texttt{sputn} fails, calls \texttt{os.setstate(ios_base::failbit)}.

Returns: \( os \)

\begin{verbatim}
template<class charT, class traits, class Allocator>
basic_istream<charT,traits>&
getline(basic_istream<charT,traits>&& is,
      basic_string<charT,traits,Allocator>&& str,
      charT delim);
\end{verbatim}

Effects: Behaves as an unformatted input function (27.6.1.3), except that it does not affect the value returned by subsequent calls to \texttt{basic_istream<>::gcount()}. After constructing a sentry object, if the sentry converts to true, calls \texttt{str.erase()} and then extracts characters from \( is \) and appends them to \( str \) as if by calling \texttt{str.append(1, c)} until any of the following occurs:

- end-of-file occurs on the input sequence (in which case, the getline function calls \texttt{is.setstate(ios_base::eofbit)}).
- \texttt{traits::eq(c, delim)} for the next available input character \( c \) (in which case, \( c \) is extracted but not appended) (27.4.4.3)
- \texttt{str.max_size()} characters are stored (in which case, the function calls \texttt{is.setstate(ios_base::failbit)}) (27.4.4.3)
The conditions are tested in the order shown. In any case, after the last character is extracted, the sentry object $k$ is destroyed.

If the function extracts no characters, it calls $is$.setstate(ios_base::failbit) which may throw ios_base::failure (27.4.4.3).

Returns: $is$.

```
template<class charT, class traits, class Allocator>
basic_istream<charT,traits>&
getline(basic_istream<charT,traits>& k is,
    basic_string<charT,traits,Allocator>& k str)
```

Returns: getline($is$,str,$is$.widen(’\n’))

## 21.4 Null-terminated sequence utilities

[lib.c.strings]

Tables 59, 60, 61, and 63 describe headers `<cctype>`, `<cwctype>`, `<cstring>`, `<cwchar>`, and `<cstdlib>` (character conversions), respectively.

### Table 59: Header `<cctype>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions:</td>
<td></td>
</tr>
<tr>
<td>isalnum</td>
<td>isblank</td>
</tr>
<tr>
<td>isdigit</td>
<td>isprint</td>
</tr>
<tr>
<td>isupper</td>
<td></td>
</tr>
<tr>
<td>tolower</td>
<td>isalpha</td>
</tr>
<tr>
<td>isgraph</td>
<td>ispunct</td>
</tr>
<tr>
<td>isxdigit</td>
<td></td>
</tr>
<tr>
<td>toupper</td>
<td>iscntrl</td>
</tr>
<tr>
<td>islower</td>
<td>isspace</td>
</tr>
</tbody>
</table>

### Table 60: Header `<cwctype>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td>WEOF <code>&lt;cwctype&gt;</code></td>
</tr>
<tr>
<td>Types:</td>
<td>wctrans_t wctype_t wint_t <code>&lt;cwctype&gt;</code></td>
</tr>
<tr>
<td>Functions:</td>
<td></td>
</tr>
<tr>
<td>iswalnum</td>
<td>iswcntrl</td>
</tr>
<tr>
<td>iswgraph</td>
<td>iswpunct</td>
</tr>
<tr>
<td>iswxdigit</td>
<td>towupper</td>
</tr>
<tr>
<td>iswalpha</td>
<td>iswctype</td>
</tr>
<tr>
<td>iswlower</td>
<td>iswspace</td>
</tr>
<tr>
<td>towtrans</td>
<td>wctrans</td>
</tr>
<tr>
<td>iswblank</td>
<td>iswdigit</td>
</tr>
<tr>
<td>iswprint</td>
<td>iswupper</td>
</tr>
<tr>
<td>towlower</td>
<td>wctype</td>
</tr>
</tbody>
</table>

The contents of these headers are the same as the Standard C library headers `<ctype.h>`, `<cwctype.h>`, `<string.h>`, `<wchar.h>` and `<cstdlib.h>` respectively, with the following modifications:

- None of the headers shall define the type `wchar_t` (2.11).
- The function signature `strchr(const char*, int)` is replaced by the two declarations:

  231) `isblank` added by TR1.
  232) `wcstof`, `wctold`, `wctoull`, `wcstoul`, `vfscanf`, `vfscanf`, and `vwscanf` added by TR1.
  233) `atoll`, `strtoll`, `stroull`, `strtof`, and `strtold` added by TR1.
Table 61: Header `<cstring>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td>NULL <code>&lt;cstring&gt;</code></td>
</tr>
<tr>
<td>Type:</td>
<td>size_t <code>&lt;cstring&gt;</code></td>
</tr>
<tr>
<td>Functions:</td>
<td>memchr strcat strcspn strncpy strtok</td>
</tr>
<tr>
<td></td>
<td>memcmp strchr strerror strpbrk strxfrm</td>
</tr>
<tr>
<td></td>
<td>memcpy strcmp strlen strrcchr</td>
</tr>
<tr>
<td></td>
<td>memmove strcoll strncat strspn</td>
</tr>
<tr>
<td></td>
<td>memset strcpyp strncmp strstr</td>
</tr>
</tbody>
</table>

Table 62: Header `<cwchar>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td>NULL <code>&lt;cwchar&gt;</code></td>
</tr>
<tr>
<td>Types:</td>
<td>WCHAR_MAX WCHAR_MIN WEOF <code>&lt;cwchar&gt;</code></td>
</tr>
<tr>
<td>Functions:</td>
<td>mbstate_t wint_t <code>&lt;cwchar&gt;</code> size_t tm</td>
</tr>
<tr>
<td></td>
<td>btowc mbrlen vfwscanf wcscpy wcsspn wcsxfrm</td>
</tr>
<tr>
<td></td>
<td>fgetwc mbtowc vswchar wcscspn wcscstr wcstab</td>
</tr>
<tr>
<td></td>
<td>fgetws mbsinit vswprintf wcstable wcstod wmemchr</td>
</tr>
<tr>
<td></td>
<td>fputwc mbsrtowcs vwprintf wcslen wcstof wmemcstr</td>
</tr>
<tr>
<td></td>
<td>fwide putwchar wcrtomb wcsncmp wcstol wmemmove</td>
</tr>
<tr>
<td></td>
<td>fwprintf swprintf wcsat wcscat wcsncpy wcstold wmemset</td>
</tr>
<tr>
<td></td>
<td>fwide printf swprintf wcsat wcscat wcsncat wcsat wcstol wmemset</td>
</tr>
<tr>
<td></td>
<td>getwc ungetwc wcscmp wcscat wcspbrk wcstoll wprintf</td>
</tr>
<tr>
<td></td>
<td>getwchar vfwprintf wcscoll wcsrtombs wcstoull</td>
</tr>
</tbody>
</table>

Table 63: Header `<cstdlib>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td>MB_CUR_MAX</td>
</tr>
<tr>
<td>Functions:</td>
<td>atof mblen strtol wcstom</td>
</tr>
<tr>
<td></td>
<td>atoi mbtowc strtol wcstol wcstombs</td>
</tr>
<tr>
<td></td>
<td>atol mbstowcs strtol</td>
</tr>
<tr>
<td></td>
<td>atoll strtol strtoul</td>
</tr>
</tbody>
</table>
const char* strchr(const char* s, int c);
char* strchr(char* s, int c);

both of which have the same behavior as the original declaration.

5 The function signature `strpbrk(const char*, const char*)` is replaced by the two declarations:

   const char* strpbrk(const char* s1, const char* s2);
   char* strpbrk(char* s1, const char* s2);

   both of which have the same behavior as the original declaration.

6 The function signature `strrchr(const char*, int)` is replaced by the two declarations:

   const char* strrchr(const char* s, int c);
   char* strrchr(char* s, int c);

   both of which have the same behavior as the original declaration.

7 The function signature `strstr(const char*, const char*)` is replaced by the two declarations:

   const char* strstr(const char* s1, const char* s2);
   char* strstr(char* s1, const char* s2);

   both of which have the same behavior as the original declaration.

8 The function signature `memchr(const void*, int, size_t)` is replaced by the two declarations:

   const void* memchr(const void* s, int c, size_t n);
   void* memchr(void* s, int c, size_t n);

   both of which have the same behavior as the original declaration.

9 The function signature `wcschr(const wchar_t*, wchar_t)` is replaced by the two declarations:

   const wchar_t* wcschr(const wchar_t* s, wchar_t c);
   wchar_t* wcschr(wchar_t* s, wchar_t c);

   both of which have the same behavior as the original declaration.

10 The function signature `wcsrchr(const wchar_t*, wchar_t)` is replaced by the two declarations:

    const wchar_t* wcsrchr(const wchar_t* s, wchar_t c);
    wchar_t* wcsrchr(wchar_t* s, wchar_t c);

    both of which have the same behavior as the original declaration.

11 The function signature `wcsstr(const wchar_t*, const wchar_t*)` is replaced by the two declarations:

    const wchar_t* wcsstr(const wchar_t* s, const wchar_t* c);
    wchar_t* wcsstr(wchar_t* s, wchar_t* c);

    both of which have the same behavior as the original declaration.
const wchar_t* wcsstr(const wchar_t* s1, const wchar_t* s2);
wchar_t* wcsstr( wchar_t* s1, const wchar_t* s2);

both of which have the same behavior as the original declaration.

The function signature wmemchr(const wchar_t*, int, size_t) is replaced by the two declarations:

const wchar_t* wmemchr(const wchar_t* s, wchar_t c, size_t n);
wchar_t* wmemchr( wchar_t* s, wchar_t c, size_t n);

both of which have the same behavior as the original declaration.

SEE ALSO: ISO C subclauses 7.3, 7.10.7, 7.10.8, and 7.11. Amendment 1 subclauses 4.4, 4.5, and 4.6.
This clause describes components that C++ programs may use to encapsulate (and therefore be more portable when confronting) cultural differences. The locale facility includes internationalization support for character classification and string collation, numeric, monetary, and date/time formatting and parsing, and message retrieval.

The following subclauses describe components for locales themselves, the standard facets, and facilities from the ISO C library, as summarized in Table 64.

### Table 64: Localization library summary

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.1 Locales</td>
<td>&lt;locale&gt;</td>
</tr>
<tr>
<td>22.2 Standard locale Categories</td>
<td>&lt;locale&gt;</td>
</tr>
<tr>
<td>22.3 C library locales</td>
<td>&lt;locale&gt;</td>
</tr>
</tbody>
</table>

#### 22.1 Locales

**Header <locale> synopsis**

```cpp
namespace std {
    // 22.1.1, locale:
    class locale;
    template <class Facet> const Facet& use_facet(const locale&);
    template <class Facet> bool has_facet(const locale&) throw();

    // 22.1.3, convenience interfaces:
    template <class charT> bool isspace(charT c, const locale& loc);
    template <class charT> bool isprint(charT c, const locale& loc);
    template <class charT> bool iscntrl(charT c, const locale& loc);
    template <class charT> bool isupper(charT c, const locale& loc);
    template <class charT> bool islower(charT c, const locale& loc);
    template <class charT> bool isalpha(charT c, const locale& loc);
    template <class charT> bool isalnum(charT c, const locale& loc);
    template <class charT> bool isgraph(charT c, const locale& loc);
    template <class charT> charT toupper(charT c, const locale& loc);
    template <class charT> charT tolower(charT c, const locale& loc);
```
The header `<locale>` defines classes and declares functions that encapsulate and manipulate the information peculiar to a locale.\(^{234}\)

### 22.1.1 Class `locale`

```cpp
namespace std {
    // 22.2.1 and 22.2.3, ctype:
    class ctype_base;
    template <class charT> class ctype;
    template <> class ctype<char>;
        // specialization
    template <class charT> class ctype_byname;
    template <> class ctype_byname<char>;
        // specialization
    class codecvt_base;
    template <class internT, class externT, class stateT>
        class codecvt;
    template <class internT, class externT, class stateT>
        class codecvt_byname;

    // 22.2.2 and 22.2.3, numeric:
    template <class charT, class InputIterator> class num_get;
    template <class charT, class OutputIterator> class num_put;
    template <class charT> class numpunct;
    template <class charT> class numpunct_byname;

    // 22.2.4, collation:
    template <class charT> class collate;
    template <class charT> class collate_byname;

    // 22.2.5, date and time:
    class time_base;
    template <class charT, class InputIterator> class time_get;
    template <class charT, class OutputIterator> class time_get_byname;
    template <class charT, class InputIterator> class time_put;
    template <class charT, class OutputIterator> class time_put_byname;

    // 22.2.6, money:
    class money_base;
    template <class charT, class InputIterator> class money_get;
    template <class charT, class OutputIterator> class money_put;
    template <class charT, bool Intl> class moneypunct;
    template <class charT, bool Intl> class moneypunct_byname;

    // 22.2.7, message retrieval:
    class messages_base;
    template <class charT> class messages;
    template <class charT> class messages_byname;
}
```

\(^{234}\) In this subclause, the type name `struct tm` is an incomplete type that is defined in `<ctime>`. Draft
class locale {
public:
    // types:
    class facet;
    class id;
    typedef int category;  // values assigned here are for exposition only
    static const category
        none = 0,
        collate = 0x010, ctype = 0x020,
        monetary = 0x040, numeric = 0x080,
        time = 0x100, messages = 0x200,
        all = collate | ctype | monetary | numeric | time | messages;

    // construct/copy/destroy:
    locale() throw();
    locale(const locale& other) throw();
    explicit locale(const char* std_name);
    explicit locale(const string& std_name);
    locale(const locale& other, const char* std_name, category);
    locale(const locale& other, const string& std_name, category);
    template <class Facet> locale(const locale& other, Facet* f);
    locale(const locale& other, const locale& one, category);
    "locale() throw();  // non-virtual
    const locale& operator=(const locale& other) throw();
    template <class Facet> locale combine(const locale& other) const;

    // locale operations:
    basic_string<char> name() const;
    bool operator==(const locale& other) const;
    bool operator!=(const locale& other) const;

    template <class charT, class Traits, class Allocator>
    bool operator()(const basic_string<charT,Traits,Allocator>& s1,
                    const basic_string<charT,Traits,Allocator>& s2) const;

    // global locale objects:
    static locale global(const locale&);
    static const locale& classic();
};

Class `locale` implements a type-safe polymorphic set of facets, indexed by facet `type`. In other words, a facet has a dual role: in one sense, it’s just a class interface; at the same time, it’s an index into a locale’s set of facets.

Access to the facets of a `locale` is via two function templates, `use_facet<>` and `has_facet<>`. [Example: An iostream operator<< might be implemented as:][235] Notice that, in the call to `put`, the stream is implicitly converted to an `ostreambuf_iterator<charT,traits>`.

[235] Notice that, in the call to `put`, the stream is implicitly converted to an `ostreambuf_iterator<charT,traits>`.

Draft
template <class charT, class traits>
basic_ostream<charT,traits>&
operator<< (basic_ostream<charT,traits>& s, Date d)
{
    typename basic_ostream<charT,traits>::sentry cerberos(s);
    if (cerberos) {
        ios_base::iostate err = 0;
        tm tmbuf; d.extract(tmbuf);
        use_facet< time_put<charT,ostreambuf_iterator<charT,traits> > >(
            s.getloc()).put(s, s, s.fill(), err, &tmbuf, 'x');
        s.setstate(err);
        // might throw
    }
    return s;
}

— end example ]

4 In the call to use_facet<Facet>(loc), the type argument chooses a facet, making available all members of the named type. If Facet is not present in a locale, it throws the standard exception bad_cast. A C++ program can check if a locale implements a particular facet with the function template has_facet<Facet>(). User-defined facets may be installed in a locale, and used identically as may standard facets (22.2.8).

5 [ Note: All locale semantics are accessed via use_facet<> and has_facet<> except that:

| — A member operator template operator()(basic_string<C,T,A>&, basic_string<C,T,A>&) is provided so that a locale may be used as a predicate argument to the standard collections, to collate strings.

| — Convenient global interfaces are provided for traditional ctype functions such as isdigit() and isspace(), so that given a locale object loc a C++ program can call isspace(c, loc). (This eases upgrading existing extractors (27.6.1.2)) — end note ]

6 Once a facet reference is obtained from a locale object by calling use_facet<> that reference remains usable, and the results from member functions of it may be cached and re-used, as long as some locale object refers to that facet.

7 In successive calls to a locale facet member function on a facet object installed in the same locale, the returned result shall be identical.

8 A locale constructed from a name string (such as "POSIX"), or from parts of two named locales, has a name; all others do not. Named locales may be compared for equality; an unnamed locale is equal only to (copies of) itself. For an unnamed locale, locale::name() returns the string ".*".

22.1.1.1 locale types [lib.locale.types]

22.1.1.1.1 Type locale::category [lib.locale.category]

typedef int category;

1 Valid category values include the locale member bitmask elements collate, ctype, monetary, numeric, time, and messages, each of which represents a single locale category. In addition, locale member bitmask constant none is defined as zero and represents no category. And locale member bitmask constant all is defined such that the expression
is true, and represents the union of all categories. Further, the expression \((X \mid Y)\), where \(X\) and \(Y\) each represent a single category, represents the union of the two categories.

1. **locale** member functions expecting a category argument require one of the category values defined above, or the union of two or more such values. Such a category value identifies a set of locale categories. Each locale category, in turn, identifies a set of locale facets, including at least those shown in Table 65:

<table>
<thead>
<tr>
<th>Category</th>
<th>Includes Facets</th>
</tr>
</thead>
<tbody>
<tr>
<td>collate</td>
<td>collate&lt;char&gt;, collate&lt;wchar_t&gt;</td>
</tr>
<tr>
<td>ctype</td>
<td>ctype&lt;char&gt;, ctype&lt;wchar_t&gt;</td>
</tr>
<tr>
<td></td>
<td>codecvt&lt;char, char, mbstate_t&gt;</td>
</tr>
<tr>
<td></td>
<td>codecvt&lt;wchar_t, char, mbstate_t&gt;</td>
</tr>
<tr>
<td>monetary</td>
<td>moneypunct&lt;char&gt;, moneypunct&lt;wchar_t&gt;</td>
</tr>
<tr>
<td></td>
<td>moneypunct&lt;char, true&gt;, moneypunct&lt;wchar_t, true&gt;</td>
</tr>
<tr>
<td></td>
<td>money_get&lt;char&gt;, money_get&lt;wchar_t&gt;</td>
</tr>
<tr>
<td></td>
<td>money_put&lt;char&gt;, money_put&lt;wchar_t&gt;</td>
</tr>
<tr>
<td>numeric</td>
<td>numpunct&lt;char&gt;, numpunct&lt;wchar_t&gt;</td>
</tr>
<tr>
<td></td>
<td>num_get&lt;char&gt;, num_get&lt;wchar_t&gt;</td>
</tr>
<tr>
<td></td>
<td>num_put&lt;char&gt;, num_put&lt;wchar_t&gt;</td>
</tr>
<tr>
<td>time</td>
<td>time_get&lt;char&gt;, time_get&lt;wchar_t&gt;</td>
</tr>
<tr>
<td></td>
<td>time_put&lt;char&gt;, time_put&lt;wchar_t&gt;</td>
</tr>
<tr>
<td>messages</td>
<td>messages&lt;char&gt;, messages&lt;wchar_t&gt;</td>
</tr>
</tbody>
</table>

2. For any **locale** \(\text{loc}\) either constructed, or returned by **locale::classic()**, and any facet **Facet** shown in Table 65, \(\text{has_facet}\<\text{Facet}\>(\text{loc})\) is true. Each **locale** member function which takes a **locale::category** argument operates on the corresponding set of facets.

3. An implementation is required to provide those specializations for facet templates identified as members of a category, and for those shown in Table 66:

4. The provided implementation of members of facets **num_get<charT>** and **num_put<charT>** calls **use_facet<F>**(1) only for facet \(F\) of types **numpunct<charT>** and **ctype<charT>**, and for locale \(l\) the value obtained by calling member \(\text{getloc()}\) on the **ios_base&** argument to these functions.

5. In declarations of facets, a template formal parameter with name **InputIterator** or **OutputIterator** indicates the set of all possible specializations on parameters that satisfy the requirements of an Input Iterator or an Output Iterator, respectively (24.1). A template formal parameter with name **C** represents the set of all possible specializations on a parameter that satisfies the requirements for a character on which any of the iostream components can be instantiated. A template formal parameter with name **International** represents the set of all possible specializations on a bool parameter.

22.1.1.2 **Class** **locale::facet**

Draft
Table 66: Required Specializations

<table>
<thead>
<tr>
<th>Category</th>
<th>Includes Facets</th>
</tr>
</thead>
<tbody>
<tr>
<td>collate</td>
<td>collatebyname&lt;char&gt;, collatebyname&lt;wchar_t&gt;</td>
</tr>
<tr>
<td>ctype</td>
<td>ctypename&lt;char&gt;, ctypename&lt;wchar_t&gt;, codecvtbyname&lt;char,char,mbstate_t&gt;, codecvtbyname&lt;wchar_t,char,mbstate_t&gt;</td>
</tr>
<tr>
<td>numeric</td>
<td>numpunctbyname&lt;char&gt;, numpunctbyname&lt;wchar_t&gt;, num_get&lt;C,InputIterator&gt;, num_put&lt;C,OutputIterator&gt;</td>
</tr>
<tr>
<td>time</td>
<td>time_get&lt;char,InputIterator&gt;, time_getbyname&lt;char,InputIterator&gt;, time_get&lt;wchar_t,InputIterator&gt;, time_getbyname&lt;wchar_t,InputIterator&gt;, time_put&lt;char,OutputIterator&gt;, time_putbyname&lt;char,OutputIterator&gt;, time_put&lt;wchar_t,OutputIterator&gt;, time_putbyname&lt;wchar_t,OutputIterator&gt;</td>
</tr>
<tr>
<td>messages</td>
<td>messagesbyname&lt;char&gt;, messagesbyname&lt;wchar_t&gt;</td>
</tr>
</tbody>
</table>

namespace std {
    class locale::facet {
        protected:
            explicit facet(size_t refs = 0);
            virtual ~facet();
        private:
            facet(const facet&); // not defined
            void operator=(const facet&); // not defined
    };
}

1 Template parameters in this clause which are required to be facets are those named Facet in declarations. A program that passes a type that is not a facet, or a type that refers to a volatile-qualified facet, as an (explicit or deduced) template parameter to a locale function expecting a facet, is ill-formed. A const-qualified facet is a valid template argument to any locale function that expects a Facet template parameter.

2 The refs argument to the constructor is used for lifetime management.

   — For refs == 0, the implementation performs delete static_cast<locale::facet*>(f) (where f is a pointer to the facet) when the last locale object containing the facet is destroyed; for refs == 1, the implementation never destroys the facet.

3 Constructors of all facets defined in this clause take such an argument and pass it along to their facet base class constructor. All one-argument constructors defined in this clause are explicit, preventing their participation in automatic
For some standard facets a standard “...byname” class, derived from it, implements the virtual function semantics equivalent to that facet of the locale constructed by `locale(const char*)` with the same name. Each such facet provides a constructor that takes a `const char*` argument, which names the locale, and a `refs` argument, which is passed to the base class constructor. Each such facet also provides a constructor that takes a `string` argument `str` and a `refs` argument, which has the same effect as calling the first constructor with the two arguments `str.c_str()` and `refs`. If there is no “...byname” version of a facet, the base class implements named locale semantics itself by reference to other facets.

### 22.1.1.1.3 Class `locale::id`

```cpp
namespace std {
    class locale::id {
        public:
            id();
        private:
            void operator=(const id&); // not defined
            id(const id&); // not defined
    };
}
```

The class `locale::id` provides identification of a locale facet interface, used as an index for lookup and to encapsulate initialization.

- [Note: Because facets are used by iostreams, potentially while static constructors are running, their initialization cannot depend on programmed static initialization. One initialization strategy is for `locale` to initialize each facet’s `id` member the first time an instance of the facet is installed into a locale. This depends only on static storage being zero before constructors run (3.6.2). — end note]

### 22.1.1.2 `locale` constructors and destructor

- `locale() throw();`
  - Default constructor: a snapshot of the current global locale.

- `locale(const locale& other) throw();`
  - **Effects:** Constructs a locale which is a copy of `other`.

- `const locale& operator=(const locale& other) throw();`
  - **Effects:** Creates a copy of `other`, replacing the current value.

- `Returns: *this`
22.1 Locales

explicit locale(const char* std_name);

Effects: Constructs a locale using standard C locale names, e.g. "POSIX". The resulting locale implements semantics defined to be associated with that name.

Throws: runtime_error if the argument is not valid, or is null.

Remarks: The set of valid string argument values is "C", ",", and any implementation-defined values.

explicit locale(const string& std_name);

Effects: The same as locale(std_name.c_str()).

locale(const locale& other, const char* std_name, category);

Effects: Constructs a locale as a copy of other except for the facets identified by the category argument, which instead implement the same semantics as locale(std_name).

Throws: runtime_error if the argument is not valid, or is null.

Remarks: The locale has a name if and only if other has a name.

locale(const locale& other, const string& std_name, category cat);

Effects: The same as locale(other, std_name.c_str(), cat).

template <class Facet> locale(const locale& other, Facet* f);

Effects: Constructs a locale incorporating all facets from the first argument except that one facet of other identified by Facet. If f is null, the resulting object is a copy of other.

Remarks: The resulting locale has no name.

locale(const locale& other, const locale& one, category cats);

Effects: Constructs a locale incorporating all facets from the first argument except those that implement cats, which are instead incorporated from the second argument.

Remarks: The resulting locale has a name if and only if the first two arguments have names.

~locale() throw();

A non-virtual destructor that throws no exceptions.

22.1.3 locale members

template <class Facet> locale combine(const locale& other) const;

Effects: Constructs a locale incorporating all facets from *this except for that one facet of other that is identified by Facet.

Returns: The newly created locale.

Throws: runtime_error if has_facet<Facet>(other) is false.
Remarks: The resulting locale has no name.

basic_string<char> name() const;

Returns: The name of *this, if it has one; otherwise, the string "+". If *this has a name, then locale(name().
c_str()) is equivalent to *this. Details of the contents of the resulting string are otherwise implementation-defined.

22.1.4 locale operators

bool operator==(const locale& other) const;

Returns: true if both arguments are the same locale, or one is a copy of the other, or each has a name and the
names are identical; false otherwise.

bool operator!=(const locale& other) const;

Returns: The result of the expression: !(*this == other).

template <class charT, class Traits, class Allocator>
bool operator()(const basic_string<charT,Traits,Allocator>& s1,
const basic_string<charT,Traits,Allocator>& s2) const;

Effects: Compares two strings according to the collate<charT> facet.

Remarks: This member operator template (and therefore locale itself) satisfies requirements for a comparator
predicate template argument (clause 25) applied to strings.

Returns: The result of the following expression:

use_facet< collate<charT> >>(*this).compare
    (s1.data(), s1.data()+s1.size(), s2.data(), s2.data()+s2.size()) < 0;

[Example: A vector of strings v can be collated according to collation rules in locale loc simply by (25.3.1,
23.2.5):

    std::sort(v.begin(), v.end(), loc);

— end example ]

22.1.5 locale static members

static locale global(const locale& loc);

Sets the global locale to its argument.

Effects: Causes future calls to the constructor locale() to return a copy of the argument. If the argument has a
name, does

    std::setlocale(LC_ALL, loc.name().c_str());

Draft
otherwise, the effect on the C locale, if any, is implementation-defined. No library function other than `locale::global()` shall affect the value returned by `locale()`.

Returns: The previous value of `locale()`.

```cpp
static const locale& classic();
```

The "C" locale.

Returns: A locale that implements the classic "C" locale semantics, equivalent to the value `locale("C")`.

Remarks: This locale, its facets, and their member functions, do not change with time.

### 22.1.2 locale globals

#### [lib.locale.global.templates] locale globals

```cpp
template <class Facet> const Facet& use_facet(const locale& loc);
```

Requires: `Facet` is a facet class whose definition contains the public static member `id` as defined in 22.1.1.1.2.

Returns: a reference to the corresponding facet of `loc`, if present.

Throws: `bad_cast` if `has_facet<Facet>(loc)` is false.

Remarks: The reference returned remains valid at least as long as any copy of `loc` exists.

```cpp
template <class Facet> bool has_facet(const locale& loc) throw();
```

Returns: true if the facet requested is present in `loc`; otherwise false.

### 22.1.3 Convenience interfaces

#### [lib.locale.convenience] Convenience interfaces

##### 22.1.3.1 Character classification

#### [lib.classification] Character classification

```cpp
template <class charT> bool isspace (charT c, const locale& loc);
template <class charT> bool isprint (charT c, const locale& loc);
template <class charT> bool iscntrl (charT c, const locale& loc);
template <class charT> bool isupper (charT c, const locale& loc);
template <class charT> bool islower (charT c, const locale& loc);
template <class charT> bool isalpha (charT c, const locale& loc);
template <class charT> bool isdigit (charT c, const locale& loc);
template <class charT> bool ispunct (charT c, const locale& loc);
template <class charT> bool isxdigit(charT c, const locale& loc);
template <class charT> bool isalnum (charT c, const locale& loc);
template <class charT> bool isgraph (charT c, const locale& loc);
```

Each of these functions `isF` returns the result of the expression:

```
use_facet< ctype<charT> >(loc).is(ctype_base::F, c)
```
where \( F \) is the \ctype_base::mask value corresponding to that function (22.2.1).\(^{236}\)

### 22.1.3.2 Character conversions

```
template <class charT> charT toupper(charT c, const locale& loc);
```

\( \text{Returns: use facet<ctype<charT> >(loc).toupper(c).} \)

```
template <class charT> charT tolower(charT c, const locale& loc);
```

\( \text{Returns: use facet<ctype<charT> >(loc).tolower(c).} \)

### 22.2 Standard locale categories

Each of the standard categories includes a family of facets. Some of these implement formatting or parsing of a datum, for use by standard or users' iostream operators « and>>, as members put() and get(), respectively. Each such member function takes an \ios_base& argument whose members flags(), precision(), and width(), specify the format of the corresponding datum. (27.4.2). Those functions which need to use other facets call its member getloc() to retrieve the locale imbued there. Formatting facets use the character argument fill to fill out the specified width where necessary.

The put() members make no provision for error reporting. (Any failures of the OutputIterator argument must be extracted from the returned iterator.) The get() members take an \ios_base::iostate& argument whose value they ignore, but set to \ios_base::failbit in case of a parse error.

### 22.2.1 The ctype category

```
namespace std {
    class ctype_base {
    public:
        typedef T mask;

        // numeric values are for exposition only.
        static const mask space = 1 << 0;
        static const mask print = 1 << 1;
        static const mask cntrl = 1 << 2;
        static const mask upper = 1 << 3;
        static const mask lower = 1 << 4;
        static const mask alpha = 1 << 5;
        static const mask digit = 1 << 6;
        static const mask punct = 1 << 7;
        static const mask alnum = alpha | digit;
        static const mask graph = alnum | punct;
    };
}
```

\( \text{The type mask is a bitmask type (17.3.2.1.2).} \)

### 22.2.1.1 Class template ctype

\(^{236}\)When used in a loop, it is faster to cache the \ctype<> facet and use it directly, or use the vector form of \ctype<>::is.
22.2 Standard locale categories

namespace std {
    template <class charT>
    class ctype : public locale::facet, public ctype_base {
        public:
            typedef charT char_type;
            explicit ctype(size_t refs = 0);

            bool is(mask m, charT c) const;
            const charT* is(const charT* low, const charT* high, mask* vec) const;
            const charT* scan_is(mask m,
                                const charT* low, const charT* high) const;
            const charT* scan_not(mask m,
                                  const charT* low, const charT* high) const;
            charT toupper(charT c) const;
            const charT* toupper(charT* low, const charT* high) const;
            charT tolower(charT c) const;
            const charT* tolower(charT* low, const charT* high) const;

            charT widen(char c) const;
            const char* widen(const char* low, const char* high, charT* to) const;
            char narrow(charT c, char default) const;
            const charT* narrow(const charT* low, const charT*, char default,
                                 char* to) const;

            static locale::id id;
        
        protected:
            // virtual
            ~ctype();
            virtual bool do_is(mask m, charT c) const;
            virtual const charT* do_is(const charT* low, const charT* high,
                                        mask* vec) const;
            virtual const charT* do_scan_is(mask m,
                                                 const charT* low, const charT* high) const;
            virtual const charT* do_scan_not(mask m,
                                               const charT* low, const charT* high) const;
            virtual charT do_toupper(charT c) const;
            virtual const charT* do_toupper(charT* low, const charT* high) const;
            virtual charT do_tolower(charT c) const;
            virtual const charT* do_tolower(charT* low, const charT* high) const;
            virtual charT do_widen(char c) const;
            virtual const char* do_widen(const char* low, const char* high,
                                          charT* dest) const;
            virtual char do_narrow(charT, char default) const;
            virtual const charT* do_narrow(const charT* low, const charT* high,
                                          char default, char* dest) const;
    };
}

Class ctype encapsulates the C library <cctype> features. istream members are required to use ctype<> for character classing during input parsing.

Draft
The specializations required in Table 65 (22.1.1.1.1), namely \texttt{ctype<char>} and \texttt{ctype<wchar_t>}, implement character classing appropriate to the implementation's native character set.

### 22.2.1.1.1 \texttt{ctype} members

1. \texttt{bool is\,(mask \ m, charT \ c) const;}
2. \texttt{const charT* is\,(const charT\* \ low, const charT\* \ high, mask* \ vec) const;

   Returns: do\_is\,(m, c) or do\_is\,(low, high, vec)

3. \texttt{const charT* scan\_is\,(mask \ m,}
   
   \texttt{const charT\* \ low, const charT\* \ high) const;

   Returns: do\_scan\_is\,(m, low, high)

4. \texttt{const charT* scan\_not\,(mask \ m,}
   
   \texttt{const charT\* \ low, const charT\* \ high) const;

   Returns: do\_scan\_not\,(m, low, high)

5. \texttt{charT toupper\,(charT \ c) const;}
6. \texttt{const charT* toupper\,(charT\* \ low, const charT\* \ high) const;

   Returns: do\_toupper\,(c) or do\_toupper\,(low, high)

7. \texttt{charT tolower\,(charT \ c) const;}
8. \texttt{const charT* tolower\,(charT\* \ low, const charT\* \ high) const;

   Returns: do\_tolower\,(c) or do\_tolower\,(low, high)

9. \texttt{charT widen\,(char \ c) const;}
10. \texttt{const char* widen\,(const char* \ low, const char* \ high, char* \ to) const;

    Returns: do\_widen\,(c) or do\_widen\,(low, high, to)

11. \texttt{char narrow\,(charT \ c, char \ default) const;}
12. \texttt{const charT* narrow\,(const charT\* \ low, const charT\*, char \ default, char* \ to) const;

    Returns: do\_narrow\,(c, default) or do\_narrow\,(low, high, default, to)

### 22.2.1.1.2 \texttt{ctype} virtual functions

1. \texttt{bool do\_is\,(mask \ m, charT \ c) const;}
2. \texttt{const charT* do\_is\,(const charT\* \ low, const charT\* \ high, mask* \ vec) const;

   Effects: Classifies a character or sequence of characters. For each argument character, identifies a value \( M \) of type \texttt{ctype\_base::mask}. The second form identifies a value \( M \) of type \texttt{ctype\_base::mask} for each \( p \) where \((\text{low} \leq p \land p < \text{high})\), and places it into \texttt{vec}[p - \text{low}].
2.2 Standard locale categories

Returns: The first form returns the result of the expression \((M & m) \neq 0\); i.e., true if the character has the characteristics specified. The second form returns high.

```cpp
const charT* do_scan_is(mask m,
const charT* low, const charT* high) const;
```

Effects: Locates a character in a buffer that conforms to a classification \(m\).

Returns: The smallest pointer \(p\) in the range \([low, high]\) such that \(is(m, *p)\) would return true; otherwise, returns high.

```cpp
const charT* do_scan_not(mask m,
const charT* low, const charT* high) const;
```

Effects: Locates a character in a buffer that fails to conform to a classification \(m\).

Returns: The smallest pointer \(p\), if any, in the range \([low, high]\) such that \(is(m, *p)\) would return false; otherwise, returns high.

```cpp
charT do_toupper(charT c) const;
```

Effects: Converts a character or characters to upper case. The second form replaces each character \(*p\) in the range \([low, high]\) for which a corresponding upper-case character exists, with that character.

Returns: The first form returns the corresponding upper-case character if it is known to exist, or its argument if not. The second form returns high.

```cpp
charT do_tolower(charT c) const;
```

Effects: Converts a character or characters to lower case. The second form replaces each character \(*p\) in the range \([low, high]\) and for which a corresponding lower-case character exists, with that character.

Returns: The first form returns the corresponding lower-case character if it is known to exist, or its argument if not. The second form returns high.

```cpp
charT do_widen(char c) const;
```

Effects: Applies the simplest reasonable transformation from a char value or sequence of char values to the corresponding \texttt{charT} value or values.\(^{237}\) The only characters for which unique transformations are required are those in the basic source character set (2.2).

For any named ctype category with a \texttt{ctype<charT>} facet \texttt{ctc} and valid \texttt{ctype_base::mask} value \(M\), (\texttt{ctc.
\texttt{is}(M, c) \ || \ !\texttt{is}(M, \texttt{do_widen}(c))\}) is true.\(^{238}\)

The second form transforms each character \(*p\) in the range \([low, high]\), placing the result in \texttt{dest}[p-low].

Returns: The first form transforms the transformed value. The second form returns high.

\(^{237}\) The char argument of \texttt{do_widen} is intended to accept values derived from character literals for conversion to the locale’s encoding.

\(^{238}\) In other words, the transformed character is not a member of any character classification that \(c\) is not also a member of.
char do_narrow(charT c, char dfault) const;

const charT* do_narrow(const charT* low, const charT* high,
           char dfault, char* dest) const;

**Effects:** Applies the simplest reasonable transformation from a charT value or sequence of charT values to the corresponding char value or values.

For any character c in the basic source character set(2.2) the transformation is such that
do_widen(do_narrow(c,0)) == c

For any named ctype category with a ctype<char> facet ctc however, and ctype_base::mask value M,

(is(M,c) || !ctc.is(M, do_narrow(c, dfault)))

is true (unless do_narrow returns dfault). In addition, for any digit character c, the expression (do_narrow(c, dfault) - '0') evaluates to the digit value of the character. The second form transforms each character *p in the range [low, high), placing the result (or dfault if no simple transformation is readily available) in dest[p-low].

**Returns:** The first form returns the transformed value; or dfault if no mapping is readily available. The second form returns high.

### 22.2.1.2 Class template ctype_byname

```cpp	namespace std {
  template <class charT>
  class ctype_byname : public ctype<charT> {
  public:
    typedef ctype<charT>::mask mask;
    explicit ctype_byname(const char*, size_t refs = 0);
    explicit ctype_byname(const string&, size_t refs = 0);
  protected:
    ~ctype_byname(); // virtual
  }
}
```

### 22.2.1.3 ctype specializations

```cpp	namespace std {
  template <> class ctype<char>
    : public locale::facet, public ctype_base {
  public:
    typedef char char_type;
    explicit ctype(const mask* tab = 0, bool del = false,
                   size_t refs = 0);

    bool is(mask m, char c) const;
    const char* is(const char* low, const char* high, mask* vec) const;
    const char* scan_is (mask m,
```
22.2 Standard locale categories

Localization library 546

const char* scan_not(mask m,
    const char* low, const char* high) const;

const char* toupper(char c) const;

const char* tolower(char* low, const char* high) const;

char widen(char c) const;

const char* widen(const char* low, const char* high, char* to) const;

char narrow(char c, char default) const;

const char* narrow(const char* low, const char* high, char default, char* to) const;

static locale::id id;
static const size_t table_size = IMPLEMENTATION_DEFINED;

protected:
    const mask* table() const throw();
    static const mask* classic_table() throw();

~ctype();

// virtual
virtual char do_toupper(char c) const;

virtual const char* do_toupper(char* low, const char* high) const;

virtual char do_tolower(char c) const;

virtual const char* do_tolower(char* low, const char* high) const;

virtual char do_widen(char c) const;

virtual const char* do_widen(const char* low,
    const char* high,
    char* to) const;

virtual char do_narrow(char c, char default) const;

virtual const char* do_narrow(const char* low,
    const char* high,
    char default, char* to) const;
};

A specialization ctype<char> is provided so that the member functions on type char can be implemented inline.239) The implementation-defined value of member table_size is at least 256.

22.2.1.3.1 ctype<char> destructor [lib.facet.ctype.char.dtor]

~ctype();

Effects: If the constructor's first argument was nonzero, and its second argument was true, does delete [] table().

239) Only the char (not unsigned char and signed char) form is provided. The specialization is specified in the standard, and not left as an implementation detail, because it affects the derivation interface for ctype<char>.

Draft
22.2.1.3.2 **ctype<char> members**

In the following member descriptions, for unsigned char values \( v \) where \( v \geq \text{table.size} \), \( \text{table()[v]} \) is assumed to have an implementation-defined value (possibly different for each such value \( v \)) without performing the array lookup.

```cpp
explicit ctype(const mask* tbl = 0, bool del = false,
               size_t refs = 0);
```

**Precondition:** \( tbl \) either 0 or an array of at least \( \text{table.size} \) elements.

**Effects:** Passes its \( \text{refs} \) argument to its base class constructor.

```cpp
bool is(mask m, char c) const;
const char* is(const char* low, const char* high,
               mask* vec) const;
```

**Effects:** The second form, for all \( *p \) in the range \([low, high)\), assigns into \( \text{vec}[p-low] \) the value \( \text{table()[ (unsigned char) *p] } \).

**Returns:** The first form returns \( \text{table()[ (unsigned char) c] } & m \); the second form returns \( \text{high} \).

```cpp
const char* scan_is(mask m,
                    const char* low, const char* high) const;
```

**Returns:** The smallest \( p \) in the range \([low, high)\) such that

\[
\text{table()[ (unsigned char) *p] } & m
\]

is true.

```cpp
const char* scan_not(mask m,
                     const char* low, const char* high) const;
```

**Returns:** The smallest \( p \) in the range \([low, high)\) such that

\[
\text{table()[ (unsigned char) *p] } & m
\]

is false.

```cpp
char toupper(char c) const;
const char* toupper(char* low, const char* high) const;
```

**Returns:** \( \text{do_toupper(c)} \) or \( \text{do_toupper(low, high)} \), respectively.

```cpp
char tolower(char c) const;
const char* tolower(char* low, const char* high) const;
```

**Returns:** \( \text{do_tolower(c)} \) or \( \text{do_tolower(low, high)} \), respectively.

```cpp
char widen(char c) const;
const char* widen(const char* low, const char* high,
                  char* to) const;
```

**Returns:** \( \text{do_widen(c)} \) or \( \text{do_widen(low, high, to)} \), respectively.
22.2 Standard locale categories

<table>
<thead>
<tr>
<th>Standard locale categories</th>
<th>Localization library</th>
</tr>
</thead>
<tbody>
<tr>
<td>char</td>
<td>narrow(char c, char dfault) const;</td>
</tr>
<tr>
<td>const char* narrow(const char* low, const char* high, char dfault, char* to) const;</td>
<td></td>
</tr>
<tr>
<td>const mask* table() const throw();</td>
<td></td>
</tr>
</tbody>
</table>

Returns: do_narrow(c, dfault) or do_narrow(low, high, dfault, to), respectively.

1

Returns: The first constructor argument, if it was non-zero, otherwise classic_table().

### 22.2.1.3.3 
ctype<char> static members

static const mask* classic_table() throw();

Returns: A pointer to the initial element of an array of size table_size which represents the classifications of characters in the "C" locale.

### 22.2.1.3.4 
ctype<char> virtual functions

char do_toupper(char) const;
const char* do_toupper(char* low, const char* high) const;
char do_tolower(char) const;
const char* do_tolower(char* low, const char* high) const;

virtual char do_widen(char c) const;
virtual const char* do_widen(const char* low, const char* high, char* to) const;

virtual char do_narrow(char c, char dfault) const;
virtual const char* do_narrow(const char* low, const char* high, char dfault, char* to) const;

These functions are described identically as those members of the same name in the ctype class template (22.2.1.1.1).

### 22.2.1.4 
Class template codecvt

namespace std {
class codecvt_base {
enum result { ok, partial, error, noconv };
};
template <class internT, class externT, class stateT>
class codecvt : public locale::facet, public codecvt_base {
public:
typedef internT intern_type;
typedef externT extern_type;
typedef stateT state_type;

explicit codecvt(size_t refs = 0);
}

Draft
The class \texttt{codecvt<internT,externT,stateT>} is for use when converting from one codeset to another, such as from wide characters to multibyte characters or between wide character encodings such as Unicode and EUC.

The \texttt{stateT} argument selects the pair of codesets being mapped between.

The specializations required in Table 65 (22.1.1.1), namely \texttt{codecvt<wchar_t, char, mbstate_t>} and \texttt{codecvt<char, char, mbstate_t>}, convert the implementation-defined native character set. \texttt{codecvt<char, char, mbstate_t>} implements a degenerate conversion; it does not convert at all. \texttt{codecvt<wchar_t, char, mbstate_t>} converts between the native character sets for tiny and wide characters. Specializations on \texttt{mbstate_t} perform conversion between encodings known to the library implementor. Other encodings can be converted by specializing on a user-defined \texttt{stateT} type. The \texttt{stateT} object can contain any state that is useful to communicate to or from the specialized \texttt{do_in} or \texttt{do_out} members.

\subsection*{22.2.1.4.1 codecvt members \textnormal{[lib.locale.codecvt.members]}}
result out(stateT& state, 
    const internT* from, const internT* from_end, const internT*& from_next, 
    externT* to, externT* to_limit, externT*& to_next) const;

    // Returns: do_out(state, from, from_end, from_next, to, to_limit, to_next)

result unshift(stateT& state, 
    externT* to, externT* to_limit, externT*& to_next) const;

    // Returns: do_unshift(state, to, to_limit, to_next)

result in(stateT& state, 
    const externT* from, const externT* from_end, const externT*& from_next, 
    internT* to, internT* to_limit, internT*& to_next) const;

    // Returns: do_in(state, from, from_end, from_next, to, to_limit, to_next)

int encoding() const throw();

    // Returns: do_encoding()

bool always_noconv() const throw();

    // Returns: do_always_noconv()

int length(stateT& state, const externT* from, const externT* from_end, 
    size_t max) const;

    // Returns: do_length(state, from, from_end, max)

int max_length() const throw();

    // Returns: do_max_length()

22.2.1.4.2  codecvt virtual functions

result do_out(stateT& state, 
    const internT* from, const internT* from_end, const internT*& from_next, 
    externT* to, externT* to_limit, externT*& to_next) const;

result do_in(stateT& state, 
    const externT* from, const externT* from_end, const externT*& from_next, 
    internT* to, internT* to_limit, internT*& to_next) const;

    // Preconditions: (from<=from_end && to<=to_end) well-defined and true; state initialized, if at the beginning of a sequence, or else equal to the result of converting the preceding characters in the sequence.

    // Effects: Translates characters in the source range [from, from_end), placing the results in sequential positions starting at destination to. Converts no more than (from_end-from) source elements, and stores no more than (to_limit-to) destination elements.

    // Stops if it encounters a character it cannot convert. It always leaves the from_next and to_next pointers pointing one beyond the last element successfully converted. If returns noconv, internT and externT are the...
A codecv facet that is used by basic_filebuf (27.8) shall have the property that if

\[
\text{do_out}(\text{state}, \text{from}, \text{from}_\text{end}, \text{from}_\text{next}, \text{to}, \text{to}_\text{limit}, \text{to}_\text{next})
\]

would return ok, where from \(!=\) from_end, then

\[
\text{do_out}(\text{state}, \text{from}, \text{from} + 1, \text{from}_\text{next}, \text{to}, \text{to}_\text{end}, \text{to}_\text{next})
\]

shall also return ok, and that if

\[
\text{do_in}(\text{state}, \text{from}, \text{from}_\text{end}, \text{from}_\text{next}, \text{to}, \text{to}_\text{limit}, \text{to}_\text{next})
\]

would return ok, where to \(!=\) to_end, then

\[
\text{do_in}(\text{state}, \text{from}, \text{from}_\text{end}, \text{from}_\text{next}, \text{to}, \text{to} + 1, \text{to}_\text{next})
\]

shall also return ok.\(^{240}\)

Remarks: It\'s operations on state are unspecified. \[\text{Note: This argument can be used, for example, to maintain shift state, to specify conversion options (such as count only), or to identify a cache of seek offsets. —end note}\]

Returns: An enumeration value, as summarized in Table 67:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ok</td>
<td>completed the conversion</td>
</tr>
<tr>
<td>partial</td>
<td>not all source characters converted</td>
</tr>
<tr>
<td>error</td>
<td>encountered a character in [from, from_end] that it could not convert</td>
</tr>
<tr>
<td>noconv</td>
<td>internT and externT are the same type, and input sequence is identical to converted sequence</td>
</tr>
</tbody>
</table>

A return value of partial, if (from_next==from_end), indicates that either the destination sequence has not absorbed all the available destination elements, or that additional source elements are needed before another destination element can be produced.

\[
\text{result do_unshift(stateT& state, externT* to, externT* to}_\text{limit}, externT*& to_next) const;}
\]

Requires: (to \(\leq\) to_end) well defined and true; state initialized, if at the beginning of a sequence, or else equal to the result of converting the preceding characters in the sequence.

Effects: Places characters starting at to that should be appended to terminate a sequence when the current stateT is given by state.\(^{241}\) Stores no more than (to_limit-to) destination elements, and leaves the to_next

\(^{240}\)Informally, this means that basic_filebuf assumes that the mappings from internal to external characters is 1 to N: a codecv facet that is used by basic_filebuf must be able to translate characters one internal character at a time.

\(^{241}\) Typically these will be characters to return the state to stateT()
pointer pointing one beyond the last element successfully stored. `codecvt<char, char, mbstate_t>` stores no characters.

**Returns:** An enumeration value, as summarized in Table 68:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ok</td>
<td>completed the sequence</td>
</tr>
<tr>
<td>partial</td>
<td>space for more than <code>to_limit-to</code> destination elements was needed to terminate a sequence given the value of <code>state</code></td>
</tr>
<tr>
<td>error</td>
<td>an unspecified error has occurred</td>
</tr>
<tr>
<td>noconv</td>
<td>no termination is needed for this <code>state_type</code></td>
</tr>
</tbody>
</table>

`codecvt<char,char,mbstate_t>`, returns `noconv`.

```cpp
int do_encoding() const throw();
```

**Returns:** -1 if the encoding of the `externT` sequence is state-dependent; else the constant number of `externT` characters needed to produce an internal character; or 0 if this number is not a constant.

```cpp
bool do_always_noconv() const throw();
```

**Returns:** true if `do_in()` and `do_out()` return `noconv` for all valid argument values. `codecvt<char, char, mbstate_t>` returns true.

```cpp
int do_length(stateT& state, const externT* from, const externT* from_end, size_t max) const;
```

**Preconditions:** `(from<=from_end)` well-defined and true; `state` initialized, if at the beginning of a sequence, or else equal to the result of converting the preceding characters in the sequence.

**Effects:** The effect on the `state` argument is “as if” it called `do_in(state, from, from_end, from, to, to+max, to)` for `to` pointing to a buffer of at least `max` elements.

**Returns:** `(from_next-from)` where `from_next` is the largest value in the range `[from, from_end)` such that the sequence of values in the range `[from, from_next)` represents `max` or fewer valid complete characters of type `internT`. The specialization `codecvt<char, char, mbstate_t>::do_length(stateT& state, const externT* from, const externT* from_end, size_t max)` returns the lesser of `max` and `(from_end-from)`.

```cpp
int do_max_length() const throw();
```

**Returns:** The maximum value that `do_length(state, from, from_end, i)` can return for any valid range `[from, from_end) and stateT value state`. The specialization `codecvt<char, char, mbstate_t>::do_max_length()` returns 1.

---

242) If `encoding()` yields -1, then more than `max_length()` `externT` elements may be consumed when producing a single `internT` character, and additional `externT` elements may appear at the end of a sequence after those that yield the final `internT` character.
22.2.1.5 Class template codecvt_byname

namespace std {
    template <class internT, class externT, class stateT>
    class codecvt_byname : public codecvt<internT, externT, stateT> {
public:
    explicit codecvt_byname(const char*, size_t refs = 0);
    explicit codecvt_byname(const string&, size_t refs = 0);
protected:
    ~codecvt_byname();  // virtual
    
};
}

22.2.2 The numeric category

The classes num_get<> and num_put<> handle numeric formatting and parsing. Virtual functions are provided for several numeric types. Implementations may (but are not required to) delegate extraction of smaller types to extractors for larger types.\textsuperscript{243)}

All specifications of member functions for num_put and num_get in the subclauses of 22.2.2 only apply to the specializations required in Tables 65 and 66 (22.1.1.1.1), namely num_get<char>, num_get<wchar_t>, num_get<C, InputIterator>, num_put<char>, num_put<wchar_t>, and num_put<C, OutputIterator>. These specializations refer to the ios_base argument for formatting specifications (22.2), and to its imbued locale for the numpunct<> facet to identify all numeric punctuation preferences, and also for the ctype<> facet to perform character classification.

Extractor and inserter members of the standard iostreams use num_get<> and num_put<> member functions for formatting and parsing numeric values (27.6.1.2.1, 27.6.2.5.1).

22.2.2.1 Class template num_get

namespace std {
    template <class charT, class InputIterator = istreambuf_iterator<charT> >
    class num_get : public locale::facet {
public:
        typedef charT char_type;
        typedef InputIterator iter_type;

        explicit num_get(size_t refs = 0);

        iter_type get(iter_type in, iter_type end, ios_base&,
                      ios_base::iostate& err, bool& v) const;
        iter_type get(iter_type in, iter_type end, ios_base&,
                      ios_base::iostate& err, long& v) const;
        iter_type get(iter_type in, iter_type end, ios_base&,
                      ios_base::iostate& err, unsigned short& v) const;
        iter_type get(iter_type in, iter_type end, ios_base&,
                      ios_base::iostate& err, unsigned int& v) const;
        iter_type get(iter_type in, iter_type end, ios_base&,
                      ios_base::iostate& err, unsigned long& v) const;

\textsuperscript{243)} Parsing "-1" correctly into (e.g.) an unsigned short requires that the corresponding member get() at least extract the sign before delegating.
The facet `num_get` is used to parse numeric values from an input sequence such as an istream.

### 22.2.2.1.1 num_get members

```cpp
iter_type get(iter_type in, iter_type end, ios_base&,
              ios_base::iostate& err, float& v) const;
iter_type get(iter_type in, iter_type end, ios_base&,
              ios_base::iostate& err, double& v) const;
iter_type get(iter_type in, iter_type end, ios_base&,
              ios_base::iostate& err, long double& v) const;
iter_type get(iter_type in, iter_type end, ios_base&,
              ios_base::iostate& err, void*& v) const;
```
iter_type get(iter_type in, iter_type end, ios_base& str,
           ios_base::iostate& err, double& val) const;
iter_type get(iter_type in, iter_type end, ios_base& str,
           ios_base::iostate& err, long double& val) const;
iter_type get(iter_type in, iter_type end, ios_base& str,
           ios_base::iostate& err, void*& val) const;

Returns: do_get(in, end, str, err, val).

22.2.2.1.2 num_get virtual functions
[lib_facet.num.get.virtuals]

iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, long& val) const;
iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, unsigned short& val) const;
iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, unsigned int& val) const;
iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, unsigned long& val) const;
iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, float& val) const;
iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, double& val) const;
iter_type do_get(iter_type in, iter_type end, ios_base& str,
                 ios_base::iostate& err, void*& val) const;

Effects: Reads characters from in, interpreting them according to str.flags(), use_facet<ctype<charT> >(loc), and use_facet<numpunct<charT> >(loc), where loc is str.getloc(). If an error occurs, val is unchanged; otherwise it is set to the resulting value.

The details of this operation occur in three stages

— Stage 1: Determine a conversion specifier

— Stage 2: Extract characters from in and determine a corresponding char value for the format expected by the conversion specification determined in stage 1.

— Stage 3: Store results

The details of the stages are presented below.

Stage 1: The function initializes local variables via

```cpp
fmtflags flags = str.flags();
fmtflags basefield = (flags & ios_base::basefield);
fmtflags uppercase = (flags & ios_base::uppercase);
fmtflags boolalpha = (flags & ios_base::boolalpha);
```

For conversion to an integral type, the function determines the integral conversion specifier as indicated in Table 69. The table is ordered. That is, the first line whose condition is true applies.
Table 69: Integer Conversions

<table>
<thead>
<tr>
<th>State</th>
<th>stdio equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>basefield == oct</td>
<td>%o</td>
</tr>
<tr>
<td>basefield == hex</td>
<td>%X</td>
</tr>
<tr>
<td>basefield == 0</td>
<td>%i</td>
</tr>
<tr>
<td>signed integral type</td>
<td>%d</td>
</tr>
<tr>
<td>unsigned integral type</td>
<td>%u</td>
</tr>
</tbody>
</table>

For conversions to a floating type the specifier is %g.

For conversions to void* the specifier is %p.

A length modifier is added to the conversion specification, if needed, as indicated in Table 70.

Table 70: Length Modifier

<table>
<thead>
<tr>
<th>type</th>
<th>length modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>short</td>
<td>h</td>
</tr>
<tr>
<td>unsigned short</td>
<td>h</td>
</tr>
<tr>
<td>long</td>
<td>l</td>
</tr>
<tr>
<td>unsigned long</td>
<td>l</td>
</tr>
<tr>
<td>double</td>
<td>l</td>
</tr>
<tr>
<td>long double</td>
<td>L</td>
</tr>
</tbody>
</table>

Stage 2: If \texttt{in == end} then stage 2 terminates. Otherwise a charT is taken from \texttt{in} and local variables are initialized as if by

```cpp
char_type ct = *in;
char c = src[find(atoms, atoms + sizeof(src) - 1, ct) - atoms];
if (ct == use_facet<numpunct<charT> >(loc).decimal_point())
    c = '.';
bool discard =
    (ct == use_facet<numpunct<charT> >(loc).thousands_sep())
    &&
    use_facet<numpunct<charT> >(loc).grouping().length() != 0);
```

where the values src and atoms are defined as if by:

```cpp
static const char src[] = "0123456789abcdefxABCDEFX+-";
char_type atoms[sizeof(src)];
use_facet<ctype<charT> >(loc).widen(src, src + sizeof(src), atoms);
```

for this value of \textit{loc}.

If \texttt{discard} is true, then if '.' has not yet been accumulated, then the position of the character is remembered, but the character is otherwise ignored. Otherwise, if '.' has already been accumulated, the character is discarded and Stage 2 terminates.
If the character is either discarded or accumulated then \( \text{in} \) is advanced by \( ++\text{in} \) and processing returns to the beginning of stage 2.

**Stage 3:** The result of stage 2 processing can be one of

- A sequence of chars has been accumulated in stage 2 that is converted (according to the rules of `scanf`) to a value of the type of \( \text{val} \). This value is stored in \( \text{val} \) and `ios_base::goodbit` is stored in `err`.

- The sequence of chars accumulated in stage 2 would have caused `scanf` to report an input failure. `ios_base::failbit` is assigned to `err`.

4 Digit grouping is checked. That is, the positions of discarded separators is examined for consistency with `use_-facet<numpunct<charT> >((\text{loc}).grouping())`. If they are not consistent then `ios_base::failbit` is assigned to `err`.

5 In any case, if stage 2 processing was terminated by the test for \( \text{in}==\text{end} \) then `err |=ios_base::eofbit` is performed.

iter_type do_get(iter_type \( \text{in} \), iter_type \( \text{end} \), ios_base& \( \text{str} \),
ios_base::iostate& \( \text{err} \), bool& \( \text{val} \)) const;

6 **Effects:** If `(\text{str}.flags()&ios_base::boolalpha) ==0` then input proceeds as it would for a `long` except that if a value is being stored into \( \text{val} \), the value is determined according to the following: If the value to be stored is 0 then `false` is stored. If the value is 1 then `true` is stored. Otherwise `err |=ios_base::failbit` is performed and no value is stored.

7 Otherwise target sequences are determined "as if" by calling the members `falsename()` and `truename()` of the facet obtained by `use_facet<numpunct<charT> >(\text{str}.getloc())`. Successive characters in the range \([\text{in},\text{end})\) (see 23.1.1) are obtained and matched against corresponding positions in the target sequences only as necessary to identify a unique match. The input iterator \( \text{in} \) is compared to \( \text{end} \) only when necessary to obtain a character. If and only if a target sequence is uniquely matched, \( \text{val} \) is set to the corresponding value.

8 The \( \text{in} \) iterator is always left pointing one position beyond the last character successfully matched. If \( \text{val} \) is set, then `err` is set to `str.goodbit`; or to `str.eofbit` if, when seeking another character to match, it is found that \( \text{in}==\text{end} \). If \( \text{val} \) is not set, then `err` is set to `str.failbit`; or to `(str.failbit|str.eofbit)` if the reason for the failure was that \( \text{in}==\text{end} \). [Example: For targets true: "a" and false: "abb", the input sequence "a" yields `val == true` and `err == str.eofbit`; the input sequence "abc" yields `err == str.failbit`, with `in` ending at the 'c' element. For targets true: "1" and false: "0", the input sequence "1" yields `val == true` and `err == str.goodbit`. For empty targets (""), any input sequence yields `err == str.failbit`. — end example]

9 **Returns:** \( \text{in} \).

22.2.2.2 **Class template** `num_put` [lib.locale.nm.put]

namespace std {
    template <class charT, class OutputIterator = ostreambuf_iterator<charT> > 
    class num_put : public locale::facet {
        public:
            typedef charT char_type;
            typedef OutputIterator iter_type;

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The facet num_put is used to format numeric values to a character sequence such as an ostream.

### num_put members

```cpp
itertools.put(iter_type out, ios_base& str, char_type fill, bool val) const;
itertools.put(iter_type out, ios_base& str, char_type fill, long val) const;
itertools.put(iter_type out, ios_base& str, char_type fill, unsigned long val) const;
itertools.put(iter_type out, ios_base& str, char_type fill, double val) const;
itertools.put(iter_type out, ios_base& str, char_type fill, long double val) const;
itertools.put(iter_type out, ios_base& str, char_type fill, const void* val) const;
```
Returns: do_put(out, str, fill, val).

### 22.2.2.2 num_put virtual functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>iter_type do_put(iter_type out, ios_base&amp; str, char_type fill, long val) const;</code></td>
<td></td>
</tr>
<tr>
<td><code>iter_type do_put(iter_type out, ios_base&amp; str, char_type fill, unsigned long val) const;</code></td>
<td></td>
</tr>
<tr>
<td><code>iter_type do_put(iter_type out, ios_base&amp; str, char_type fill, double val) const;</code></td>
<td></td>
</tr>
<tr>
<td><code>iter_type do_put(iter_type out, ios_base&amp; str, char_type fill, long double val) const;</code></td>
<td></td>
</tr>
<tr>
<td><code>iter_type do_put(iter_type out, ios_base&amp; str, char_type fill, const void* val) const;</code></td>
<td></td>
</tr>
</tbody>
</table>

Effects: Writes characters to the sequence out, formatting val as desired. In the following description, a local variable initialized with

```cpp
locale loc = str.getloc();
```

The details of this operation occur in several stages:

- **Stage 1:** Determine a printf conversion specifier spec and determining the characters that would be printed by printf(27.8.2) given this conversion specifier for
  ```cpp
  printf(spec, val )
  ```
  assuming that the current locale is the "C" locale.

- **Stage 2:** Adjust the representation by converting each char determined by stage 1 to a charT using a conversion and values returned by members of use_facet< numpunct<charT> >(str.getloc())

- **Stage 3:** Determine where padding is required.

- **Stage 4:** Insert the sequence into the out.

Returns: out.

Stage 1: The first action of stage 1 is to determine a conversion specifier. The tables that describe this determination use the following local variables:

```cpp
fmtflags flags = str.flags();
fmtflags basefield = (flags & (ios_base::basefield));
fmtflags uppercase = (flags & (ios_base::uppercase));
fmtflags floatfield = (flags & (ios_base::floatfield));
fmtflags showpos = (flags & (ios_base::showpos));
fmtflags showbase = (flags & (ios_base::showbase));
```
All tables used in describing stage 1 are ordered. That is, the first line whose condition is true applies. A line without a condition is the default behavior when none of the earlier lines apply.

For conversion from an integral type other than a character type, the function determines the integral conversion specifier as indicated in Table 71.

<table>
<thead>
<tr>
<th>State</th>
<th>stdio equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>basefield == ios_base::oct</td>
<td>%o</td>
</tr>
<tr>
<td>(basefield == ios_base::hex) &amp;&amp; !uppercase</td>
<td>%x</td>
</tr>
<tr>
<td>(basefield == ios_base::hex)</td>
<td>%X</td>
</tr>
<tr>
<td>for a signed integral type</td>
<td>%d</td>
</tr>
<tr>
<td>for an unsigned integral type</td>
<td>%u</td>
</tr>
</tbody>
</table>

For conversion from a floating-point type, the function determines the floating-point conversion specifier as indicated in Table 72:

<table>
<thead>
<tr>
<th>State</th>
<th>stdio equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>floatfield == ios_base::fixed</td>
<td>%f</td>
</tr>
<tr>
<td>floatfield == ios_base::scientific &amp;&amp; !uppercase</td>
<td>%e</td>
</tr>
<tr>
<td>floatfield == ios_base::scientific</td>
<td>%E</td>
</tr>
<tr>
<td>!uppercase</td>
<td>%g</td>
</tr>
<tr>
<td>otherwise</td>
<td>%G</td>
</tr>
</tbody>
</table>

For conversions from an integral or floating type a length modifier is added to the conversion specifier as indicated in Table 73

<table>
<thead>
<tr>
<th>type</th>
<th>length modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>long</td>
<td>l</td>
</tr>
<tr>
<td>unsigned long</td>
<td>l</td>
</tr>
<tr>
<td>long double</td>
<td>L</td>
</tr>
<tr>
<td>otherwise</td>
<td>none</td>
</tr>
</tbody>
</table>

The conversion specifier has the following optional additional qualifiers prepended as indicated in Table 74

For conversion from a floating-point type, str.precision() is specified in the conversion specification.

For conversion from void* the specifier is %p.

The representations at the end of stage 1 consists of the char’s that would be printed by a call of printf(s, val) where s is the conversion specifier determined above.
Table 74: Numeric conversions

<table>
<thead>
<tr>
<th>Type(s)</th>
<th>State</th>
<th>stdio equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>an integral type</td>
<td>flags &amp; showpos</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>flags &amp; showbase</td>
<td>#</td>
</tr>
<tr>
<td>a floating-point type</td>
<td>flags &amp; showpos</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>flags &amp; showpoint</td>
<td>#</td>
</tr>
</tbody>
</table>

Stage 2: Any character `c` other than a decimal point(.) is converted to a `charT` via `use_facet<ctype<charT> >(loc).widen(c)`

A local variable `punct` is initialized via

```
numpunct<charT> punct = use_facet<numpunct<charT> >(str.getloc());
```

For arithmetic types, `punct.thousands_sep()` characters are inserted into the sequence as determined by the value returned by `punct.do_grouping()` using the method described in 22.2.3.1.2

Decimal point characters(.) are replaced by `punct.decimal_point()`

Stage 3: A local variable is initialized as

```
fmtflags adjustfield = (flags & (ios_base::adjustfield));
```

The location of any padding\(^{244}\) is determined according to Table 75

Table 75: Fill padding

<table>
<thead>
<tr>
<th>State</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjustfield == ios_base::left</td>
<td>pad after</td>
</tr>
<tr>
<td>adjustfield == ios_base::right</td>
<td>pad before</td>
</tr>
<tr>
<td>adjustfield == internal and a sign occurs in the representation</td>
<td>pad after the sign</td>
</tr>
<tr>
<td>adjustfield == internal and representation after stage 1 began with 0x of 0X</td>
<td>pad after x or X</td>
</tr>
<tr>
<td>otherwise</td>
<td>pad before</td>
</tr>
</tbody>
</table>

If `str.width()` is nonzero and the number of `charT`'s in the sequence after stage 2 is less than `str.width()`, then enough `fill` characters are added to the sequence at the position indicated for padding to bring the length of the sequence to `str.width()`.

`str.width(0)` is called.

Stage 4: The sequence of `charT`'s at the end of stage 3 are output via

```
*out++ = c;
```

```
iter_type do_put(iter_type out, ios_base& str, char_type fill,
                 bool val) const;
```

\(^{244}\) The conversion specification `#o` generates a leading 0 which is not a padding character.
6  Returns: If `str.flags() & ios_base::boolalpha) == 0` returns `do_put(out, str, fill, (int)val)`, otherwise obtains a string `s` as if by

\[
\text{string}_\text{type} s = \begin{cases} 
\text{use}_\text{facet}\langle\text{ctype}<\text{char}_\text{T}\rangle>(\text{loc}).\text{truename()} & \text{if `val` is true} \\
\text{use}_\text{facet}\langle\text{ctype}<\text{char}_\text{T}\rangle>(\text{loc}).\text{falsename()} & \text{otherwise}
\end{cases}
\]

and then inserts each character `c` of `s` into `out` via `*out++ = c` and returns `out`.

22.2.3 The numeric punctuation facet

22.2.3.1 Class template `numpunct`

```cpp
namespace std {
    template <class charT>
    class numpunct : public locale::facet {
    public:
        typedef charT char_type;
        typedef basic_string<charT> string_type;

        explicit numpunct(size_t refs = 0);

        char_type decimal_point() const;
        char_type thousands_sep() const;
        string grouping() const;
        string_type truename() const;
        string_type falsename() const;

        static locale::id id;

    protected:
        "numpunct(); // virtual
        virtual char_type do_decimal_point() const;
        virtual char_type do_thousands_sep() const;
        virtual string do_grouping() const;
        virtual string_type do_truename() const; // for bool
        virtual string_type do_falsename() const; // for bool
    };
}
```

1. `numpunct<>` specifies numeric punctuation. The specializations required in Table 65 (22.1.1.1.1), namely `numpunct<wchar_t>` and `numpunct<char>`, provide classic "C" numeric formats, i.e. they contain information equivalent to that contained in the "C" locale or their wide character counterparts as if obtained by a call to `widen`.

2. The syntax for number formats is as follows, where `digit` represents the radix set specified by the `fmtflags` argument value, and `thousands-sep` and `decimal-point` are the results of corresponding `numpunct<charT>` members. Integer values have the format:

```plaintext
integer ::= [sign] units
sign ::= plusminus
```

Draft
Localization library

plusminus ::= ’+’ | ’-’
units ::= digits [thousands-sep units]
digits ::= digit [digits]

and floating-point values have:

floatval ::= [sign] units [decimal-point [digits]] [e [sign] digits] |
            [sign] decimal-point digits [e [sign] digits]
e ::= ’e’ | ’E’

where the number of digits between thousands-seps is as specified by do_grouping(). For parsing, if the digits
portion contains no thousands-separators, no grouping constraint is applied.

22.2.3.1.1 numpunct members

char_type decimal_point() const;
1 Returns: do_decimal_point()

char_type thousands_sep() const;
2 Returns: do_thousands_sep()

string grouping() const;
3 Returns: do_grouping()

string_type truename() const;
string_type falsename() const;
4 Returns: do_truename() or do_falsename(), respectively.

22.2.3.1.2 numpunct virtual functions

char_type do_decimal_point() const;
1 Returns: A character for use as the decimal radix separator. The required specializations return ’.’ or L’.’.

char_type do_thousands_sep() const;
2 Returns: A character for use as the digit group separator. The required specializations return ’,’ or L’,’.

string do_grouping() const;
3 Returns: A basic_string<char> vec used as a vector of integer values, in which each element vec[i] represents
the number of digits\footnote{Thus, the string ”003” specifies groups of 3 digits each, and ”3” probably indicates groups of 51 (!) digits each, because 51 is the ASCII value of ”3".}. The size of
the digit group is unlimited.

The required specializations return the empty string, indicating no grouping.
string_type do_truename() const;
string_type do_falsename() const;

Returns: A string representing the name of the boolean value true or false, respectively.

In the base class implementation these names are "true" and "false", or L"true" and L"false".

### 22.2.3.2 Class template numpunctbyname

```cpp
namespace std {
    template <class charT>
    class numpunctbyname : public numpunct<charT> {
        // this class is specialized for char and wchar_t.
        public:
            typedef charT char_type;
            typedef basic_string<charT> string_type;
            explicit numpunctbyname(const char*, size_t refs = 0);
            explicit numpunctbyname(const string&, size_t refs = 0);
        protected:
            ~numpunctbyname(); // virtual
    };
}
```

### 22.2.4 The collate category

#### 22.2.4.1 Class template collate

```cpp
namespace std {
    template <class charT>
    class collate : public locale::facet {
        public:
            typedef charT char_type;
            typedef basic_string<charT> string_type;
            explicit collate(size_t refs = 0);
            int compare(const charT* low1, const charT* high1,
                         const charT* low2, const charT* high2) const;
            string_type transform(const charT* low, const charT* high) const;
            long hash(const charT* low, const charT* high) const;
            static locale::id id;
        protected:
            ~collate(); // virtual
            virtual int do_compare(const charT* low1, const charT* high1,
                                    const charT* low2, const charT* high2) const;
            virtual string_type do_transform(const charT* low, const charT* high) const;
            virtual long do_hash(const charT* low, const charT* high) const;
    };
}
```
The class `collate<charT>` provides features for use in the collation (comparison) and hashing of strings. A locale member function template, `operator()`, uses the collate facet to allow a locale to act directly as the predicate argument for standard algorithms (clause 25) and containers operating on strings. The specializations required in Table 65 (22.1.1.1.1), namely `collate<char>` and `collate<wchar_t>`, apply lexicographic ordering (25.3.8).

Each function compares a string of characters `*p` in the range `[low, high)`.

### 22.2.4.1 collate members

```cpp
int compare(const charT* low1, const charT* high1,
            const charT* low2, const charT* high2) const;
```

**Returns:**
1. 1 if the first string is greater than the second,
2. -1 if less, zero otherwise.
3. The specializations required in Table 65 (22.1.1.1.1), namely `collate<char>` and `collate<wchar_t>`, implement a lexicographical comparison (25.3.8).

```cpp
string_type transform(const charT* low, const charT* high) const;
```

**Returns:**
1. A `basic_string<charT>` value that, compared lexicographically with the result of calling `transform()` on another string, yields the same result as calling `do_compare()` on the same two strings.246

```cpp
long hash(const charT* low, const charT* high) const;
```

**Returns:**
1. An integer value equal to the result of calling `hash()` on any other string for which `do_compare()` returns 0 (equal) when passed the two strings. [**Note:** The probability that the result equals that for another string which does not compare equal should be very small, approaching `(1.0/numeric_limits<unsigned long>::max())`. — end note]

### 22.2.4.2 Class template collate_byname

246 This function is useful when one string is being compared to many other strings.
namespace std {
    template <class charT>
    class collate_byname : public collate<charT> {
    public:
        typedef basic_string<charT> string_type;
        explicit collate_byname(const char*, size_t refs = 0);
        explicit collate_byname(const string &, size_t refs = 0);
        protected:
            "collate_byname"(); //virtual
    };
}

22.2.5 The time category

Templates \texttt{time\_get<\charT, \text{InputIterator}>} and \texttt{time\_put<\charT, \text{OutputIterator}>} provide date and time formatting and parsing. All specifications of member functions for \texttt{time\_put} and \texttt{time\_get} in the subclauses of 22.2.5 only apply to the specializations required in Tables 65 and 66 (22.1.1.1.1). Their members use their \texttt{ios\_base\&}, \texttt{ios\_base::iostate\&}, and \texttt{fill} arguments as described in (22.2), and the \texttt{ctype<\> facet}, to determine formatting details.

22.2.5.1 Class template \texttt{time\_get}

namespace std {
    class time_base {
    public:
        enum dateorder { no_order, dmy, mdy, ymd, ydm };
    }

    template <class charT, class InputIterator = istreambuf_iterator<charT> >
    class time_get : public locale::facet, public time_base {
    public:
        typedef charT char_type;
        typedef InputIterator iter_type;
        explicit time_get(size_t refs = 0);

        dateorder date_order() const { return do_date_order(); }
        iter_type get_time(iter_type s, iter_type end, ios_base & f,
            ios_base::iostate & err, tm * t) const;
        iter_type get_date(iter_type s, iter_type end, ios_base & f,
            ios_base::iostate & err, tm * t) const;
        iter_type get_weekday(iter_type s, iter_type end, ios_base & f,
            ios_base::iostate & err, tm * t) const;
        iter_type get_monthname(iter_type s, iter_type end, ios_base & f,
            ios_base::iostate & err, tm * t) const;
        iter_type get_year(iter_type s, iter_type end, ios_base & f,
            ios_base::iostate & err, tm * t) const;

        static locale::id id;
    protected:

    };
}
time_get();        // virtual
   virtual dateorder do_date_order() const;
   virtual iter_type do_time(iter_type s, iter_type end, ios_base&,
                              ios_base::iostate& err, tm* t) const;
   virtual iter_type do_date(iter_type s, iter_type end, ios_base&,
                              ios_base::iostate& err, tm* t) const;
   virtual iter_type do_weekday(iter_type s, iter_type end, ios_base&,
                                ios_base::iostate& err, tm* t) const;
   virtual iter_type do_monthname(iter_type s, iter_type end, ios_base&,
                                  ios_base::iostate& err, tm* t) const;
   virtual iter_type do_year(iter_type s, iter_type end, ios_base&,
                            ios_base::iostate& err, tm* t) const;

1 time_get is used to parse a character sequence, extracting components of a time or date into a struct tm record. Each
   get member parses a format as produced by a corresponding format specifier to time_put<>::put. If the sequence
   being parsed matches the correct format, the corresponding members of the struct tm argument are set to the values
   used to produce the sequence; otherwise either an error is reported or unspecified values are assigned.

2 If the end iterator is reached during parsing by any of the get() member functions, the member sets ios_base::eof-
   bit in err.

22.2.5.1.1 time_get members

   dateorder date_order() const;

1   Returns: do_date_order()

   iter_type get_time(iter_type s, iter_type end, ios_base& str,
                      ios_base::iostate& err, tm* t) const;
2   Returns: do_get_time(s, end, str, err, t)

   iter_type get_date(iter_type s, iter_type end, ios_base& str,
                      ios_base::iostate& err, tm* t) const;
3   Returns: do_get_date(s, end, str, err, t)

   iter_type get_weekday(iter_type s, iter_type end, ios_base& str,
                          ios_base::iostate& err, tm* t) const;
   iter_type get_monthname(iter_type s, iter_type end, ios_base& str,
                          ios_base::iostate& err, tm* t) const;
4   Returns: do_get_weekday(s, end, str, err, t) or do_get_monthname(s, end, str, err, t)

   iter_type get_year(iter_type s, iter_type end, ios_base& str,
                      ios_base::iostate& err, tm* t) const;
5   Returns: do_get_year(s, end, str, err, t)

247) In other words, user confirmation is required for reliable parsing of user-entered dates and times, but machine-generated formats can be parsed
   reliably. This allows parsers to be aggressive about interpreting user variations on standard formats.
22.2.5.1.2 time_get virtual functions

```

dateorder do_date_order() const;
```

1. **Returns:** An enumeration value indicating the preferred order of components for those date formats that are composed of day, month, and year.²⁴⁸ Returns no_order if the date format specified by ‘x’ contains other variable components (e.g. Julian day, week number, week day).

```
iter_type do_get_time(iter_type s, iter_type end, ios_base& str,
    ios_base::iostate& err, tm* t) const;
```

2. **Effects:** Reads characters starting at s until it has extracted those struct tm members, and remaining format characters, used by time_put<>::put to produce the format specified by "%H:%M:%S", or until it encounters an error or end of sequence.

```
Returns: An iterator pointing immediately beyond the last character recognized as possibly part of a valid time.
```

```
iter_type do_get_date(iter_type s, iter_type end, ios_base& str,
    ios_base::iostate& err, tm* t) const;
```

3. **Effects:** Reads characters starting at s until it has extracted those struct tm members, and remaining format characters, used by time_put<>::put to produce one of the following formats, or until it encounters an error. The format depends on the value returned by date_order() as in Table 76:

<table>
<thead>
<tr>
<th>date_order()</th>
<th>format</th>
</tr>
</thead>
<tbody>
<tr>
<td>no_order</td>
<td>&quot;%m%d%y&quot;</td>
</tr>
<tr>
<td>dmy</td>
<td>&quot;%d%m%y&quot;</td>
</tr>
<tr>
<td>mdy</td>
<td>&quot;%m%d%y&quot;</td>
</tr>
<tr>
<td>ymd</td>
<td>&quot;%y%m%d&quot;</td>
</tr>
<tr>
<td>ydm</td>
<td>&quot;%y%d%m&quot;</td>
</tr>
</tbody>
</table>

An implementation may also accept additional implementation-defined formats.

```
Returns: An iterator pointing immediately beyond the last character recognized as possibly part of a valid date.
```

```
iter_type do_get_weekday(iter_type s, iter_type end, ios_base& str,
    ios_base::iostate& err, tm* t) const;
```

4. **Effects:** Reads characters starting at s until it has extracted the (perhaps abbreviated) name of a weekday or month. If it finds an abbreviation that is followed by characters that could match a full name, it continues reading until it matches the full name or fails. It sets the appropriate struct tm member accordingly.

```
Returns: An iterator pointing immediately beyond the last character recognized as part of a valid name.
```

```
iter_type do_get_monthname(iter_type s, iter_type end, ios_base& str,
    ios_base::iostate& err, tm* t) const;
```

5. **Effects:** Reads characters starting at s until it has extracted the (perhaps abbreviated) name of a weekday or month. If it finds an abbreviation that is followed by characters that could match a full name, it continues reading until it matches the full name or fails. It sets the appropriate struct tm member accordingly.

```
Returns: An iterator pointing immediately beyond the last character recognized as part of a valid name.
```

```
iter_type do_get_year(iter_type s, iter_type end, ios_base& str,
    ios_base::iostate& err, tm* t) const;
```

6. **Returns:** An iterator pointing immediately beyond the last character recognized as part of a valid name.

²⁴⁸ This function is intended as a convenience only, for common formats, and may return no_order in valid locales.
Effects: Reads characters starting at s until it has extracted an unambiguous year identifier. It is implementation-defined whether two-digit year numbers are accepted, and (if so) what century they are assumed to lie in. Sets the t->tm_year member accordingly.

Returns: An iterator pointing immediately beyond the last character recognized as part of a valid year identifier.

22.2.5.2 Class template time_get_byname

namespace std {
    template <class charT, class InputIterator = istreambuf_iterator<charT> >
    class time_get_byname : public time_get<charT, InputIterator> {
    public:
        typedef time_base::dateorder dateorder;
        typedef InputIterator iter_type;

        explicit time_get_byname(const char*, size_t refs = 0);
        explicit time_get_byname(const string&, size_t refs = 0);

    protected:
        ~time_get_byname();  // virtual
    };
}

22.2.5.3 Class template time_put

namespace std {
    template <class charT, class OutputIterator = ostreambuf_iterator<charT> >
    class time_put : public locale::facet {
    public:
        typedef charT char_type;
        typedef OutputIterator iter_type;

        explicit time_put(size_t refs = 0);

        // the following is implemented in terms of other member functions.
        iter_type put(iter_type s, ios_base& f, char_type fill, const tm* tmb,
                      const charT* pattern, const charT* pat_end) const;
        iter_type put(iter_type s, ios_base& f, char_type fill,
                      const tm* tmb, char format, char modifier = 0) const;

        static locale::id id;

    protected:
        ~time_put();  // virtual
        virtual iter_type do_put(iter_type s, ios_base& f, char_type, const tm* t,
                                  char format, char modifier) const;
    };
}

22.2.5.3.1 time_put members

Draft
22.2 Standard locale categories

Localization library

iter_type put(iter_type s, ios_base& str, char_type fill, const tm* t, 
const charT* pattern, const charT* pat_end) const;
iter_type put(iter_type s, ios_base& str, char_type fill, const tm* t, 
char format, char modifier = 0) const;

Effects: The first form steps through the sequence from pattern to pat_end, identifying characters that are part of a format sequence. Each character that is not part of a format sequence is written to s immediately, and each format sequence, as it is identified, results in a call to do_put; thus, format elements and other characters are interleaved in the output in the order in which they appear in the pattern. Format sequences are identified by converting each character c to a char value as if by ct.narrow(c, 0), where ct is a reference to ctype<charT> obtained from str.getloc(). The first character of each sequence is equal to '%', followed by an optional modifier character mod and a format specifier character spec as defined for the function strftime. If no modifier character is present, mod is zero. For each valid format sequence identified, calls do_put(s, str, fill, t, spec, mod).

The second form calls do_put(s, str, fill, t, format, modifier).

[Note: The fill argument may be used in the implementation-defined formats, or by derivations. A space character is a reasonable default for this argument. — end note]

Returns: An iterator pointing immediately after the last character produced.

22.2.5.3.2 time_put virtual functions [lib.locale.time.put.virtuals]

iter_type do_put(iter_type s, ios_base& char_type fill, const tm* t, 
char format, char modifier) const;

Effects: Formats the contents of the parameter t into characters placed on the output sequence s. Formatting is controlled by the parameters format and modifier, interpreted identically as the format specifiers in the string argument to the standard library function strftime(). except that the sequence of characters produced for those specifiers that are described as depending on the C locale are instead implementation-defined.

Returns: An iterator pointing immediately after the last character produced. [Note: The fill argument may be used in the implementation-defined formats, or by derivations. A space character is a reasonable default for this argument. — end note]

22.2.5.4 Class template time_put_byname [lib.locale.time.put.basename]

namespace std {
  template <class charT, class OutputIterator = ostreambuf_iterator<charT> >
  class time_put_byname : public time_put<charT, OutputIterator> 
  {
    public:
      typedef charT char_type;
      typedef OutputIterator iter_type;

249) Although the C programming language defines no modifiers, most vendors do.
250) Interpretation of the modifier argument is implementation-defined, but should follow POSIX conventions.
251) Implementations are encouraged to refer to other standards (such as POSIX) for these definitions.

Draft
22.2.6 The monetary category

These templates handle monetary formats. A template parameter indicates whether local or international monetary formats are to be used.

All specifications of member functions for money_put and money_get in the subclauses of 22.2.6 only apply to the specializations required in Tables 65 and 66 (22.1.1.1.1). Their members use their ios_base&, ios_base::iostate&, and fill arguments as described in (22.2), and the moneypunct<> and ctype<> facets, to determine formatting details.

22.2.6.1 Class template money_get

namespace std {
    template <class charT,
              class InputIterator = istreambuf_iterator<charT> >
    class money_get : public locale::facet {
    public:
        typedef charT char_type;
        typedef InputIterator iter_type;
        typedef basic_string<charT> string_type;

        explicit money_get(size_t refs = 0);

        iter_type get(iter_type s, iter_type end, bool intl,
                       ios_base& f, ios_base::iostate& err,
                       long double& units) const;
        iter_type get(iter_type s, iter_type end, bool intl,
                       ios_base& f, ios_base::iostate& err,
                       string_type& digits) const;

        static locale::id id;
    protected:
        ~money_get(); // virtual
        virtual iter_type do_get(iter_type, iter_type, bool, ios_base&,
                                  ios_base::iostate& err, long double& units) const;
        virtual iter_type do_get(iter_type, iter_type, bool, ios_base&,
                                  ios_base::iostate& err, string_type& digits) const;
    }
}

22.2.6.1.1 money_get members

iter_type get(iter_type s, iter_type end, bool intl,
              ios_base& f, ios_base::iostate& err,
long double& quant) const;
iter_type get(s, iter_type end, bool Intl, ios_base& f,
    ios_base::iostate& err, string_type& quant) const;

Returns: do_get(s, end, Intl, f, err, quant)

22.2.6.1.2 money_get virtual functions

iter_type do_get(iter_type s, iter_type end, bool Intl,
    ios_base& str, ios_base::iostate& err,
    long double& units) const;
iter_type do_get(iter_type s, iter_type end, bool Intl,
    ios_base& str, ios_base::iostate& err,
    string_type& digits) const;

Effects: Reads characters from s to parse and construct a monetary value according to the format specified by a moneypunct<CharT,Intl> facet reference mp and the character mapping specified by a ctype<CharT> facet reference ct obtained from the locale returned by str.getloc(), and str.flags(). If a valid sequence is recognized, does not change err; otherwise, sets err to (err | str.failbit), or (err | str.failbit | str.eofbit) if no more characters are available, and does not change units or digits. Uses the pattern returned by mp.neg_format() to parse all values. The result is returned as an integral value stored in units or as a sequence of digits possibly preceded by a minus sign (as produced by ct.widen(c) where c is '−' or in the range from '0' through '9', inclusive) stored in digits. [Example: The sequence $1,056.23 in a common United States locale would yield, for units, 105623, or, for digits, "105623". —end example] If mp.grouping() indicates that no thousands separators are permitted, any such characters are not read, and parsing is terminated at the point where they first appear. Otherwise, thousands separators are optional; if present, they are checked for correct placement only after all format components have been read.

2 Where space or none appears in the format pattern, except at the end, optional white space (as recognized by ct.is) is consumed after any required space. If (str.flags() & str.showbase) is false, the currency symbol is optional and is consumed only if other characters are needed to complete the format; otherwise, the currency symbol is required.

3 If the first character (if any) in the string pos returned by mp.positive_sign() or the string neg returned by mp.negative_sign() is recognized in the position indicated by sign in the format pattern, it is consumed and any remaining characters in the string are required after all the other format components. [Example: If showbase is off, then for a neg value of "()" and a currency symbol of "$", in "(100 $)" the "$" is consumed; but if neg is "−", the "L" in "−100 L" is not consumed. —end example] If pos or neg is empty, the sign component is optional, and if no sign is detected, the result is given the sign that corresponds to the source of the empty string. Otherwise, the character in the indicated position must match the first character of pos or neg, and the result is given the corresponding sign. If the first character of pos is equal to the first character of neg, or if both strings are empty, the result is given a positive sign.

4 Digits in the numeric monetary component are extracted and placed in digits, or into a character buffer buf1 for conversion to produce a value for units, in the order in which they appear, preceded by a minus sign if and only if the result is negative. The value units is produced as if by

\[252\] The semantics here are different from ct.narrow.

Draft
for (int i = 0; i < n; ++i)
    buf2[i] = src[find(atoms, atoms+sizeof(src), buf1[i]) - atoms];
buf2[n] = 0;
sscanf(buf2, "%Lf", &units);

where n is the number of characters placed in buf1, buf2 is a character buffer, and the values src and atoms are defined as if by

    static const char src[] = "0123456789-";
    charT atoms[sizeof(src)];
    ct.widen(src, src + sizeof(src) - 1, atoms);

    Returns: An iterator pointing immediately beyond the last character recognized as part of a valid monetary quantity.

### 22.2.6.2 Class template money_put

namespace std {
    template <class charT,
          class OutputIterator = ostreambuf_iterator<charT> >
    class money_put : public locale::facet {
        public:
            typedef charT char_type;
            typedef OutputIterator iter_type;
            typedef basic_string<charT> string_type;

            explicit money_put(size_t refs = 0);

            iter_type put(iter_type s, bool intl, ios_base& f, char_type fill, long double units) const;
            iter_type put(iter_type s, bool intl, ios_base& f, string_type& digits) const;

            static locale::id id;

        protected:
            ~money_put(); // virtual
            virtual iter_type do_put(iter_type, bool, ios_base& f, char_type fill, long double units) const;
            virtual iter_type do_put(iter_type, bool, ios_base& f, string_type& digits) const;
    };
}

### 22.2.6.2.1 money_put members

iter_type put(iter_type s, bool intl, ios_base& f, char_type fill, string_type& digits) const;
22.2.6.2.2 money_put virtual functions [lib.locale.money.put.virtuals]

iter_type do_put(iter_type s, bool intl, ios_base& str, char_type fill, long double units) const;
iter_type do_put(iter_type s, bool intl, ios_base& str, char_type fill, const string_type& digits) const;

Effects: Writes characters to s according to the format specified by a moneypunct<charT,Intl> facet reference mp and the character mapping specified by a ctype<charT> facet reference ct obtained from the locale returned by str.getloc(), and str.flags()(). The argument units is transformed into a sequence of wide characters as if by

\[ \text{ct.widen(buf1, buf1 + sprintf(buf1, ".0Lf", units), buf2) \] for character buffers buf1 and buf2. If the first character in digits or buf2 is equal to \text{ct.widen('-')}, then the pattern used for formatting is the result of mp.neg_format(); otherwise the pattern is the result of mp.pos_format(). Digit characters are written, interspersed with any thousands separators and decimal point specified by the format, in the order they appear (after the optional leading minus sign) in digits or buf2. In digits, only the optional leading minus sign and the immediately subsequent digit characters (as classified according to ct) are used; any trailing characters (including digits appearing after a non-digit character) are ignored. Calls str.width(0).

Remarks: The currency symbol is generated if and only if (str.flags() & str.showbase) is nonzero. If the number of characters generated for the specified format is less than the value returned by str.width() on entry to the function, then copies of fill are inserted as necessary to pad to the specified width. For the value \text{af} equal to (str.flags() & str.adjustfield), if (\text{af} == str.internal) is true, the fill characters are placed where none or space appears in the formatting pattern; otherwise if (\text{af} == str.left) is true, they are placed after the other characters; otherwise, they are placed before the other characters. [Note: It is possible, with some combinations of format patterns and flag values, to produce output that cannot be parsed using num_get<>::get. — end note]

Returns: An iterator pointing immediately after the last character produced.

22.2.6.3 Class template moneypunct [lib.locale.moneypunct]

namespace std {
    class money_base {
    public:
        enum part { none, space, symbol, sign, value }
        struct pattern { char field[4]; }
    }

template <class charT, bool International = false>
The moneypunct<> facet defines monetary formatting parameters used by money_get<> and money_put<>.

A monetary format is a sequence of four components, specified by a pattern value p, such that the part value static_cast<part>(p.field[i]) determines the i-th component of the format. In the field member of a pattern object, each value symbol, sign, value, and either space or none appears exactly once. The value none, if present, is not first; the value space, if present, is neither first nor last.

Where none or space appears, white space is permitted in the format, except where none appears at the end, in which case no white space is permitted. The value space indicates that at least one space is required at that position. Where symbol appears, the sequence of characters returned by curr_symbol() is permitted, and can be required. Where sign appears, the first (if any) of the sequence of characters returned by positive_sign() or negative_sign() (respectively as the monetary value is non-negative or negative) is required. Any remaining characters of the sign sequence are required after all other format components. Where value appears, the absolute numeric monetary value is required.

253) An array of char, rather than an array of part, is specified for pattern::field purely for efficiency.
The format of the numeric monetary value is a decimal number:

\[
\text{value} ::= \text{units} \ [ \text{decimal-point} \ [ \text{digits} ] ] \ |
\text{decimal-point} \ \text{digits}
\]

if \( \text{frac_digits()} \) returns a positive value, or

\[
\text{value} ::= \text{units}
\]

otherwise. The symbol \text{decimal-point} indicates the character returned by \text{decimal_point()}. The other symbols are defined as follows:

\[
\text{units} ::= \text{digits} \ [ \text{thousands-sep} \ \text{units} ]
\]

\[
\text{digits} ::= \text{adigit} \ [ \text{digits} ]
\]

In the syntax specification, the symbol \text{adigit} is any of the values \( \text{ct}.\text{widen}(c) \) for \( c \) in the range '0' through '9', inclusive, and \( \text{ct} \) is a reference of type \text{const} \ \text{ctype}<\text{T}>& obtained as described in the definitions of \text{money_get<}> \text{and} \text{money_put<}>. The symbol \text{thousands-sep} is the character returned by \text{thousands_sep()}. The space character used is the value \( \text{ct}.\text{widen}(\ ' ') \). White space characters are those characters \( c \) for which \( \text{ci}.\text{is(space,c)} \) returns true. The number of digits required after the decimal point (if any) is exactly the value returned by \text{frac_digits()}. The placement of thousands-separator characters (if any) is determined by the value returned by \text{grouping()}, defined identically as the member \text{numpunct<>::do_grouping()}. 

22.2.6.3.1 moneypunct members

- \text{charT} \ \text{decimal_point()} \ \text{const};
- \text{charT} \ \text{thousands_sep()} \ \text{const};
- \text{string} \ \text{grouping()} \ \text{const};
- \text{string_type} \ \text{curr_symbol()} \ \text{const};
- \text{string_type} \ \text{positive_sign()} \ \text{const};
- \text{string_type} \ \text{negative_sign()} \ \text{const};
- \text{int} \ \text{frac_digits()} \ \text{const};
- \text{pattern} \ \text{pos_format()} \ \text{const};
- \text{pattern} \ \text{neg_format()} \ \text{const};

Each of these functions \( F \) returns the result of calling the corresponding virtual member function \text{do\_F()}. 

22.2.6.3.2 moneypunct virtual functions

- \text{charT} \ \text{do_decimal_point()} \ \text{const};

  Returns: The radix separator to use in case \text{do\_frac\_digits()} is greater than zero.\(^{254}\)

- \text{charT} \ \text{do\_thousands\_sep()} \ \text{const};

  Returns: The digit group separator to use in case \text{do\_grouping()} specifies a digit grouping pattern.\(^{255}\)

- \text{string} \ \text{do\_grouping()} \ \text{const};

\(^{254}\) In common U.S. locales this is ', '.

\(^{255}\) In common U.S. locales this is ', '.

Draft
string_type do_curr_symbol() const;

Returns: A string to use as the currency identifier symbol.

string_type do_positive_sign() const;
string_type do_negative_sign() const;

Returns: do_positive_sign() returns the string to use to indicate a positive monetary value; do_negative_sign() returns the string to use to indicate a negative value.

int do_frac_digits() const;

Returns: The number of digits after the decimal radix separator, if any.

pattern do_pos_format() const;
pattern do_neg_format() const;

Returns: The specializations required in Table 66 (22.1.1.1), namely moneypunct<char>, moneypunct<wchar_t>, moneypunct<char,true>, and moneypunct<wchar_t,true>, return an object of type pattern initialized to (symbol, sign, none, value).

22.2.6.4 Class template moneypunctbyname

namespace std {
    template <class charT, bool Intl = false>
    class moneypunctbyname : public moneypunct<charT, Intl> {
        public:
            typedef money_base::pattern pattern;
            typedef basic_string<charT> string_type;

            explicit moneypunctbyname(const char*, size_t refs = 0);
            explicit moneypunctbyname(const string&, size_t refs = 0);

            protected:
                ~moneypunctbyname();  // virtual
        };
    }
}

22.2.7 The message retrieval category

Class messages<charT> implements retrieval of strings from message catalogs.

22.2.7.1 Class template messages

---

256] To specify grouping by 3s, the value is "\003" not "3".

257] For international specializations (second template parameter true) this is always four characters long, usually three letters and a space.

258] This is usually the empty string.

259] In common U.S. locales, this is 2.

260] Note that the international symbol returned by do_curr_sym() usually contains a space, itself; for example, "USD ".

Draft
namespace std {
    class messages_base {
    public:
        typedef int catalog;
    };

template <class charT>
class messages : public locale::facet, public messages_base {
    public:
        typedef charT char_type;
        typedef basic_string<charT> string_type;

        explicit messages(size_t refs = 0);

        catalog open(const basic_string<char>& fn, const locale&) const;
        string_type get(catalog c, int set, intmsgid,
                        const string_type& default) const;
        void close(catalog c) const;

        static locale::id id;
    protected:
        ~messages(); // virtual
        virtual catalog do_open(const basic_string<char>&, const locale&) const;
        virtual string_type do_get(catalog, int set, intmsgid,
                                    const string_type& default) const;
        virtual void do_close(catalog) const;
    };
}

1 Values of type messages_base::catalog usable as arguments to members get and close can be obtained only by calling member open.

22.2.7.1.1 messages members


1 catalog open(const basic_string<char>& name, const locale& loc) const;

1 Returns: do_open(name, loc).


1 string_type get(catalog cat, int set, intmsgid,
                 const string_type& default) const;

1 Returns: do_get(cat, set,msgid, default).

1 void close(catalog cat) const;

1 Effects: Calls do_close(cat).

22.2.7.1.2 messages virtual functions

Draft
catalog do_open(const basic_string<char>& name,
  const locale& loc) const;

Returns: A value that may be passed to get() to retrieve a message, from the message catalog identified by
the string name according to an implementation-defined mapping. The result can be used until it is passed to
close().

Returns a value less than 0 if no such catalog can be opened.

Remarks: The locale argument loc is used for character set code conversion when retrieving messages, if needed.

string_type do_get(catalog cat, int set, int msgid,
  const string_type& dfault) const;

Requires: A catalog cat obtained from open() and not yet closed.

Returns: A message identified by arguments set, msgid, and dfault, according to an implementation-defined
mapping. If no such message can be found, returns dfault.

void do_close(catalog cat) const;

Requires: A catalog cat obtained from open() and not yet closed.

Effects: Releases unspecified resources associated with cat.

Remarks: The limit on such resources, if any, is implementation-defined.

22.2.7.2 Class template messages_byname

namespace std {
  template <class charT>
  class messages_byname : public messages<charT> {
  public:
    typedef messages_base::catalog catalog;
    typedef basic_string<charT> string_type;

    explicit messages_byname(const char*, size_t refs = 0);
    explicit messages_byname(const string&, size_t refs = 0);
    protected:
    ~messages_byname(); // virtual
  };
}

22.2.8 Program-defined facets

A C++ program may define facets to be added to a locale and used identically as the built-in facets. To create a new facet
interface, C++ programs simply derive from locale::facet a class containing a static member: static locale::id id.

[ Note: The locale member function templates verify its type and storage class. — end note ]

[ Note: This paragraph is intentionally empty. — end note ]

Draft
22.2 Standard locale categories

Example: Traditional global localization is still easy:

```cpp
#include <iostream>
#include <locale>

int main(int argc, char** argv)
{
    using namespace std;
    locale::global(locale(""));  // set the global locale
    cin.imbue(locale());
    cout.imbue(locale());
    cerr.imbue(locale());
    wcin.imbue(locale());
    wcout.imbue(locale());
    wcerr.imbue(locale());

    return MyObject(argc, argv).doit();
}
```

— end example

Example: Greater flexibility is possible:

```cpp
#include <iostream>
#include <locale>

int main()
{
    using namespace std;
    cin.imbue(locale(""));  // the user’s preferred locale
    cout.imbue(locale::classic());
    double f;
    while (cin >> f) cout << f << endl;
    return (cin.fail() != 0);
}
```

In a European locale, with input 3.456,78, output is 3456.78. — end example

This can be important even for simple programs, which may need to write a data file in a fixed format, regardless of a user’s preference.

Example: Here is an example of the use of locales in a library interface.

```cpp
// file: Date.h
#include <iosfwd>
#include <string>
#include <locale>
...  
class Date {
    ... 
    public:
        Date(unsigned day, unsigned month, unsigned year);
        std::string asString(const std::locale& = std::locale());

    Draft
This example illustrates two architectural uses of class `locale`.

The first is as a default argument in `Date::asString()`, where the default is the global (presumably user-preferred) locale.

The second is in the operators `<<` and `>>`, where a locale “hitchhikes” on another object, in this case a stream, to the point where it is needed.

```cpp
#include "Date"    // includes <ctime>
#include <sstream>
std::string Date::asString(const std::locale& l)
{
    using namespace std;
    ostringstream s; s.imbue(l);
    s << *this; return s.str();
}

std::istream& operator>>(std::istream& s, Date& d)
{
    using namespace std;
    istream::sentry cerberos(s);
    if (cerberos) {
        ios_base::iostate err = goodbit;
        struct tm t;
        use_facet< time_get<char> >(s.getloc()).get_date(s, 0, s, err, &t);
        if (!err) d = Date(t.tm_day, t.tm_mon + 1, t.tm_year + 1900);
        s.setstate(err);
    }
    return s;
}

// end example
```

A locale object may be extended with a new facet simply by constructing it with an instance of a class derived from `locale::facet`. The only member a C++ program must define is the static member `id`, which identifies your class interface as a new facet.

```cpp
namespace My {
    using namespace std;
    class Jctype : public locale::facet {
        public:
            static locale::id id;    // required for use as a new locale facet
```

Draft
### 22.2 Standard locale categories

bool is_kanji(wchar_t c) const;

JCtype() {}

protected:
  "JCtype() {}"

};

// file: filt.C
#include <iostream>
#include <locale>
#include "jctype" // above
std::locale::id My::JCtype::id; // the static JCtype member declared above.

int main()
{
  using namespace std;
  typedef ctype<wchar_t> wctype;
  locale loc(locale(""), // the user’s preferred locale ...
              new My::JCtype); // and a new feature ...
  wchar_t c = use_facet<wctype>(loc).widen('!');
  if (!use_facet<My::JCtype>(loc).is_kanji(c))
    cout << "no it isn’t!" << endl;
  return 0;
}

The new facet is used exactly like the built-in facets. — end example }

[Example: Replacing an existing facet is even easier. Here we do not define a member id because we are reusing the numpunct<charT> facet interface:

```
// file: my_bool.C
#include <iostream>
#include <locale>
#include <string>
namespace My {
  using namespace std;
  typedef numpunctbyname<char> cnumpunct;
  class BoolNames : public cnumpunct {
    protected:
      string do_truename() const { return "Oui Oui!"; }
      string do_falsename() const { return "Mais Non!"; }
    ~BoolNames() {}
  public:
    BoolNames(const char* name) : cnumpunct(name) {}
  }
}

int main(int argc, char** argv)
{
  using namespace std;
```
583

Localization library

22.3

C Library Locales

// make the user’s preferred locale, except for...
locale loc(locale(""), new My::BoolNames(""));
cout.imbue(loc);
cout << boolalpha << "Any arguments today? " << (argc > 1) << endl;
return 0;
}

— end example ]
22.3
1

C Library Locales

[lib.c.locales]

Header <clocale> (Table 77):
Table 77: Header <clocale> synopsis
Name(s)
LC_ALL
LC_COLLATE LC_CTYPE
LC_MONETARY LC_NUMERIC LC_TIME
NULL
Struct:
lconv
Functions: localeconv
setlocale
Type
Macros:

2

The contents are the same as the Standard C library header <locale.h>.
S EE ALSO : ISO C clause 7.4.

Draft


Chapter 23  Containers library  [lib.containers]

This clause describes components that C++ programs may use to organize collections of information.

The following subclauses describe container requirements, and components for sequences and associative containers, as summarized in Table 78:

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.1 Requirements</td>
<td></td>
</tr>
<tr>
<td>23.2 Sequences</td>
<td>&lt;array&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;deque&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;list&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;queue&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;stack&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;vector&gt;</td>
</tr>
<tr>
<td>23.3 Associative containers</td>
<td>&lt;map&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;set&gt;</td>
</tr>
<tr>
<td>23.3.5 bitset</td>
<td>&lt;bitset&gt;</td>
</tr>
<tr>
<td>23.4 Unordered associative containers</td>
<td>&lt;unordered_map&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;unordered_set&gt;</td>
</tr>
</tbody>
</table>

23.1 Container requirements  [lib.container.requirements]

Containers are objects that store other objects. They control allocation and deallocation of these objects through constructors, destructors, insert and erase operations.

All of the complexity requirements in this clause are stated solely in terms of the number of operations on the contained objects. [Example: the copy constructor of type `vector` `<vector<int>`> has linear complexity, even though the complexity of copying each contained `vector<int>` is itself linear. — end example ]

The type of objects stored in these components shall meet the requirements of CopyConstructible types (20.1.3).

Table 79 defines the Assignable requirement. Some containers require this property of the types to be stored in the container. `T` is the type used to instantiate the container, `t` is a value of `T`, and `u` is a value of (possibly const) `T`.

In Tables 80 and 81, `X` denotes a container class containing objects of type `T`, `a` and `b` denote values of type `X`, `u` denotes an identifier and `r` denotes a value of `X&`. 
### 23.1 Container requirements

#### Table 79: Assignable requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>post-condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>t = u</code></td>
<td><code>T&amp;</code></td>
<td><code>t</code> is equivalent to <code>u</code></td>
</tr>
</tbody>
</table>

#### Table 80: Container requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>X::value_-type</code></td>
<td><code>T</code></td>
<td><code>T</code> is CopyConstructible</td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X::reference</code></td>
<td><code>lvalue of T</code></td>
<td></td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X::const_-reference</code></td>
<td><code>const lvalue of T</code></td>
<td></td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X::iterator</code></td>
<td>iterator type whose value type is <code>T</code></td>
<td>any iterator category except output iterator</td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X::const_-iterator</code></td>
<td>constant iterator type whose value type is <code>T</code></td>
<td>any iterator category except output iterator</td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X::difference_type</code></td>
<td>signed integral type</td>
<td>is identical to the difference type of <code>X::iterator</code> and <code>X::const_iterator</code></td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X::size_type</code></td>
<td>unsigned integral type</td>
<td><code>size_type</code> can represent any non-negative value of <code>difference_type</code></td>
<td>compile time</td>
<td></td>
</tr>
<tr>
<td><code>X u;</code></td>
<td>post: <code>u.size() == 0</code></td>
<td>constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td><code>X();</code></td>
<td><code>X().size() == 0</code></td>
<td>constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td><code>X(a);</code></td>
<td><code>a == X(a)</code></td>
<td>linear</td>
<td></td>
<td></td>
</tr>
<tr>
<td><code>X u(a);</code></td>
<td>post: <code>u == a</code></td>
<td>linear</td>
<td></td>
<td></td>
</tr>
<tr>
<td><code>X u = a;</code></td>
<td>Equivalent to: <code>X u; u = a;</code></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(<code>a</code>)-&gt;~<code>X();</code></td>
<td>void</td>
<td>note: the destructor is applied to every element of <code>a</code>; all the memory is deallocated.</td>
<td>linear</td>
<td></td>
</tr>
<tr>
<td><code>a.begin();</code></td>
<td>iterator; <code>const_-iterator</code> for constant <code>a</code></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Draft
<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>a.end();</code></td>
<td>iterator; <code>const_iterator</code> for constant <code>a</code></td>
<td></td>
<td></td>
<td>constant</td>
</tr>
<tr>
<td><code>a.cbegin();</code></td>
<td><code>const_iterator</code></td>
<td><code>const_cast&lt;X const&amp;&gt;(a).begin();</code></td>
<td></td>
<td>constant</td>
</tr>
<tr>
<td><code>a.cend();</code></td>
<td><code>const_iterator</code></td>
<td><code>const_cast&lt;X const&amp;&gt;(a).end();</code></td>
<td></td>
<td>constant</td>
</tr>
<tr>
<td><code>a == b</code></td>
<td>convertible to <code>bool</code></td>
<td><code>==</code> is an equivalence relation. <code>a.size() == b.size()</code> &amp; <code>equal(a.begin(), a.end(), b.begin())</code></td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a != b</code></td>
<td>convertible to <code>bool</code></td>
<td>Equivalent to: <code>!(a == b)</code></td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a.swap(b);</code></td>
<td><code>void</code></td>
<td><code>swap(a,b)</code> (Note A)</td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>r = a X&amp;</code></td>
<td><code>size_type</code></td>
<td><code>a.end() - a.begin()</code> (Note A)</td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a.size()</code></td>
<td><code>size_type</code></td>
<td><code>size() of the largest possible container</code> (Note A)</td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a.empty()</code></td>
<td>convertible to <code>bool</code></td>
<td><code>a.size() == 0</code></td>
<td></td>
<td>constant</td>
</tr>
<tr>
<td><code>a &lt; b</code></td>
<td>convertible to <code>bool</code></td>
<td>lexicographical_ordering. <code>compare(a.begin(), a.end(), b.begin(), b.end())</code> pre: <code>&lt;</code> is defined for values of <code>T</code>. <code>&lt;</code> is a total ordering relationship.</td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a &gt; b</code></td>
<td>convertible to <code>bool</code></td>
<td><code>b &lt; a</code></td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a &lt;= b</code></td>
<td>convertible to <code>bool</code></td>
<td><code>!(a &gt; b)</code></td>
<td></td>
<td>linear</td>
</tr>
<tr>
<td><code>a &gt;= b</code></td>
<td>convertible to <code>bool</code></td>
<td><code>!(a &lt; b)</code></td>
<td></td>
<td>linear</td>
</tr>
</tbody>
</table>

Notes: the algorithms `swap()`, `equal()` and `lexicographical_compare()` are defined in clause 25. Those entries marked “(Note A)” should have constant complexity.

6 The member function `size()` returns the number of elements in the container. Its semantics is defined by the rules of constructors, inserts, and erases.

7 `begin()` returns an iterator referring to the first element in the container. `end()` returns an iterator which is the past-
the-end value for the container. If the container is empty, then \texttt{begin()} == \texttt{end()};

8 In the expressions

\begin{verbatim}
i == j
i != j
i < j
i <= j
i > j
i >= j
i - j
\end{verbatim}

where \texttt{i} and \texttt{j} denote objects of a container's \texttt{iterator} type, either or both may be replaced by an object of the container's \texttt{const_iterator} type referring to the same element with no change in semantics.

9 Copy constructors for all container types defined in this clause copy an allocator argument from their respective first parameters. All other constructors for these container types take an \texttt{Allocator} argument (20.1.6), an allocator whose value type is the same as the container's value type. A copy of this argument is used for any memory allocation performed, by these constructors and by all member functions, during the lifetime of each container object. In all container types defined in this clause, the member \texttt{get_allocator()} returns a copy of the \texttt{Allocator} object used to construct the container.\footnote{As specified in 20.1.6, paragraphs 4-5, the semantics described in this clause applies only to the case where allocators compare equal.}

10 If the iterator type of a container belongs to the bidirectional or random access iterator categories (24.1), the container is called \textit{reversible} and satisfies the additional requirements in Table 81.

Table 81: Reversible container requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{X::reverse_iterator}</td>
<td>iterator type pointing to \texttt{T}</td>
<td>\texttt{reverse_iterator&lt;iterator&gt;}</td>
<td>compile time</td>
</tr>
<tr>
<td>\texttt{X::const_reverse_iterator}</td>
<td>iterator type pointing to const \texttt{T}</td>
<td>\texttt{reverse_iterator&lt;const_iterator&gt;}</td>
<td>compile time</td>
</tr>
<tr>
<td>\texttt{a.rbegin()}</td>
<td>\texttt{reverse_iterator}; const_reverse_iterator for constant \texttt{a}</td>
<td>\texttt{reverse_iterator(end())}</td>
<td>constant</td>
</tr>
<tr>
<td>\texttt{a.rend()}</td>
<td>\texttt{reverse_iterator}; const_reverse_iterator for constant \texttt{a}</td>
<td>\texttt{reverse_iterator(begin())}</td>
<td>constant</td>
</tr>
<tr>
<td>\texttt{a.crbegin()}</td>
<td>const_reverse_iterator</td>
<td>const_cast\textlt;\texttt{X} \texttt{const&amp;}\texttt{&gt;(a).rbegin()};</td>
<td>constant</td>
</tr>
<tr>
<td>\texttt{a.crend()}</td>
<td>const_reverse_iterator</td>
<td>const_cast\textlt;\texttt{X} \texttt{const&amp;}\texttt{&gt;(a).rend()};</td>
<td>constant</td>
</tr>
</tbody>
</table>

11 Unless otherwise specified (see 23.2.2.3 and 23.2.5.4) all container types defined in this clause meet the following
additional requirements:
— if an exception is thrown by an `insert()` function while inserting a single element, that function has no effects.
— if an exception is thrown by a `push_back()` or `push_front()` function, that function has no effects.
— no `erase()`, `pop_back()` or `pop_front()` function throws an exception.
— no copy constructor or assignment operator of a returned iterator throws an exception.
— no `swap()` function throws an exception unless that exception is thrown by the copy constructor or assignment operator of the container’s Compare object (if any; see 23.1.2).
— no `swap()` function invalidates any references, pointers, or iterators referring to the elements of the containers being swapped.

12 Unless otherwise specified (either explicitly or by defining a function in terms of other functions), invoking a container member function or passing a container as an argument to a library function shall not invalidate iterators to, or change the values of, objects within that container.

### 23.1.1 Sequences

1 A sequence is a kind of container that organizes a finite set of objects, all of the same type, into a strictly linear arrangement. The library provides three basic kinds of sequence containers: `vector`, `list`, and `deque`. It also provides container adaptors that make it easy to construct abstract data types, such as stacks or queues, out of the basic sequence kinds (or out of other kinds of sequences that the user might define).

2 `vector`, `list`, and `deque` offer the programmer different complexity trade-offs and should be used accordingly. `vector` is the type of sequence that should be used by default. `list` should be used when there are frequent insertions and deletions from the middle of the sequence. `deque` is the data structure of choice when most insertions and deletions take place at the beginning or at the end of the sequence.

3 In Tables 82 and 83, `X` denotes a sequence class, `a` denotes a value of `X`, `i` and `j` denote iterators satisfying input iterator requirements, `[i, j)` denotes a valid range, `n` denotes a value of `X::size_type`, `p` denotes a valid iterator to `a`, `q` denotes a valid dereferenceable iterator to `a`, `[q1, q2)` denotes a valid range in `a`, and `t` denotes a value of `X::value_type`.

4 The complexities of the expressions are sequence dependent.

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>X(n, t)</code></td>
<td>iterator</td>
<td>post: <code>size() == n</code> creates a sequence with <code>n</code> copies of <code>t</code></td>
</tr>
<tr>
<td><code>X a(n, t)</code></td>
<td>iterator</td>
<td>post: <code>size() == distance between i and j</code> creates a sequence equal to the range <code>[i, j)</code></td>
</tr>
<tr>
<td><code>a.insert(p, t)</code></td>
<td>iterator</td>
<td>inserts a copy of <code>t</code> before <code>p</code></td>
</tr>
<tr>
<td><code>a.insert(p, n, t)</code></td>
<td>void</td>
<td>inserts <code>n</code> copies of <code>t</code> before <code>p</code></td>
</tr>
</tbody>
</table>

Table 82: Sequence requirements (in addition to container)
## 23.1 Container requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.insert(p, i, j)</td>
<td>void</td>
<td>pre: i and j are not iterators into a. inserts copies of elements in [i, j) before p</td>
</tr>
<tr>
<td>a.erase(q)</td>
<td>iterator</td>
<td>erases the element pointed to by q</td>
</tr>
<tr>
<td>a.erase(q1, q2)</td>
<td>iterator</td>
<td>erases the elements in the range [q1, q2).</td>
</tr>
<tr>
<td>a.clear()</td>
<td>void</td>
<td>erase(begin(), end()) post: size() == 0</td>
</tr>
<tr>
<td>a.assign(i, j)</td>
<td>void</td>
<td>pre: i, j are not iterators into a. Replaces elements in a with a copy of [i, j).</td>
</tr>
<tr>
<td>a.assign(n, t)</td>
<td>void</td>
<td>pre: t is not a reference into a. Replaces elements in a with n copies of t.</td>
</tr>
</tbody>
</table>

5. iterator and const_iterator types for sequences shall be at least of the forward iterator category.

6. The iterator returned from a.insert(p, t) points to the copy of t inserted into a.

7. The iterator returned from a.erase(q) points to the element immediately following q prior to the element being erased. If no such element exists, a.end() is returned.

8. The iterator returned by a.erase(q1, q2) points to the element pointed to by q2 prior to any elements being erased. If no such element exists, a.end() is returned.

9. For every sequence defined in this clause and in clause 21:
   - If the constructor
     ```
     template <class InputIterator>
     X(InputIterator first, InputIterator last,
        const allocator_type& alloc = allocator_type())
     ```
     is called with a type InputIterator that does not qualify as an input iterator, then the constructor will behave as if the overloaded constructor:
     ```
     X(size_type, const value_type& = value_type(),
        const allocator_type& = allocator_type())
     ```
     were called instead, with the arguments static_cast<size_type>(first), last and alloc, respectively.
   - If the member functions of the forms:
     ```
     template <class InputIterator> // such as insert()
     rt fx1(iterator p, InputIterator first, InputIterator last);
     ```
     ```
     template <class InputIterator> // such as append(), assign()
     rt fx2(InputIterator first, InputIterator last);
     ```
     ```
     template <class InputIterator> // such as replace()
     rt fx3(iterator i1, iterator i2, InputIterator first, InputIterator last);
     ```
     Draft
are called with a type InputIterator that does not qualify as an input iterator, then these functions will behave as if the overloaded member functions:

\[
\text{rt fx1(iterator, size\_type, const value\_type&);} \\
\text{rt fx2(size\_type, const value\_type&);} \\
\text{rt fx3(iterator, iterator, size\_type, const value\_type&);} \\
\]

were called instead, with the same arguments.

In the previous paragraph the alternative binding will fail if first is not implicitly convertible to \(X::\text{size\_type}\) or if last is not implicitly convertible to \(X::\text{value\_type}\).

The extent to which an implementation determines that a type cannot be an input iterator is unspecified, except that as a minimum integral types shall not qualify as input iterators.

Table 83 lists sequence operations that are provided for some types of sequential containers but not others. An implementation shall provide these operations for all container types shown in the “container” column, and shall implement them so as to take amortized constant time.

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
<th>container</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.front()</td>
<td>reference; const_reference for constant a</td>
<td>*a.begin()</td>
<td>vector, list, deque</td>
</tr>
</tbody>
</table>
| a.back()     | reference; const\_reference for constant a | { iterator tmp = a.end(); 
  -tmp; 
  return *tmp; } | vector, list, deque |
| a.push\_front(x) | void                             | a.insert(a.begin(), x) | list, deque |
| a.push\_back(x) | void                             | a.insert(a.end(), x) | vector, list, deque |
| a.pop\_front() | void                             | a.erase(a.begin()) | list, deque |
| a.pop\_back() | void                             | { iterator tmp = a.end(); 
  -tmp; 
  a.erase(tmp); } | vector, list, deque |
| a[n]         | reference; const\_reference for constant a | *(a.begin() + n) | vector, deque |
| a.at(n)      | reference; const\_reference for constant a | *(a.begin() + n) | vector, deque |

The member function \(\text{at()}\) provides bounds-checked access to container elements. \(\text{at()}\) throws \text{out\_of\_range} if \(n >= a\text{.size()}\).
23.1 Container requirements

23.1.2 Associative containers

Associative containers provide an ability for fast retrieval of data based on keys. The library provides four basic kinds of associative containers: `set`, `multiset`, `map` and `multimap`.

Each associative container is parameterized on `Key` and an ordering relation `Compare` that induces a strict weak ordering (25.3) on elements of `Key`. In addition, `map` and `multimap` associate an arbitrary type `T` with the `Key`. The object of type `Compare` is called the `comparison object` of a container. This comparison object may be a pointer to function or an object of a type with an appropriate function call operator.

The phrase "equivalence of keys" means the equivalence relation imposed by the comparison and `not` the `operator==` on keys. That is, two keys `k1` and `k2` are considered to be equivalent if for the comparison object `comp`, `comp(k1, k2) == false && comp(k2, k1) == false`. For any two keys `k1` and `k2` in the same container, calling `comp(k1, k2)` shall always return the same value.

An associative container supports `unique keys` if it may contain at most one element for each key. Otherwise, it supports `equivalent keys`. The `set` and `map` classes support unique keys; the `multiset` and `multimap` classes support equivalent keys.

For `set` and `multiset` the value type is the same as the key type. For `map` and `multimap` it is equal to `pair<const Key, T>`. Keys in an associative container are immutable.

Iterator of an associative container is of the bidirectional iterator category. For associative containers where the value type is the same as the key type, both `iterator` and `const_iterator` are constant iterators. It is unspecified whether or not `iterator` and `const_iterator` are the same type.

In Table 84, `X` is an associative container class, `a` is a value of `X`, `a_uniq` is a value of `X` when `X` supports unique keys, and `a_eq` is a value of `X` when `X` supports multiple keys, `i` and `j` satisfy input iterator requirements and refer to elements of `value_type`, `[i,j)` is a valid range, `p` is a valid iterator to `a`, `q` is a valid dereferenceable iterator to `a`, `[q1, q2)` is a valid range in `a`, `t` is a value of `X::value_type`, `k` is a value of `X::key_type` and `c` is a value of type `X::key_compare`.

Table 84: Associative container requirements (in addition to container)

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>X::key_type</code></td>
<td>Key</td>
<td>Key is CopyConstructible and Assignable</td>
<td>compile time</td>
</tr>
<tr>
<td><code>X::key_compare</code></td>
<td>Compare</td>
<td>defaults to less&lt;key_type&gt;</td>
<td>compile time</td>
</tr>
<tr>
<td><code>X::value_compare</code></td>
<td>a binary predicate type</td>
<td>is the same as key_compare for set and multiset; is an ordering relation on pairs induced by the first component (i.e. Key) for map and multimap.</td>
<td>compile time</td>
</tr>
<tr>
<td><code>X(c)</code></td>
<td></td>
<td>constructs an empty container</td>
<td>constant</td>
</tr>
<tr>
<td><code>X a(c);</code></td>
<td></td>
<td>uses <code>c</code> as a comparison object</td>
<td></td>
</tr>
<tr>
<td>expression</td>
<td>return type</td>
<td>assertion/note pre/post-condition</td>
<td>complexity</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>-----------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>( X() )</td>
<td>( X a; )</td>
<td>constructs an empty container; uses ( \text{Compare}() ) as a comparison object</td>
<td>constant</td>
</tr>
<tr>
<td>( X(i,j,c) )</td>
<td>( X a(i,j,c); )</td>
<td>constructs an empty container and inserts elements from the range ([i, j)) into it; uses ( c ) as a comparison object. ( N \log N ) in general (( N ) is the distance from ( i ) to ( j )); linear if ([i, j)) is sorted with ( \text{value_comp}() )</td>
<td>( N \log N )</td>
</tr>
<tr>
<td>( X(i,j) )</td>
<td>( X a(i,j); )</td>
<td>same as above, but uses ( \text{Compare}() ) as a comparison object</td>
<td>same as above</td>
</tr>
<tr>
<td>( a_.key_\text{-comp}() )</td>
<td>( X::\text{key_compare} )</td>
<td>returns the comparison object out of which ( a ) was constructed.</td>
<td>constant</td>
</tr>
<tr>
<td>( a_.value_\text{-comp}() )</td>
<td>( X::\text{value_compare} )</td>
<td>returns an object of ( \text{value_compare} ) constructed out of the comparison object</td>
<td>constant</td>
</tr>
<tr>
<td>( a_.\text{uniq.} ) ( \text{insert}(t) )</td>
<td>( \text{pair&lt;iterator, bool&gt;} )</td>
<td>inserts ( t ) if and only if there is no element in the container with key equivalent to the key of ( t ). The ( \text{bool} ) component of the returned pair is true if and only if the insertion takes place, and the ( \text{iterator} ) component of the pair points to the element with key equivalent to the key of ( t ).</td>
<td>logarithmic</td>
</tr>
<tr>
<td>( a_.\text{eq.} ) ( \text{insert}(t) )</td>
<td>( \text{iterator} )</td>
<td>inserts ( t ) and returns the iterator pointing to the newly inserted element.</td>
<td>logarithmic</td>
</tr>
<tr>
<td>( a_.\text{insert}(p, t) )</td>
<td>( \text{iterator} )</td>
<td>inserts ( t ) if and only if there is no element with key equivalent to the key of ( t ) in containers with unique keys; always inserts ( t ) in containers with equivalent keys. always returns the iterator pointing to the element with key equivalent to the key of ( t ). iterator ( p ) is a hint pointing to where the insert should start to search.</td>
<td>logarithmic in general, but amortized constant if ( t ) is inserted right after ( p ).</td>
</tr>
</tbody>
</table>
### 23.1 Container requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.insert(i, j)</td>
<td>void</td>
<td>pre: i, j are not iterators into a. inserts each element from the range [i, j) if and only if there is no element with key equivalent to the key of that element in containers with unique keys; always inserts that element in containers with equivalent keys.</td>
<td>$N \log(\text{size}() + N)$ ($N$ is the distance from i to j)</td>
</tr>
<tr>
<td>a.erase(k)</td>
<td>size_type</td>
<td>erases all elements in the container with key equivalent to k. returns the number of erased elements.</td>
<td>$\log(\text{size}()) + \text{count}(k)$</td>
</tr>
<tr>
<td>a.erase(q)</td>
<td>iterator</td>
<td>erases the element pointed to by q. Returns an iterator pointing to the element immediately following q prior to the element being erased. If no such element exists, returns a.end().</td>
<td>amortized constant</td>
</tr>
<tr>
<td>a.erase(q1, q2)</td>
<td>iterator</td>
<td>erases all the elements in the range [q1, q2). Returns q2.</td>
<td>$\log(\text{size}()) + N$ where $N$ is the distance from q1 to q2.</td>
</tr>
<tr>
<td>a.clear()</td>
<td>void</td>
<td>erase(a.begin(), a.end()) post: size() == 0</td>
<td>linear in size().</td>
</tr>
<tr>
<td>a.find(k)</td>
<td>iterator;</td>
<td>returns an iterator pointing to an element with the key equivalent to k, or a.end() if such an element is not found</td>
<td>logarithmic</td>
</tr>
<tr>
<td>const_iterator for constant a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.count(k)</td>
<td>size_type</td>
<td>returns the number of elements with key equivalent to k</td>
<td>$\log(\text{size}()) + \text{count}(k)$</td>
</tr>
<tr>
<td>a.lower_bound(k)</td>
<td>iterator;</td>
<td>returns an iterator pointing to the first element with key not less than k, or a.end() if such an element is not found.</td>
<td>logarithmic</td>
</tr>
<tr>
<td>const_iterator for constant a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.upper_bound(k)</td>
<td>iterator;</td>
<td>returns an iterator pointing to the first element with key greater than k, or a.end() if such an element is not found.</td>
<td>logarithmic</td>
</tr>
<tr>
<td>const_iterator for constant a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.equal_range(k)</td>
<td>pair&lt;iterator, iterator&gt;; pair&lt;const_iterator, const_iterator&gt; for constant a.</td>
<td>equivalent to make_pair(a.lower_bound(k), a.upper_bound(k)).</td>
<td>logarithmic</td>
</tr>
</tbody>
</table>
The insert members shall not affect the validity of iterators and references to the container, and the erase members shall invalidate only iterators and references to the erased elements.

The fundamental property of iterators of associative containers is that they iterate through the containers in the non-descending order of keys where non-descending is defined by the comparison that was used to construct them. For any two dereferenceable iterators `i` and `j` such that distance from `i` to `j` is positive, 

\[ \text{value_comp}(*j, *i) == \text{false} \]

For associative containers with unique keys the stronger condition holds,

\[ \text{value_comp}(*i, *j) \neq \text{false}. \]

When an associative container is constructed by passing a comparison object the container shall not store a pointer or reference to the passed object, even if that object is passed by reference. When an associative container is copied, either through a copy constructor or an assignment operator, the target container shall then use the comparison object from the container being copied, as if that comparison object had been passed to the target container in its constructor.

### 23.1.3 Unordered associative containers

Unordered associative containers provide an ability for fast retrieval of data based on keys. The worst-case complexity for most operations is linear, but the average case is much faster. The library provides four unordered associative containers: `unordered_set`, `unordered_map`, `unordered_multiset`, and `unordered_multimap`.

Unordered associative containers conform to the requirements for Containers ([lib.container.requirements]), except that the expressions in table 85 are not required to be valid, where `a` and `b` denote values of a type `X`, and `X` is an unordered associative container class:

Table 85: Container requirements that are not required for unordered associative containers

<table>
<thead>
<tr>
<th>unsupported expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>a == b</code></td>
</tr>
<tr>
<td><code>a != b</code></td>
</tr>
<tr>
<td><code>a &lt; b</code></td>
</tr>
<tr>
<td><code>a &gt; b</code></td>
</tr>
<tr>
<td><code>a &lt;= b</code></td>
</tr>
<tr>
<td><code>a &gt;= b</code></td>
</tr>
</tbody>
</table>

Each unordered associative container is parameterized by `Key`, by a function object `Hash` that acts as a hash function for values of type `Key`, and by a binary predicate `Pred` that induces an equivalence relation on values of type `Key`. Additionally, `unordered_map` and `unordered_multimap` associate an arbitrary `mapped type T` with the `Key`.

A hash function is a function object that takes a single argument of type `Key` and returns a value of type `std::size_t`.

Two values `k1` and `k2` of type `Key` are considered equal if the container’s equality function object returns `true` when passed those values. If `k1` and `k2` are equal, the hash function shall return the same value for both.

An unordered associative container supports `unique keys` if it may contain at most one element for each key. Otherwise, it supports `equivalent keys`. `unordered_set` and `unordered_map` support unique keys. `unordered_multiset` and

Draft
23.1 Container requirements

unordered_multimap support equivalent keys. In containers that support equivalent keys, elements with equivalent keys are adjacent to each other.

7 For unordered_set and unordered_multiset the value type is the same as the key type. For unordered_map and unordered_multimap it is std::pair<const Key, T>.

8 The elements of an unordered associative container are organized into buckets. Keys with the same hash code appear in the same bucket. The number of buckets is automatically increased as elements are added to an unordered associative container, so that the average number of elements per bucket is kept below a bound. Rehashing invalidates iterators, changes ordering between elements, and changes which buckets elements appear in, but does not invalidate pointers or references to elements.

9 In table 86: X is an unordered associative container class, a is an object of type X, b is a possibly const object of type X, auniq is an object of type X when X supports unique keys, a_eq is an object of type X when X supports equivalent keys, i and j are input iterators that refer to value_type, [i, j] is a valid range, p and q2 are valid iterators to a, q and q1 are valid dereferenceable iterators to a, [q1, q2) is a valid range in a, r and r1 are valid dereferenceable const iterators to a, r2 is a valid const iterator to a, [r1, r2) is a valid range in a, t is a value of type X::value_type, k is a value of type key_type, hf is a possibly const value of type hasher, eq is a possibly const value of type key_equal, n is a value of type size_type, and z is a value of type float.

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>X::key_type</td>
<td>Key</td>
<td>Key shall be Assignable and CopyConstructible</td>
<td>compile time</td>
</tr>
<tr>
<td>X::hasher</td>
<td>Hash</td>
<td>Hash shall be a unary function object type such that the expression hf(k) has type std::size_t.</td>
<td>compile time</td>
</tr>
<tr>
<td>X::key_equal</td>
<td>Pred</td>
<td>Pred shall be a binary predicate that takes two arguments of type Key. Pred is an equivalence relation.</td>
<td>compile time</td>
</tr>
<tr>
<td>X::local_iterator</td>
<td>An iterator type whose category, value type, difference type, and pointer and reference types are the same as X::iterator's.</td>
<td>A local_iterator object may be used to iterate through a single bucket, but may not be used to iterate across buckets.</td>
<td>compile time</td>
</tr>
<tr>
<td>X::const_local_iterator</td>
<td>An iterator type whose category, value type, difference type, and pointer and reference types are the same as X::const_iterator's.</td>
<td>A const_local_iterator object may be used to iterate through a single bucket, but may not be used to iterate across buckets.</td>
<td>compile time</td>
</tr>
</tbody>
</table>

Table 86: Unordered associative container requirements (in addition to container)
<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>X(n, hf, eq)</td>
<td>X</td>
<td>Constructs an empty container with at least n buckets, using hf as the hash function and eq as the key equality predicate.</td>
<td>( \mathcal{O}(n) )</td>
</tr>
<tr>
<td>X a(n, hf, eq)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X(n, hf)</td>
<td>X</td>
<td>Constructs an empty container with at least n buckets, using hf as the hash function and key_equal() as the key equality predicate.</td>
<td>( \mathcal{O}(n) )</td>
</tr>
<tr>
<td>X a(n, hf)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X(n)</td>
<td>X</td>
<td>Constructs an empty container with at least n buckets, using hasher() as the hash function and key_equal() as the key equality predicate.</td>
<td>( \mathcal{O}(n) )</td>
</tr>
<tr>
<td>X a(n)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X()</td>
<td>X</td>
<td>Constructs an empty container with an unspecified number of buckets, using hasher() as the hash function and key_equal() as the key equality predicate.</td>
<td>constant</td>
</tr>
<tr>
<td>X a</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X(i, j, n, hf, eq)</td>
<td>X</td>
<td>Constructs an empty container with at least n buckets, using hf as the hash function and eq as the key equality predicate, and inserts elements from ([i, j)) into it.</td>
<td>( \mathcal{O}(N) ) ((N) is distance(i, j)), worst case ( \mathcal{O}(N^2) )</td>
</tr>
<tr>
<td>X a(i, j, n, hf, eq)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X(i, j, n, hf)</td>
<td>X</td>
<td>Constructs an empty container with at least n buckets, using hf as the hash function and key_equal() as the key equality predicate, and inserts elements from ([i, j)) into it.</td>
<td>( \mathcal{O}(N) ) ((N) is distance(i, j)), worst case ( \mathcal{O}(N^2) )</td>
</tr>
<tr>
<td>X a(i, j, n, hf)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X(i, j, n)</td>
<td>X</td>
<td>Constructs an empty container with at least n buckets, using hasher() as the hash function and key_equal() as the key equality predicate, and inserts elements from ([i, j)) into it.</td>
<td>( \mathcal{O}(N) ) ((N) is distance(i, j)), worst case ( \mathcal{O}(N^2) )</td>
</tr>
<tr>
<td>X a(i, j, n)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X(i, j)</td>
<td>X</td>
<td>Constructs an empty container with an unspecified number of buckets, using hasher() as the hash function and key_equal() as the key equality predicate, and inserts elements from ([i, j)) into it.</td>
<td>( \mathcal{O}(N) ) ((N) is distance(i, j)), worst case ( \mathcal{O}(N^2) )</td>
</tr>
<tr>
<td>X a(i, j)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## 23.1 Container requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>X(b)</td>
<td>X</td>
<td>Copy constructor. In addition to the contained elements, copies the hash function, predicate, and maximum load factor.</td>
<td>Average case linear in b.size(), worst case quadratic.</td>
</tr>
<tr>
<td>X a(b)</td>
<td>X</td>
<td>Copy assignment operator. In addition to the contained elements, copies the hash function, predicate, and maximum load factor.</td>
<td>Average case linear in b.size(), worst case quadratic.</td>
</tr>
<tr>
<td>a = b</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.hash_function()</td>
<td>hasher</td>
<td>Returns b’s hash function.</td>
<td>constant</td>
</tr>
<tr>
<td>b.key_eq()</td>
<td>key_equal</td>
<td>Returns b’s key equality predicate.</td>
<td>constant</td>
</tr>
<tr>
<td>a uniq.insert(t)</td>
<td>pair&lt;iterator, bool&gt;</td>
<td>Inserts t if and only if there is no element in the container with key equivalent to the key of t. The bool component of the returned pair indicates whether the insertion takes place, and the iterator component points to the element with key equivalent to the key of t.</td>
<td>Average case $\Theta(1)$, worst case $\Theta(a uniq.size())$.</td>
</tr>
<tr>
<td>a_eq.insert(t)</td>
<td>iterator</td>
<td>Inserts t, and returns an iterator pointing to the newly inserted element.</td>
<td>Average case $\Theta(1)$, worst case $\Theta(a_eq.size())$.</td>
</tr>
<tr>
<td>a.insert(q, t)</td>
<td>iterator</td>
<td>Equivalent to a.insert(t). Return value is an iterator pointing to the element with the key equivalent to that of t. The iterator q is a hint pointing to where the search should start. Implementations are permitted to ignore the hint.</td>
<td>Average case $\Theta(1)$, worst case $\Theta(a.size())$.</td>
</tr>
<tr>
<td>a.insert(r, t)</td>
<td>const_iterator</td>
<td>Equivalent to a.insert(t). Return value is an iterator pointing to the element with the key equivalent to that of t. The iterator r is a hint pointing to where the search should start. Implementations are permitted to ignore the hint.</td>
<td>Average case $\Theta(1)$, worst case $\Theta(a.size())$.</td>
</tr>
<tr>
<td>a.insert(i, j)</td>
<td>void</td>
<td>Pre: i and j are not iterators in a. Equivalent to a.insert(t) for each element in [i, j).</td>
<td>Average case $\Theta(N)$, where N is distance(i, j). Worst case $\Theta(N * a.size())$.</td>
</tr>
<tr>
<td>expression</td>
<td>return type</td>
<td>assertion/note pre/post-condition</td>
<td>complexity</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>a.erase(k)</td>
<td>size_type</td>
<td>Erases all elements with key</td>
<td>Average case</td>
</tr>
<tr>
<td></td>
<td></td>
<td>equivalent to k. Returns the</td>
<td>O(a.count(k)).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>number of elements erased.</td>
<td>Worst case</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O(a.size()).</td>
</tr>
<tr>
<td>a.erase(q)</td>
<td>iterator</td>
<td>Erases the element pointed to by q.</td>
<td>Average case</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return value is the iterator</td>
<td>O(1), worst case</td>
</tr>
<tr>
<td></td>
<td></td>
<td>immediately following q prior to</td>
<td>O(a.size()).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the erasure.</td>
<td></td>
</tr>
<tr>
<td>a.erase(r)</td>
<td>const_iterator</td>
<td>Erases the element pointed to by r.</td>
<td>Average case</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return value is the iterator</td>
<td>O(1), worst case</td>
</tr>
<tr>
<td></td>
<td></td>
<td>immediately following r prior to</td>
<td>O(a.size()).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the erasure.</td>
<td></td>
</tr>
<tr>
<td>a.erase(q1, q2)</td>
<td>iterator</td>
<td>Erases all elements in the range [q1, q2]. Return value is the iterator immediately following the erased elements prior to the erasure.</td>
<td>Average case linear in distance(q1, q2), worst case O(a.size()).</td>
</tr>
<tr>
<td>a.erase(r1, r2)</td>
<td>const_iterator</td>
<td>Erases all elements in the range [r1, r2]. Return value is the iterator immediately following the erased elements prior to the erasure.</td>
<td>Average case linear in distance(r1, r2), worst case O(a.size()).</td>
</tr>
<tr>
<td>a.clear()</td>
<td>void</td>
<td>Erases all elements in the container. Post: a.size() == 0</td>
<td>Linear.</td>
</tr>
<tr>
<td>b.find(k)</td>
<td>iterator; const_iterator for const b.</td>
<td>Returns an iterator pointing to an element with key equivalent to k, or b.end() if no such element exists.</td>
<td>Average case O(1), worst case O(b.size()).</td>
</tr>
<tr>
<td>b.count(k)</td>
<td>size_type</td>
<td>Returns the number of elements with key equivalent to k.</td>
<td>Average case O(1), worst case O(b.size()).</td>
</tr>
<tr>
<td>b.equal_range(k)</td>
<td>pair&lt;iterator, iterator&gt;; pair&lt;const_iterator, const_iterator&gt; for const b.</td>
<td>Returns a range containing all elements with keys equivalent to k. Returns make_pair(b.end(), b.end()) if no such elements exist.</td>
<td>Average case O(b.count(k)). Worst case O(b.size()).</td>
</tr>
<tr>
<td>b.bucket_count()</td>
<td>size_type</td>
<td>Returns the number of buckets that b contains.</td>
<td>Constant</td>
</tr>
<tr>
<td>b.max_bucket_count()</td>
<td>size_type</td>
<td>Returns an upper bound on the number of buckets that b might ever contain.</td>
<td>Constant</td>
</tr>
</tbody>
</table>
### 23.1 Container requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>assertion/note pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>b.bucket(k)</code></td>
<td><code>size_type</code></td>
<td>Returns the index of the bucket in which elements with keys equivalent to <code>k</code> would be found, if any such element existed. Post: the return value shall be in the range <code>[0, b.bucket_count())</code>.</td>
<td>Constant</td>
</tr>
<tr>
<td><code>b.bucket_size(n)</code></td>
<td><code>size_type</code></td>
<td>Pre: <code>n</code> shall be in the range <code>[0, b.bucket_count())</code>. Returns the number of elements in the <code>n</code>th bucket.</td>
<td>( \Theta(b.bucket_size(n)) )</td>
</tr>
<tr>
<td><code>b.begin(n)</code></td>
<td><code>local_iterator</code>; const_local_iterator for <code>const b</code>.</td>
<td>Pre: <code>n</code> shall be in the range <code>[0, b.bucket_count())</code>. Note: <code>[b.begin(n), b.end(n))</code> is a valid range containing all of the elements in the <code>n</code>th bucket.</td>
<td>Constant</td>
</tr>
<tr>
<td><code>b.end(n)</code></td>
<td><code>local_iterator</code>; const_local_iterator for <code>const b</code>.</td>
<td>Pre: <code>n</code> shall be in the range <code>[0, b.bucket_count())</code>.</td>
<td>Constant</td>
</tr>
<tr>
<td><code>b.load_factor()</code></td>
<td><code>float</code></td>
<td>Returns the average number of elements per bucket.</td>
<td>Constant</td>
</tr>
<tr>
<td><code>b.max_load_factor()</code></td>
<td><code>float</code></td>
<td>Returns a positive number that the container attempts to keep the load factor less than or equal to. The container automatically increases the number of buckets as necessary to keep the load factor below this number.</td>
<td>Constant</td>
</tr>
<tr>
<td><code>a.max_load_factor(z)</code></td>
<td><code>void</code></td>
<td>Pre: <code>z</code> shall be positive. Changes the container’s maximum load load factor, using <code>z</code> as a hint.</td>
<td>Constant</td>
</tr>
<tr>
<td><code>a.rehash(n)</code></td>
<td><code>void</code></td>
<td>Post: ( a.bucket_count() &gt; a.size() / a.max_load_factor() ) and ( a.bucket_count() &gt;= n ). Average case linear in ( a.size() ), worst case quadratic.</td>
<td>Average case</td>
</tr>
</tbody>
</table>

10 Unordered associative containers are not required to support the expressions `a == b` or `a != b`. [Note: This is because the container requirements define operator equality in terms of equality of ranges. Since the elements of an unordered associative container appear in an arbitrary order, range equality is not a useful operation. — end note]

11 The iterator types `iterator` and `const_iterator` of an unordered associative container are of at least the forward iterator category. For unordered associative containers where the key type and value type are the same, both `iterator` and `const_iterator` are const iterators.

12 The insert members shall not affect the validity of references to container elements, but may invalidate all iterators to the container. The erase members shall invalidate only iterators and references to the erased elements.

Draft
The insert members shall not affect the validity of iterators if \((N+n) < z \times B\), where \(N\) is the number of elements in the container prior to the insert operation, \(n\) is the number of elements inserted, \(B\) is the container’s bucket count, and \(z\) is the container’s maximum load factor.

### 23.1.3.1 Exception safety guarantees

1. For unordered associative containers, no `clear()` function throws an exception. No `erase()` function throws an exception unless that exception is thrown by the container’s Hash or Pred object (if any).
2. For unordered associative containers, if an exception is thrown by any operation other than the container’s hash function from within an `insert()` function inserting a single element, the `insert()` function has no effect.
3. For unordered associative containers, no `swap` function throws an exception unless that exception is thrown by the copy constructor or copy assignment operator of the container’s Hash or Pred object (if any).
4. For unordered associative containers, if an exception is thrown from within a `rehash()` function other than by the container’s hash function or comparison function, the `rehash()` function has no effect.

### 23.2 Sequences

1. Headers `<array>`, `<deque>`, `<list>`, `<queue>`, `<stack>`, and `<vector>`.

TRI: **Header `<array>` synopsis**

```cpp
namespace std {
    template <class T, size_t N> struct array;
    template <class T, size_t N>
        bool operator==(const array<T,N>& x, const array<T,N>& y);
    template <class T, size_t N>
        bool operator!=(const array<T,N>& x, const array<T,N>& y);
    template <class T, size_t N>
        bool operator<(const array<T,N>& x, const array<T,N>& y);
    template <class T, size_t N>
        bool operator>(const array<T,N>& x, const array<T,N>& y);
    template <class T, size_t N>
        bool operator<=(const array<T,N>& x, const array<T,N>& y);
    template <class T, size_t N>
        bool operator>=(const array<T,N>& x, const array<T,N>& y);
    template <class T, size_t N>
        void swap(array<T,N>& x, array<T,N>& y);

    template <class T> class tuple_size; // forward declaration
    template <int I, class T> class tuple_element; // forward declaration
    template <class T, size_t N>
        struct tuple_size<array<T, N>>;
    template <int I, class T, size_t N>
        struct tuple_element<array<T, N>, I>;
}
```

Draft
struct tuple_element<I, array<T, N> >;
template <int I, class T, size_t N>
T& get(array<T, N>&);
template <int I, class T, size_t N>
const T& get(const array<T, N>&);
} // namespace std

Header <deque> synopsis

namespace std {
template <class T, class Allocator = allocator<T> > class deque;
template <class T, class Allocator>
bool operator==(const deque<T,Allocator>& x, const deque<T,Allocator>& y);
template <class T, class Allocator>
bool operator<(const deque<T,Allocator>& x, const deque<T,Allocator>& y);
template <class T, class Allocator>
bool operator!=(const deque<T,Allocator>& x, const deque<T,Allocator>& y);
template <class T, class Allocator>
bool operator>(const deque<T,Allocator>& x, const deque<T,Allocator>& y);
template <class T, class Allocator>
bool operator>=(const deque<T,Allocator>& x, const deque<T,Allocator>& y);
template <class T, class Allocator>
bool operator<=(const deque<T,Allocator>& x, const deque<T,Allocator>& y);
template <class T, class Allocator>
void swap(deque<T,Allocator>& x, deque<T,Allocator>& y);
}

Header <list> synopsis

namespace std {
template <class T, class Allocator = allocator<T> > class list;
template <class T, class Allocator>
bool operator==(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator<(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator!=(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator>(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator>=(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator<=(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
void swap(list<T,Allocator>& x, list<T,Allocator>& y);
}


Header `<queue>` synopsis

namespace std {
    template <class T, class Container = deque<T> > class queue;
    template <class T, class Container>  
        bool operator==(const queue<T, Container>& x,  
                        const queue<T, Container>& y);
    template <class T, class Container>  
        bool operator<(const queue<T, Container>& x,  
                        const queue<T, Container>& y);
    template <class T, class Container>  
        bool operator!=(const queue<T, Container>& x,  
                        const queue<T, Container>& y);
    template <class T, class Container>  
        bool operator>(const queue<T, Container>& x,  
                        const queue<T, Container>& y);
    template <class T, class Container>  
        bool operator>=(const queue<T, Container>& x,  
                        const queue<T, Container>& y);
    template <class T, class Container>  
        bool operator<=(const queue<T, Container>& x,  
                        const queue<T, Container>& y);

    template <class T, class Container = vector<T>,  
               class Compare = less<typename Container::value_type> >  
        class priority_queue;
}

Header `<stack>` synopsis

namespace std {
    template <class T, class Container = deque<T> > class stack;
    template <class T, class Container>  
        bool operator==(const stack<T, Container>& x,  
                        const stack<T, Container>& y);
    template <class T, class Container>  
        bool operator<(const stack<T, Container>& x,  
                        const stack<T, Container>& y);
    template <class T, class Container>  
        bool operator!=(const stack<T, Container>& x,  
                        const stack<T, Container>& y);
    template <class T, class Container>  
        bool operator>(const stack<T, Container>& x,  
                        const stack<T, Container>& y);
    template <class T, class Container>  
        bool operator>=(const stack<T, Container>& x,  
                        const stack<T, Container>& y);
    template <class T, class Container>  
        bool operator<=(const stack<T, Container>& x,  
                        const stack<T, Container>& y);

    template <class T, class Container = vector<T>,  
               class Compare = less<typename Container::value_type> >  
        class priority_stack;
}
23.2 Sequences

const stack<T, Container>& y);
}

Header <vector> synopsis

namespace std {
    template <class T, class Allocator = allocator<T> > class vector;
    template <class T, class Allocator>
        bool operator==(const vector<T,Allocator>& x,
                       const vector<T,Allocator>& y);
    template <class T, class Allocator>
        bool operator< (const vector<T,Allocator>& x,
                        const vector<T,Allocator>& y);
    template <class T, class Allocator>
        bool operator!=(const vector<T,Allocator>& x,
                        const vector<T,Allocator>& y);
    template <class T, class Allocator>
        bool operator> (const vector<T,Allocator>& x,
                        const vector<T,Allocator>& y);
    template <class T, class Allocator>
        bool operator>=(const vector<T,Allocator>& x,
                        const vector<T,Allocator>& y);
    template <class T, class Allocator>
        bool operator<=(const vector<T,Allocator>& x,
                        const vector<T,Allocator>& y);
    template <class T, class Allocator>
        void swap(vector<T,Allocator>& x, vector<T,Allocator>& y);
    template <class Allocator> class vector<bool,Allocator>;
    template <class Allocator>
        bool operator==(const vector<bool,Allocator>& x,
                        const vector<bool,Allocator>& y);
    template <class Allocator>
        bool operator< (const vector<bool,Allocator>& x,
                        const vector<bool,Allocator>& y);
    template <class Allocator>
        bool operator!=(const vector<bool,Allocator>& x,
                        const vector<bool,Allocator>& y);
    template <class Allocator>
        bool operator> (const vector<bool,Allocator>& x,
                        const vector<bool,Allocator>& y);
    template <class Allocator>
        bool operator>=(const vector<bool,Allocator>& x,
                        const vector<bool,Allocator>& y);
    template <class Allocator>
        bool operator<=(const vector<bool,Allocator>& x,
                        const vector<bool,Allocator>& y);
    template <class Allocator>
        void swap(vector<bool,Allocator>& x, vector<bool,Allocator>& y);
}
23.2.1 TR1: Class template array

The header <array> defines a class template for storing fixed-size sequences of objects. An array supports random access iterators. An instance of array<T, N> stores N elements of type T, so that size() == N is an invariant. The elements of an array are stored contiguously, meaning that if a is an array<T, N> then it obeys the identity &a[n] == &a[0] + n for all 0 <= n < N.

An array is an aggregate (8.5.1) that can be initialized with the syntax

```
array a = { initializer-list };
```

where initializer-list is a comma separated list of up to N elements whose types are convertible to T.

Unless otherwise specified, all array operations are as described in 23.1. Descriptions are provided here only for operations on array that are not described in that clause or for operations where there is additional semantic information.

The effect of calling front() or back() for a zero-sized array is implementation defined.

```c
namespace std {
    template <class T, size_t N>
    struct array {
        // types:
        typedef T & reference;
        typedef const T & const_reference;
        typedef implementation defined iterator;
        typedef implementation defined const_iterator;
        typedef size_t size_type;
        typedef ptrdiff_t difference_type;
        typedef T value_type;
        typedef std::reverse_iterator<iterator> reverse_iterator;
        typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

        T elems[N];    // Exposition only

        // No explicit construct/copy/destroy for aggregate type

        void assign(const T& u);
        void swap(array<T, N>&);

        // iterators:
        iterator begin();
        const_iterator begin() const;
        iterator end();
        const_iterator end() const;
        reverse_iterator rbegin();
        const_reverse_iterator rbegin() const;
        reverse_iterator rend();
        const_reverse_iterator rend() const;
        const_iterator cbegin() const;
    };
}
```

Draft
23.2 Sequences

const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// capacity:
size_type size() const;
size_type max_size() const;
bool empty() const;

// element access:
reference operator[](size_type n);
const_reference operator[](size_type n) const;
const_reference at(size_type n);
reference at(size_type n);
reference front();
const_reference front() const;
reference back();
const_reference back() const;

T * data();
const T * data() const;

[Note: The member variable elems is shown for exposition only, to emphasize that array is a class aggregate. The name elems is not part of array’s interface. — end note]

23.2.1.1 array constructors, copy, and assignment [lib.array.cons]

The conditions for an aggregate (8.5.1) shall be met. Class array relies on the implicitly-declared special member functions (12.1, 12.4, and 12.8) to conform to the container requirements table in 23.1.

23.2.1.2 array specialized algorithms [lib.array.special]

template <class T, size_t N> void swap(array<T,N>& x, array<T,N>& y);

Effects:
swap_ranges(x.begin(), x.end(), y.begin());

23.2.1.3 array size [lib.array.size]

template <class T, size_t N> size_type array<T,N>::size();

Returns: N

23.2.1.4 array::data [lib.array.data]

T *data();
const T *data() const;
23.2.1.5 Zero sized arrays

array shall provide support for the special case \( N == 0 \).

In the case that \( N == 0 \), \begin{function}() \end{function} == \begin{function}end() \end{function} == unique value. The return value of \begin{function}data() \end{function} is unspecified.

23.2.1.6 Tuple interface to class template array

tuple_size<array<T, N> >::value

Return type: integral constant expression.

Value: \( N \)

tuple_element<I, array<T, N> >::type

Requires: \( 0 <= I < N \). The program is ill-formed if \( I \) is out of bounds.

value: The type \( T \).

template <int I, class T, size_t N> T& get(array<T, N>& a);

Requires: \( 0 <= I < N \). The program is ill-formed if \( I \) is out of bounds.

Returns: A reference to the \( I \)th element of \( a \), where indexing is zero-based.

template <int I, class T, size_t N> const T& get(const array<T, N>& a);

Requires: \( 0 <= I < N \). The program is ill-formed if \( I \) is out of bounds.

Return type: const T&.

Returns: A const reference to the \( I \)th element of \( a \), where indexing is zero-based.

23.2.2 Class template deque

A deque is a kind of sequence that, like a vector (23.2.5), supports random access iterators. In addition, it supports constant time insert and erase operations at the beginning or the end; insert and erase in the middle take linear time. That is, a deque is especially optimized for pushing and popping elements at the beginning and end. As with vectors, storage management is handled automatically.

A deque satisfies all of the requirements of a container and of a reversible container (given in tables in 23.1) and of a sequence, including the optional sequence requirements (23.1.1). In addition to the requirements on the stored object described in 23.1, the stored object shall meet the requirements of Assignable. Descriptions are provided here only for operations on deque that are not described in one of these tables or for operations where there is additional semantic information.

namespace std {
    template <class T, class Allocator = allocator<T> >
    class deque {
        public:

Draft
23.2 Sequences

// types:
typedef typename Allocator::reference reference;
typedef typename Allocator::const_reference const_reference;
typedef implementation-defined iterator;     // See 23.1
typedef implementation-defined const_iterator;   // See 23.1
typedef implementation-defined size_type;       // See 23.1
typedef implementation-defined difference_type;// See 23.1
typedef T value_type;
typedef Allocator allocator_type;
typedef typename Allocator::pointer pointer;
typedef typename Allocator::const_pointer const_pointer;
typedef std::reverse_iterator<iterator> reverse_iterator;
typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

// 23.2.2.1 construct/copy/destroy:
explicit deque(const Allocator& = Allocator());
explicit deque(size_type n, const T& value = T(),
    const Allocator& = Allocator());
template <class InputIterator>
    deque(InputIterator first, InputIterator last,
    const Allocator& = Allocator());
deque(const deque<T,Allocator>& x);
~deque();
deque<T, Allocator>& operator=(const deque<T, Allocator>& x);
template <class InputIterator>
    void assign(InputIterator first, InputIterator last);
void assign(size_type n, const T& t);
allocator_type get_allocator() const;

// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;
const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// 23.2.2.2 capacity:
size_type size() const;
size_type max_size() const;
void resize(size_type sz, T c = T());
bool empty() const;
// element access:
reference operator[](size_type n);
const_reference operator[](size_type n) const;
reference at(size_type n);
const_reference at(size_type n) const;
reference front();
const_reference front() const;
reference back();
const_reference back() const;

// 23.2.2.3 modifiers:
void push_front(const T& x);
void push_back(const T& x);

iterator insert(iterator position, const T& x);
void insert(iterator position, size_type n, const T& x);
template<class InputIterator>
void insert (iterator position,
            InputIterator first, InputIterator last);

void pop_front();
void pop_back();

iterator erase(iterator position);
iterator erase(iterator first, iterator last);
void swap(deque<T,Allocator>&);
void clear();
};

template<class T, class Allocator>
bool operator==(const deque<T,Allocator>& x,
                const deque<T,Allocator>& y);

template<class T, class Allocator>
bool operator<(const deque<T,Allocator>& x,
               const deque<T,Allocator>& y);

template<class T, class Allocator>
bool operator!=(const deque<T,Allocator>& x,
               const deque<T,Allocator>& y);

template<class T, class Allocator>
bool operator>(const deque<T,Allocator>& x,
               const deque<T,Allocator>& y);

template<class T, class Allocator>
bool operator>=(const deque<T,Allocator>& x,
               const deque<T,Allocator>& y);

template<class T, class Allocator>
bool operator<=(const deque<T,Allocator>& x,
               const deque<T,Allocator>& y);

// specialized algorithms:

Draft
23.2 Sequences Containers library

```cpp
void swap(deque<T, Allocator>& x, deque<T, Allocator>& y);
```

23.2.2.1 deque constructors, copy, and assignment

```cpp
explicit deque(const Allocator& = Allocator());
```

**Effects:** Constructs an empty deque, using the specified allocator.

**Complexity:** Constant.

```cpp
explicit deque(size_type n, const T& value = T(),
               const Allocator& = Allocator());
```

**Effects:** Constructs a deque with `n` copies of `value`, using the specified allocator.

**Complexity:** Linear in `n`.

```cpp
template <class InputIterator>
deque(InputIterator first, InputIterator last,
      const Allocator& = Allocator());
```

**Effects:** Constructs a deque equal to the range `[first, last)`, using the specified allocator.

**Complexity:** Makes `distance(first, last)` calls to the copy constructor of `T`. 262

```cpp
template <class InputIterator>
void assign(InputIterator first, InputIterator last);
```

**Effects:**
- `erase(begin(), end());`
- `insert(begin(), first, last);`

```cpp
void assign(size_type n, const T& t);
```

**Effects:**
- `erase(begin(), end());`
- `insert(begin(), n, t);`

23.2.2.2 deque capacity

```cpp
void resize(size_type sz, T c = T());
```

**Effects:**
- if `(sz > size())`
  * `insert(end(), sz-size(), c);`
- else if `(sz < size())`
  * `erase(begin()+sz, end());`

262 This footnote is intentionally empty.
else
    ;  // do nothing

23.2.2.3  deque modifiers

iterator insert(iterator position, const T& x);
void       insert(iterator position, size_type n, const T& x);
template <class InputIterator>
    void insert(iterator position,
                InputIterator first, InputIterator last);

Effects: An insert in the middle of the deque invalidates all the iterators and references to elements of the deque. An insert at either end of the deque invalidates all the iterators to the deque, but has no effect on the validity of references to elements of the deque.

Remarks: If an exception is thrown other than by the copy constructor or assignment operator of T there are no effects.

Complexity: In the worst case, inserting a single element into a deque takes time linear in the minimum of the distance from the insertion point to the beginning of the deque and the distance from the insertion point to the end of the deque. The complexity is linear in the number of elements inserted plus the lesser of the distances to the beginning and end of the deque. Inserting a single element either at the beginning or end of a deque always takes constant time and causes a single call to the copy constructor of T.

iterator erase(iterator position);
iterator erase(iterator first, iterator last);

Effects: An erase in the middle of the deque invalidates all the iterators and references to elements of the deque. An erase at either end of the deque invalidates only the iterators and the references to the erased elements.

Complexity: The number of calls to the destructor is the same as the number of elements erased, but the number of the calls to the assignment operator is at most equal to the minimum of the number of elements before the erased elements and the number of elements after the erased elements.

Throws: Nothing unless an exception is thrown by the copy constructor or assignment operator of T.

23.2.2.4  deque specialized algorithms

template <class T, class Allocator>
    void swap(deque<T,Allocator>& x, deque<T,Allocator>& y);

Effects:
    x.swap(y);
23.2.3 Class template list

A list is a kind of sequence that supports bidirectional iterators and allows constant time insert and erase operations anywhere within the sequence, with storage management handled automatically. Unlike vectors (23.2.5) and deques (23.2.2), fast random access to list elements is not supported, but many algorithms only need sequential access anyway.

A list satisfies all of the requirements of a container and of a reversible container (given in two tables in 23.1) and of a sequence, including most of the the optional sequence requirements (23.1.1). The exceptions are the operator[] and at member functions, which are not provided. list does not require the stored type T to be Assignable unless the following methods are instantiated:

\[
\begin{align*}
\text{list}&<T,\text{Allocator}>&\text{operator}=(\text{const list}&<T,\text{Allocator}>& x); \\
\text{template}&<\text{class InputIterator}>\ &\text{void assign(InputIterator}&\text{first, InputIterator}&\text{last}); \\
&\text{void assign(size_type}&\text{n, const}&T&\text{t});
\end{align*}
\]

Descriptions are provided here only for operations on list that are not described in one of these tables or for operations where there is additional semantic information.

```cpp
namespace std {
    template <class T, class Allocator = allocator<T> >
    class list {
        public:
            // types:
            typedef typename Allocator::reference reference;
            typedef typename Allocator::const_reference const_reference;
            typedef implementation-defined iterator; // See 23.1
            typedef implementation-defined const_iterator; // See 23.1
            typedef implementation-defined size_type; // See 23.1
            typedef implementation-defined difference_type; // See 23.1
            typedef T value_type;
            typedef Allocator allocator_type;
            typedef typename Allocator::pointer pointer;
            typedef typename Allocator::const_pointer const_pointer;
            typedef std::reverse_iterator<iterator> reverse_iterator;
            typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

            // 23.2.3.1 construct/copy/destroy:
            explicit list(const Allocator& = Allocator());
            explicit list(size_type n, const T& value = T(),
                          const Allocator& = Allocator());
            template <class InputIterator>
            list(InputIterator first, InputIterator last,
                 const Allocator& = Allocator());
            list(const list<T,Allocator>& x);
            ~list();
            list<T,Allocator>& operator=(const list<T,Allocator>& x);
            template <class InputIterator>
        }
    }
}
```

---

263 These member functions are only provided by containers whose iterators are random access iterators.

264 Implementors are permitted but not required to take advantage of T’s Assignable properties for these methods.
void assign(InputIterator first, InputIterator last);
void assign(size_type n, const T& t);
allocator_type get_allocator() const;

// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;

const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// 23.2.3.2 capacity:
bool empty() const;
size_type size() const;
size_type max_size() const;
void resize(size_type sz, T c = T());

// element access:
reference front();
const_reference front() const;
reference back();
const_reference back() const;

// 23.2.3.3 modifiers:
void push_front(const T& x);
void pop_front();
void push_back(const T& x);
void pop_back();

iterator insert(iterator position, const T& x);
void insert(iterator position, size_type n, const T& x);
template <class InputIterator>
void insert(iterator position, InputIterator first,
            InputIterator last);

iterator erase(iterator position);
iterator erase(iterator position, iterator last);
void swap(list<T,Allocator>&);
void clear();

// 23.2.3.4 list operations:
void splice(iterator position, list<T,Allocator>& x);
void splice(iterator position, list<T,Allocator>& x, iterator i);
void splice(iterator position, list<T,Allocator>& x, iterator first, iterator last);

void remove(const T& value);
template <class Predicate> void remove_if(Predicate pred);

void unique();
template <class BinaryPredicate>
void unique(BinaryPredicate binary_pred);

void merge(list<T,Allocator>& x);
template <class Compare>
void merge(list<T,Allocator>& x, Compare comp);

void sort();
template <class Compare>
void sort(Compare comp);

void reverse();
};

template <class T, class Allocator>
bool operator==(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator<(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator!=(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator>(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator>=(const list<T,Allocator>& x, const list<T,Allocator>& y);
template <class T, class Allocator>
bool operator<=(const list<T,Allocator>& x, const list<T,Allocator>& y);

// specialized algorithms:
template <class T, class Allocator>
void swap(list<T,Allocator>& x, list<T,Allocator>& y);

23.2.3.1 list constructors, copy, and assignment

explicit list(const Allocator& = Allocator());

Effects: Constructs an empty list, using the specified allocator.
Complexity: Constant.

explicit list(size_type n, const T& value = T(),
const Allocator& = Allocator());

Effects: Constructs a list with n copies of value, using the specified allocator.
Complexity: Linear in n.

```c
template <class InputIterator>
list(InputIterator first, InputIterator last,
    const Allocator& = Allocator());
```

Effects: Constructs a list equal to the range \([first, last)\).

Complexity: Linear in distance\((first, last)\).

```c
template <class InputIterator>
void assign(InputIterator first, InputIterator last);
```

Effects: Replaces the contents of the list with the range \([first, last)\).

```c
void assign(size_type n, const T& t);
```

Effects: Replaces the contents of the list with \(n\) copies of \(t\).

### 23.2.3.2 list capacity

```c
void resize(size_type sz, T c = T());
```

Effects:

```
if (sz > size())
    insert(end(), sz-size(), c);
else if (sz < size()) {
    iterator i = begin();
    advance(i, sz);
    erase(i, end());
} else
    // do nothing
```

### 23.2.3.3 list modifiers

```c
iterator insert(iterator position, const T& x);
void insert(iterator position, size_type n, const T& x);
template <class InputIterator>
void insert(iterator position, InputIterator first,
            InputIterator last);
```

```c
void push_front(const T& x);
void push_back(const T& x);
```

Remarks: Does not affect the validity of iterators and references. If an exception is thrown there are no effects.

Complexity: Insertion of a single element into a list takes constant time and exactly one call to the copy constructor of \(T\). Insertion of multiple elements into a list is linear in the number of elements inserted, and the number of calls to the copy constructor of \(T\) is exactly equal to the number of elements inserted.

Draft
iterator erase(iterator position);
iterator erase(iterator first, iterator last);
void pop_front();
void pop_back();
void clear();

Effects: Invalidates only the iterators and references to the erased elements.

Throws: Nothing.

Complexity: Erasing a single element is a constant time operation with a single call to the destructor of T. Erasing a range in a list is linear time in the size of the range and the number of calls to the destructor of type T is exactly equal to the size of the range.

23.2.3.4 list operations [lib.list.ops]

Since lists allow fast insertion and erasing from the middle of a list, certain operations are provided specifically for them.\(^{265}\)

list provides three splice operations that destructively move elements from one list to another.

void splice(iterator position, list<T,Allocator>& x);

Requires: &x != this.

Effects: Inserts the contents of x before position and x becomes empty. Pointers and references to the moved elements of x now refer to those same elements but as members of *this. Iterators referring to the moved elements will continue to refer to their elements, but they now behave as iterators into *this, not into x.

Throws: Nothing

Complexity: Constant time.

void splice(iterator position, list<T,Allocator>& x, iterator i);

Effects: Inserts an element pointed to by i from list x before position and removes the element from x. The result is unchanged if position == i or position == ++i. Pointers and references to *i continue to refer to this same element but as a member of *this. Iterators to *i (including i itself) continue to refer to the same element, but now behave as iterators into *this, not into x.

Throws: Nothing

Requires: i is a valid dereferenceable iterator of x.

Complexity: Constant time.

void splice(iterator position, list<T,Allocator>& x, iterator first, iterator last);

---

\(^{265}\) As specified in 20.1.6, the requirements in this clause apply only to lists whose allocators compare equal.
Effects: Inserts elements in the range \([\text{first}, \text{last})\) before \text{position} and removes the elements from \text{x}.

Requires: \([\text{first}, \text{last})\) is a valid range in \text{x}. The result is undefined if \text{position} is an iterator in the range \([\text{first}, \text{last})\). Pointers and references to the moved elements of \text{x} now refer to those same elements but as members of \(*\text{this}*. Iterators referring to the moved elements will continue to refer to their elements, but they now behave as iterators into \(*\text{this}*, not into \text{x}.

Throws: Nothing

Complexity: Constant time if \&\text{x} == \text{this}; otherwise, linear time.

\begin{verbatim}
void remove(const \text{T} &value);
\end{verbatim}

Effects: Erases all the elements in the list referred by a list iterator \text{i} for which the following conditions hold: \text{value} == \text{i} or \text{pred}(*\text{i}) != false.

Throws: Nothing unless an exception is thrown by \text{value} or \text{pred}(*\text{i}) != false.

Remarks: Stable.

Complexity: Exactly size() applications of the corresponding predicate.

\begin{verbatim}
void unique();
\end{verbatim}

\begin{verbatim}
template <\text{class} \text{Predicate}> void remove_if(Predicate \text{pred});
\end{verbatim}

Effects: Eliminates all but the first element from every consecutive group of equal elements referred to by the iterator \text{i} in the range \([\text{first} + 1, \text{last})\) for which \text{value} == \text{i} or \text{pred}(*\text{i}, *(\text{i} - 1)) holds.

Throws: Nothing unless an exception is thrown by \text{value} or \text{pred}(*\text{i}, *(\text{i} - 1)) holds.

Complexity: If the range \([\text{first}, \text{last})\) is not empty, exactly \((\text{last} - \text{first}) - 1\) applications of the corresponding predicate, otherwise no applications of the predicate.

\begin{verbatim}
void merge(list<\text{T},\text{Allocator}> &\text{x});
\end{verbatim}

\begin{verbatim}
template <\text{class} \text{Compare}> void merge(list<\text{T},\text{Allocator}> &\text{x}, \text{Compare} \text{comp});
\end{verbatim}

Requires: \text{comp} defines a strict weak ordering (25.3), and the list and the argument list are both sorted according to this ordering.

Effects: If \&(\text{x} == \text{this}) does nothing; otherwise, merges the two sorted ranges \([\text{begin()}, \text{end}())\) and \([\text{x. begin()}, \text{x. end}())\). The result is a range in which the elements will be sorted in non-decreasing order according to the ordering defined by \text{comp}; that is, for every iterator \text{i}, in the range other than the first, the condition \text{comp}(*\text{i}, *\text{i} - 1) will be false.

Remarks: Stable. If \&\text{x} != \text{this} the range \([\text{x. begin()}, \text{x. end}())\) is empty after the merge.

Complexity: At most size() + \text{x.size()} - 1 applications of \text{comp} if \&(\text{x} != \text{this}); otherwise, no applications of \text{comp} are performed. If an exception is thrown other than by a comparison there are no effects.

\begin{verbatim}
void reverse();
\end{verbatim}

Effects: Reverses the order of the elements in the list.
23.2 Sequences

Containers library

23.2.3.5 list specialized algorithms

template <class T, class Allocator>
void swap(list<T,Allocator>& x, list<T,Allocator>& y);

Effects:

x.swap(y);

23.2.4 Container adaptors

The container adaptors each take a Container template parameter, and each constructor takes a Container reference argument. This container is copied into the Container member of each adaptor.

23.2.4.1 Class template queue

Any sequence supporting operations front(), back(), push_back() and pop_front() can be used to instantiate queue. In particular, list (23.2.3) and deque (23.2.2) can be used.

23.2.4.1.1 queue definition

namespace std {
    template <class T, class Container = deque<T> >
    class queue {
        public:
            typedef typename Container::value_type value_type;
            typedef typename Container::reference reference;
            typedef typename Container::const_reference const_reference;
            typedef typename Container::size_type size_type;
            typedef Container container_type;

        protected:
            Container c;

        public:
            explicit queue(const Container& = Container());

            bool empty() const { return c.empty(); }
    }
}
size_type size() const { return c.size(); }
reference front() { return c.front(); }
const_reference front() const { return c.front(); }
reference back() { return c.back(); }
const_reference back() const { return c.back(); }
void push(const value_type& x) { c.push_back(x); }
void pop() { c.pop_front(); }
};

template <class T, class Container>
bool operator==(const queue<T, Container>& x,
               const queue<T, Container>& y);

template <class T, class Container>
bool operator!=(const queue<T, Container>& x,
               const queue<T, Container>& y);

template <class T, class Container>
bool operator< (const queue<T, Container>& x,
               const queue<T, Container>& y);

template <class T, class Container>
bool operator<=(const queue<T, Container>& x,
                const queue<T, Container>& y);

23.2.4.1.2 queue operators

template <class T, class Container>
bool operator==(const queue<T, Container>& x,
               const queue<T, Container>& y);

template <class T, class Container>
bool operator!=(const queue<T, Container>& x,
               const queue<T, Container>& y);

template <class T, class Container>
bool operator< (const queue<T, Container>& x,
               const queue<T, Container>& y);

template <class T, class Container>
bool operator<=(const queue<T, Container>& x,
                const queue<T, Container>& y);


1 Returns: x.c == y.c.

2 Returns: x.c != y.c.

3 Returns: x.c < y.c.
23.2 Sequences

Containers library

```
const queue<T, Container>& y);
```

**Returns:** \( x.c \leq y.c \).

```
template <class T, class Container>
bool operator> (const queue<T, Container>& x,
const queue<T, Container>& y);
```

**Returns:** \( x.c > y.c \).

```
template <class T, class Container>
bool operator>=(const queue<T, Container>& x,
const queue<T, Container>& y);
```

**Returns:** \( x.c \geq y.c \).

### 23.2.4.2 Class template priority_queue

Any sequence with random access iterator and supporting operations `front()`, `push_back()` and `pop_back()` can be used to instantiate `priority_queue`. In particular, `vector` (23.2.5) and `deque` (23.2.2) can be used. Instantiating `priority_queue` also involves supplying a function or function object for making priority comparisons; the library assumes that the function or function object defines a strict weak ordering (25.3).

```
namespace std {
    template <class T, class Container = vector<T>,
             class Compare = less<typename Container::value_type> >
    class priority_queue {
    public:
        typedef typename Container::value_type value_type;
        typedef typename Container::reference reference;
        typedef typename Container::const_reference const_reference;
        typedef typename Container::size_type size_type;
        typedef Container container_type;

    protected:
        Container c;
        Compare comp;

    public:
        explicit priority_queue(const Compare& x = Compare(),
                                const Container& = Container());
        template <class InputIterator>
        priority_queue(InputIterator first, InputIterator last,
                        const Compare& x = Compare(),
                        const Container& = Container());

        bool empty() const { return c.empty(); }
        size_type size() const { return c.size(); }
        const_reference top() const { return c.front(); }
        void push(const value_type& x);    
        void pop();
    };
```
23.2.4.2.1  priority_queue constructors

priority_queue(const Compare& x = Compare(),
              const Container& y = Container());

  Requires: x defines a strict weak ordering (25.3).

  Effects: Initializes comp with x and c with y; calls make_heap(c.begin(), c.end(), comp).

template <class InputIterator>
priority_queue(InputIterator first, InputIterator last,
               const Compare& x = Compare(),
               const Container& y = Container());

  Requires: x defines a strict weak ordering (25.3).

  Effects: Initializes c with y and comp with x; calls c.insert(c.end(), first, last); and finally calls
  make_heap(c.begin(), c.end(), comp).

23.2.4.2.2  priority_queue members

void push(const value_type& x);

  Effects:
  c.push_back(x);
  push_heap(c.begin(), c.end(), comp); 

void pop();

  Effects:
  pop_heap(c.begin(), c.end(), comp);
  c.pop_back();

23.2.4.3  Class template stack

Any sequence supporting operations back(), push_back() and pop_back() can be used to instantiate stack. In
particular, vector (23.2.5), list (23.2.3) and deque (23.2.2) can be used.

23.2.4.3.1  stack definition

namespace std {
  template <class T, class Container = deque<T> >
  class stack {
    public:
      typedef typename Container::value_type value_type;
      typedef typename Container::reference reference;

Draft
typedef typename Container::const_reference const_reference;
typedef typename Container::size_type size_type;
typed Container container_type;

protected:
    Container c;

public:
    explicit stack(const Container& = Container());

    bool empty() const { return c.empty(); }
    size_type size() const { return c.size(); }
    reference top() { return c.back(); }
    const_reference top() const { return c.back(); }
    void push(const value_type& x) { c.push_back(x); }
    void pop() { c.pop_back(); }

    template <class T, class Container>
    bool operator==(const stack<T, Container>& x,
                    const stack<T, Container>& y);

    template <class T, class Container>
    bool operator< (const stack<T, Container>& x,
                    const stack<T, Container>& y);

    template <class T, class Container>
    bool operator!=(const stack<T, Container>& x,
                    const stack<T, Container>& y);

    template <class T, class Container>
    bool operator> (const stack<T, Container>& x,
                    const stack<T, Container>& y);

    template <class T, class Container>
    bool operator>=(const stack<T, Container>& x,
                    const stack<T, Container>& y);

    template <class T, class Container>
    bool operator<=(const stack<T, Container>& x,
                    const stack<T, Container>& y);

23.2.4.3.2 stack operators

    template <class T, class Container>
    bool operator==(const stack<T, Container>& x,
                    const stack<T, Container>& y);

    template <class T, class Container>
    bool operator!=(const stack<T, Container>& x,
                    const stack<T, Container>& y);

Returns: x.c == y.c.

Returns: x.c != y.c.

Draft
template <class T, class Container>
bool operator< (const stack<T, Container>& x,
const stack<T, Container>& y);

Returns: x.c < y.c.

template <class T, class Container>
bool operator<=(const stack<T, Container>& x,
const stack<T, Container>& y);

Returns: x.c <= y.c.

template <class T, class Container>
bool operator> (const stack<T, Container>& x,
const stack<T, Container>& y);

Returns: x.c > y.c.

template <class T, class Container>
bool operator>=(const stack<T, Container>& x,
const stack<T, Container>& y);

Returns: x.c >= y.c.

23.2.5 Class template vector

A vector is a kind of sequence that supports random access iterators. In addition, it supports (amortized) constant time insert and erase operations at the end; insert and erase in the middle take linear time. Storage management is handled automatically, though hints can be given to improve efficiency. The elements of a vector are stored contiguously, meaning that if v is a vector<T, Allocator> where T is some type other than bool, then it obeys the identity &v[n] == &v[0] + n for all 0 <= n < v.size().

A vector satisfies all of the requirements of a container and of a reversible container (given in two tables in 23.1) and of a sequence, including most of the optional sequence requirements (23.1.1). The exceptions are the push_front and pop_front member functions, which are not provided. In addition to the requirements on the stored object described in 23.1, the stored object shall meet the requirements ofAssignable. Descriptions are provided here only for operations on vector that are not described in one of these tables or for operations where there is additional semantic information.
	namespace std {
	
template <class T, class Allocator = allocator<T> >

class vector {
	public:

	// types:

typedef typename Allocator::reference reference;

typedef typename Allocator::const_reference const_reference;

typedef implementation-defined iterator; // See 23.1

typedef implementation-defined const_iterator; // See 23.1

typedef implementation-defined size_type; // See 23.1

typedef implementation-defined difference_type; // See 23.1

typedef T value_type;

typedef Allocator allocator_type;

Draft
typedef typename Allocator::pointer pointer;
typedef typename Allocator::const_pointer const_pointer;
typedef std::reverse_iterator<iterator> reverse_iterator;
typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

// 23.2.5.1 construct/copy/destroy:
explicit vector(const Allocator& = Allocator());
explicit vector(size_type n, const T& value = T(),
  const Allocator& = Allocator());
template <class InputIterator>
  vector(InputIterator first, InputIterator last,
  const Allocator& = Allocator());
vector(const vector<T,Allocator>& x);
~vector();
vector<T,Allocator>& operator=(const vector<T,Allocator>& x);
template <class InputIterator>
  void assign(InputIterator first, InputIterator last);
void assign(size_type n, const T& u);
allocator_type get_allocator() const;

// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;
const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// 23.2.5.2 capacity:
size_type size() const;
size_type max_size() const;
void resize(size_type sz, T c = T());
size_type capacity() const;
bool empty() const;
void reserve(size_type n);

// element access:
reference operator[](size_type n);
const_reference operator[](size_type n) const;
const_reference at(size_type n) const;
reference at(size_type n);
reference front();
const_reference front() const;
reference back();
const_reference back() const;

// 23.2.5.3 data access
pointer data();
const_pointer data() const;

// 23.2.5.4 modifiers:
void push_back(const T& x);
void pop_back();
iterator insert(iterator position, const T& x);
void insert(iterator position, size_type n, const T& x);
template <class InputIterator>
void insert(iterator position,
           InputIterator first, InputIterator last);
iterator erase(iterator position);
iterator erase(iterator first, iterator last);
void swap(vector<T, Allocator>&);
void clear();
};

template <class T, class Allocator>
bool operator==(const vector<T, Allocator>& x,
                const vector<T, Allocator>& y);

int main() {

    vector<int> v;
    v.push_back(1);
    v.push_back(2);
    v.push_back(3);
    v.push_back(4);
    v.push_back(5);
    return 0;
}
23.2 Sequences

template <class InputIterator>
vector(InputIterator first, InputIterator last,
    const Allocator& = Allocator());
vector(const vector<T,Allocator>& x);

Complexity: The constructor `template <class InputIterator> vector(InputIterator first, InputIterator last)` makes only \( N \) calls to the copy constructor of \( T \) (where \( N \) is the distance between `first` and `last`) and no reallocations if iterators `first` and `last` are of forward, bidirectional, or random access categories. It makes order \( N \) calls to the copy constructor of \( T \) and order \( \log(N) \) reallocations if they are just input iterators.

```cpp
template <class InputIterator>
void assign(InputIterator first, InputIterator last);
```

Effects:
- `erase(begin(), end())`;
- `insert(begin(), first, last)`;

```cpp
void assign(size_type n, const T& t);
```

Effects:
- `erase(begin(), end())`;
- `insert(begin(), n, t)`;

### 23.2.5.2 vector capacity

```cpp
size_type capacity() const;
```

Returns: The total number of elements that the vector can hold without requiring reallocation.

```cpp
void reserve(size_type n);
```

Effects: A directive that informs a vector of a planned change in size, so that it can manage the storage allocation accordingly. After `reserve()`, `capacity()` is greater or equal to the argument of `reserve` if reallocation happens; and equal to the previous value of `capacity()` otherwise. Reallocation happens at this point if and only if the current capacity is less than the argument of `reserve()`.

Complexity: It does not change the size of the sequence and takes at most linear time in the size of the sequence.

Throws: `length_error` if \( n > \text{max\_size()} \).

Remarks: Reallocation invalidates all the references, pointers, and iterators referring to the elements in the sequence. It is guaranteed that no reallocation takes place during insertions that happen after a call to `reserve()` until the time when an insertion would make the size of the vector greater than the value of `capacity()`.

```cpp
void swap(vector<T,Allocator>& x);
```

Effects: Exchanges the contents and `capacity()` of `*this` with that of `x`.

Complexity: Constant time.

---

266) `reserve()` uses `Allocator::allocate()` which may throw an appropriate exception.

Draft
```cpp
void resize(size_type sz, T c = T());

Effects:
if (sz > size())
    insert(end(), sz-size(), c);
else if (sz < size())
    erase(begin()+sz, end());
else
    // do nothing
```

### 23.2.5.3 Vector data

```cpp
pointer data();
const_pointer data() const;
```

1. **Returns:** A pointer such that \([\text{data()}, \text{data()} + \text{size()}]\) is a valid range. For a non-empty vector, \(\text{data()} == \&\text{front()}\).
2. **Complexity:** Constant time.
3. **Throws:** Nothing.

### 23.2.5.4 Vector modifiers

```cpp
iterator insert(iterator position, const T& x);
void insert(iterator position, size_type n, const T& x);
template <class InputIterator>
void insert(iterator position, InputIterator first, InputIterator last);
```

1. **Remarks:** Causes reallocation if the new size is greater than the old capacity. If no reallocation happens, all the iterators and references before the insertion point remain valid. If an exception is thrown other than by the copy constructor or assignment operator of \(T\) or by any InputIterator operation there are no effects.
2. **Complexity:** If \(\text{first}\) and \(\text{last}\) are forward iterators, bidirectional iterators, or random access iterators, the complexity is linear in the number of elements in the range \([\text{first}, \text{last})\) plus the distance to the end of the vector. If they are input iterators, the complexity is proportional to the number of elements in the range \([\text{first}, \text{last})\) times the distance to the end of the vector. The complexity is linear in the number of elements inserted plus the distance to the end of the vector.
3. **Effects:** Invalidates iterators and references at or after the point of the erase.
4. **Complexity:** The destructor of \(T\) is called the number of times equal to the number of the elements erased, but the assignment operator of \(T\) is called the number of times equal to the number of elements in the vector after the erased elements.
5. **Throws:** Nothing unless an exception is thrown by the copy constructor or assignment operator of \(T\).
23.2.5 vector specialized algorithms

```
template <class T, class Allocator>
void swap(vector<T,Allocator>& x, vector<T,Allocator>& y);
```

**Effects:**
```
x.swap(y);
```

23.2.6 Class vector<bool>

To optimize space allocation, a specialization of vector for bool elements is provided:

```
namespace std {
    template <class Allocator> class vector<bool, Allocator> {
        public:
            // types:
            typedef bool const_reference;
            typedef implementation-defined iterator;  // See 23.1
            typedef implementation-defined const_iterator;  // See 23.1
            typedef implementation-defined size_type;  // See 23.1
            typedef implementation-defined difference_type;  // See 23.1
            typedef bool value_type;
            typedef Allocator allocator_type;
            typedef implementation-defined pointer;
            typedef implementation-defined const_pointer;
            typedef std::reverse_iterator<iterator> reverse_iterator;
            typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

            // bit reference:
            class reference {
                friend class vector;
                reference();
                public:
                    ~reference();
                    operator bool() const;
                    reference& operator=(const bool x);
                    reference& operator=(const reference& x);
                    void flip();  // flips the bit
            };

            // construct/copy/destroy:
            explicit vector(const Allocator& = Allocator());
            explicit vector(size_type n, const bool& value = bool(),
                const Allocator& = Allocator());
            template <class InputIterator>
                vector(InputIterator first, InputIterator last,
                    const Allocator& = Allocator());
            vector(const vector<bool,Allocator>& x);
            ~vector();
```

Draft
vector<bool,Allocator>& operator=(const vector<bool,Allocator>& x);

// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;

const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// capacity:
size_type size() const;
size_type max_size() const;
void resize(size_type sz, bool c = false);
size_type capacity() const;
bool empty() const;
void reserve(size_type n);

// element access:
reference operator[](size_type n);
const_reference operator[](size_type n) const;
const_reference at(size_type n) const;
reference at(size_type n);
reference front();
const_reference front() const;
reference back();
const_reference back() const;

// modifiers:
void push_back(const bool& x);
void pop_back();
iterator insert(iterator position, const bool& x);
void insert (iterator position, size_type n, const bool& x);

// templates:

Draft
23.3 Associative containers

Headers `<map>` and `<set>`:

**Header `<map>` synopsis**

```cpp
namespace std {
    template <class Key, class T, class Compare = less<Key>,
              class Allocator = allocator<pair<const Key, T> > >
    class map;
    template <class Key, class T, class Compare, class Allocator>
    bool operator==(const map<Key,T,Compare,Allocator>& x,
                    const map<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator< (const map<Key,T,Compare,Allocator>& x,
                    const map<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator!=(const map<Key,T,Compare,Allocator>& x,
                    const map<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator> (const map<Key,T,Compare,Allocator>& x,
                    const map<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator>=(const map<Key,T,Compare,Allocator>& x,
                    const map<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator<=(const map<Key,T,Compare,Allocator>& x,
                    const map<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    void swap(map<Key,T,Compare,Allocator>& x,
              map<Key,T,Compare,Allocator>& y);

    template <class Key, class T, class Compare = less<Key>,
              class Allocator = allocator<pair<const Key, T> > >
    class multimap;
    template <class Key, class T, class Compare, class Allocator>
    bool operator==(const multimap<Key,T,Compare,Allocator>& x,
                    const multimap<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator< (const multimap<Key,T,Compare,Allocator>& x,
                    const multimap<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator!=(const multimap<Key,T,Compare,Allocator>& x,
                    const multimap<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator> (const multimap<Key,T,Compare,Allocator>& x,
                    const multimap<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator>=(const multimap<Key,T,Compare,Allocator>& x,
                    const multimap<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    bool operator<=(const multimap<Key,T,Compare,Allocator>& x,
                    const multimap<Key,T,Compare,Allocator>& y);
    template <class Key, class T, class Compare, class Allocator>
    void swap(multimap<Key,T,Compare,Allocator>& x,
              multimap<Key,T,Compare,Allocator>& y);
}
```

2 reference is a class that simulates the behavior of references of a single bit in `vector<bool>`.
template <class Key, class T, class Compare, class Allocator>
bool operator< (const multimap<Key,T,Compare,Allocator>& x,
const multimap<Key,T,Compare,Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator!=(const multimap<Key,T,Compare,Allocator>& x,
const multimap<Key,T,Compare,Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator> (const multimap<Key,T,Compare,Allocator>& x,
const multimap<Key,T,Compare,Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator>=(const multimap<Key,T,Compare,Allocator>& x,
const multimap<Key,T,Compare,Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator<=(const multimap<Key,T,Compare,Allocator>& x,
const multimap<Key,T,Compare,Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
void swap(multimap<Key,T,Compare,Allocator>& x,
multimap<Key,T,Compare,Allocator>& y);
}

Header <set> synopsis
namespace std {
    template <class Key, class Compare = less<Key>,
    class Allocator = allocator<Key> >
    class set;
    template <class Key, class Compare, class Allocator>
    bool operator==(const set<Key,Compare,Allocator>& x,
    const set<Key,Compare,Allocator>& y);
    template <class Key, class Compare, class Allocator>
    bool operator< (const set<Key,Compare,Allocator>& x,
    const set<Key,Compare,Allocator>& y);
    template <class Key, class Compare, class Allocator>
    bool operator!=(const set<Key,Compare,Allocator>& x,
    const set<Key,Compare,Allocator>& y);
    template <class Key, class Compare, class Allocator>
    bool operator> (const set<Key,Compare,Allocator>& x,
    const set<Key,Compare,Allocator>& y);
    template <class Key, class Compare, class Allocator>
    bool operator>=(const set<Key,Compare,Allocator>& x,
    const set<Key,Compare,Allocator>& y);
    template <class Key, class Compare, class Allocator>
    bool operator<=(const set<Key,Compare,Allocator>& x,
    const set<Key,Compare,Allocator>& y);
    template <class Key, class Compare, class Allocator>
    void swap(set<Key,Compare,Allocator>& x,
    set<Key,Compare,Allocator>& y);
}

Draft
23.3 Associative containers

Container library 632

class multiset;
template <class Key, class Compare, class Allocator>
bool operator==(const multiset<Key,Compare,Allocator>& x, const multiset<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator<(const multiset<Key,Compare,Allocator>& x, const multiset<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator!=(const multiset<Key,Compare,Allocator>& x, const multiset<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator>(const multiset<Key,Compare,Allocator>& x, const multiset<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator>=(const multiset<Key,Compare,Allocator>& x, const multiset<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator<=(const multiset<Key,Compare,Allocator>& x, const multiset<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
void swap(multiset<Key,Compare,Allocator>& x, multiset<Key,Compare,Allocator>& y);
}

23.3.1 Class template map

A map is a kind of associative container that supports unique keys (contains at most one of each key value) and provides for fast retrieval of values of another type T based on the keys. The map class supports bidirectional iterators.

A map satisfies all of the requirements of a container and of a reversible container (23.1) and of an associative container (23.1.2). A map also provides most operations described in (23.1.2) for unique keys. This means that a map supports the a_uniq operations in (23.1.2) but not the a_eq operations. For a map<Key,T> the key_type is Key and the value_type is pair<const Key, T>. Descriptions are provided here only for operations on map that are not described in one of those tables or for operations where there is additional semantic information.

namespace std {
    template <class Key, class T, class Compare = less<Key>, class Allocator = allocator<pair<const Key, T> > >
    class map {
    public:
        // types:
        typedef Key key_type;
        typedef T mapped_type;
        typedef pair<const Key, T> value_type;
        typedef Compare key_compare;
        typedef Allocator allocator_type;
        typedef typename Allocator::reference reference;
        typedef typename Allocator::const_reference const_reference;
        typedef implementation-defined iterator; // See 23.1
        typedef implementation-defined const_iterator; // See 23.1

        Draft
typedef implementation-defined size_type;   // See 23.1
typedef implementation-defined difference_type; // See 23.1
typedef typename Allocator::pointer pointer;
typedef typename Allocator::const_pointer const_pointer;
typedef std::reverse_iterator<iterator> reverse_iterator;
typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

class value_compare
  : public binary_function<value_type,value_type,bool> {
friend class map;
protected:
  Compare comp;
value_compare(Compare c) : comp(c) {} 
public:
  bool operator()(const value_type& x, const value_type& y) const {
    return comp(x.first, y.first);
  }
};

// 23.3.1.1 construct/copy/destroy:
explicit map(const Compare& comp = Compare(),
             const Allocator& = Allocator());
template <class InputIterator>
  map(InputIterator first, InputIterator last,
       const Compare& comp = Compare(), const Allocator& = Allocator());
map(const map<Key,T,Compare,Allocator>& x);
~map();
map<Key,T,Compare,Allocator>&
  operator=(const map<Key,T,Compare,Allocator>& x);
allocator_type get_allocator() const;

// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;
const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// capacity:
bool empty() const;
size_type size() const;
size_type max_size() const;

// 23.3.1.2 element access:
T& operator[](const key_type& x);
T& at(const key_type& x);
const T& at(const key_type& x) const;

// modifiers:
pair<iterator, bool> insert(const value_type& x);
iterator insert(iterator position, const value_type& x);
template <class InputIterator>
void insert(InputIterator first, InputIterator last);

iterator erase(iterator position);
size_type erase(const key_type& x);
iterator erase(iterator first, iterator last);
void swap(map<Key,T,Compare,Allocator>&);
void clear();

// observers:
key_compare key_comp() const;
value_compare value_comp() const;

// 23.3.1.3 map operations:
iterator find(const key_type& x);
const_iterator find(const key_type& x) const;
size_type count(const key_type& x) const;

iterator lower_bound(const key_type& x);
const_iterator lower_bound(const key_type& x) const;
iterator upper_bound(const key_type& x);
const_iterator upper_bound(const key_type& x) const;

pair<iterator,iterator>
equal_range(const key_type& x);
pair<const_iterator,const_iterator>
equal_range(const key_type& x) const;
};

Draft
const map<Key,T,Compare,Allocator>& y);

// specialized algorithms:
template <class Key, class T, class Compare, class Allocator>
void swap(map<Key,T,Compare,Allocator>& x,
          map<Key,T,Compare,Allocator>& y);

23.3.1.1 map constructors, copy, and assignment

explicit map(const Compare& comp = Compare(),
             const Allocator& = Allocator());

Effects: Constructs an empty map using the specified comparison object and allocator.

Complexity: Constant.

template <class InputIterator>
map(InputIterator first, InputIterator last,
    const Compare& comp = Compare(), const Allocator& = Allocator());

Effects: Constructs an empty map using the specified comparison object and allocator, and inserts elements from
the range \([first, last)\).

Complexity: Linear in \(N\) if the range \([first, last)\) is already sorted using \(comp\) and otherwise \(N \log N\), where
\(N\) is \(last - first\).

23.3.1.2 map element access

T& operator[](const key_type& x);

Effects: If there is no key equivalent to \(x\) in the map, inserts \(\text{value\_type}(x, T())\) into the map.

Returns: A reference to the mapped\_type corresponding to \(x\) in *this.

Complexity: Logarithmic.

T& at(const key_type& x);
const T& at(const key_type& x) const;

Returns: A reference to the element whose key is equivalent to \(x\).

Throws: An exception object of type out\_of\_range if no such element is present.
23.3 Associative containers

23.3.1.3 map operations

iterator find(const key_type& x);
const_iterator find(const key_type& x) const;

iterator lower_bound(const key_type& x);
const_iterator lower_bound(const key_type& x) const;

iterator upper_bound(const key_type& x);
const_iterator upper_bound(const key_type& x) const;

pair<iterator, iterator> equal_range(const key_type& x);
pair<const_iterator, const_iterator> equal_range(const key_type& x) const;

The find, lower_bound, upper_bound and equal_range member functions each have two versions, one const and the other non-const. In each case the behavior of the two functions is identical except that the const version returns a const_iterator and the non-const version an iterator (23.1.2).

23.3.1.4 map specialized algorithms

template <class Key, class T, class Compare, class Allocator>
void swap(map<Key,T,Compare,Allocator>& x, map<Key,T,Compare,Allocator>& y);

Effects:
x.swap(y);

23.3.2 Class template multimap

A multimap is a kind of associative container that supports equivalent keys (possibly containing multiple copies of the same key value) and provides for fast retrieval of values of another type T based on the keys. The multimap class supports bidirectional iterators.

A multimap satisfies all of the requirements of a container and of a reversible container (23.1) and of an associative container (23.1.2). A multimap also provides most operations described in (23.1.2) for equal keys. This means that a multimap supports the a_eq operations in (23.1.2) but not the a_uniq operations. For a multimap<Key,T> the key_type is Key and the value_type is pair<const Key,T>. Descriptions are provided here only for operations on multimap that are not described in one of those tables or for operations where there is additional semantic information.

namespace std {
    template <class Key, class T, class Compare = less<Key>,
              class Allocator = allocator<pair<const Key, T> > >
    class multimap {
        public:
            // types:
            typedef Key key_type;
typedef T mapped_type;
typedef pair<const Key,T> value_type;
typedef Compare key_compare;
typedef Allocator allocator_type;
typedef typename Allocator::reference reference;
typedef typename Allocator::const_reference const_reference;
typedef implementation-defined iterator;
// See 23.1
typedef implementation-defined const_iterator;
// See 23.1
typedef implementation-defined size_type; // See 23.1
typedef implementation-defined difference_type; // See 23.1
typedef typename Allocator::pointer pointer;
typedef typename Allocator::const_pointer const_pointer;
typedef std::reverse_iterator<iterator> reverse_iterator;
typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

class value_compare
 : public binary_function<value_type,value_type,bool> {
friend class multimap;
protected:
  Compare comp;
  value_compare(Compare c) : comp(c) {} 
public:
  bool operator()(const value_type& x, const value_type& y) const {
    return comp(x.first, y.first);
  }
};

// construct/copy/destroy:
explicit multimap(const Compare& comp = Compare(),
                  const Allocator& = Allocator());
template <class InputIterator>
  multimap(InputIterator first, InputIterator last,
           const Compare& comp = Compare(),
           const Allocator& = Allocator());
  ~multimap();
  multimap<Key,T,Compare,Allocator>&
  operator=(const multimap<Key,T,Compare,Allocator>& x);
  allocator_type get_allocator() const;

// iterators:
  iterator begin();
  const_iterator begin() const;
  iterator end();
  const_iterator end() const;
  reverse_iterator rbegin();
  const_reverse_iterator rbegin() const;
  reverse_iterator rend();
  const_reverse_iterator rend() const;
const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// capacity:
bool empty() const;
size_type size() const;
size_type max_size() const;

// modifiers:
iterator insert(const value_type& x);
iterator insert(iterator position, const value_type& x);
template <class InputIterator>
    void insert(InputIterator first, InputIterator last);

iterator erase(iterator position);
size_type erase(const key_type& x);
iterator erase(iterator first, iterator last);
void swap(multimap<Key,T,Compare,Allocator>&);
void clear();

// observers:
key_compare key_comp() const;
value_compare value_comp() const;

// map operations:
iterator find(const key_type& x);
const_iterator find(const key_type& x) const;
size_type count(const key_type& x) const;

iterator lower_bound(const key_type& x);
const_iterator lower_bound(const key_type& x) const;
iterator upper_bound(const key_type& x);
const_iterator upper_bound(const key_type& x) const;
pair<iterator,iterator> equal_range(const key_type& x);
pair<const_iterator,const_iterator> equal_range(const key_type& x) const;

};

template <class Key, class T, class Compare, class Allocator>
bool operator==(const multimap<Key,T,Compare,Allocator>& x,
    const multimap<Key,T,Compare,Allocator>& y);
template <class Key, class T, class Compare, class Allocator>
bool operator< (const multimap<Key,T,Compare,Allocator>& x,
    const multimap<Key,T,Compare,Allocator>& y);
bool operator!= (const multimap<Key, T, Compare, Allocator>& x, const multimap<Key, T, Compare, Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator>  (const multimap<Key, T, Compare, Allocator>& x, const multimap<Key, T, Compare, Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator>=(const multimap<Key, T, Compare, Allocator>& x, const multimap<Key, T, Compare, Allocator>& y);

template <class Key, class T, class Compare, class Allocator>
bool operator<=(const multimap<Key, T, Compare, Allocator>& x, const multimap<Key, T, Compare, Allocator>& y);

// specialized algorithms:

template <class Key, class T, class Compare, class Allocator>
void swap(multimap<Key, T, Compare, Allocator>& x, multimap<Key, T, Compare, Allocator>& y);

} // end of multimap namespace

23.3.2.1 multimap constructors [lib.multimap.cons]

explicit multimap(const Compare& comp = Compare(), const Allocator& = Allocator());
-effects: Constructs an empty multimap using the specified comparison object and allocator.
-complexity: Constant.

template <class InputIterator>
multimap(InputIterator first, InputIterator last, const Compare& comp = Compare(), const Allocator& = Allocator());
-effects: Constructs an empty multimap using the specified comparison object and allocator, and inserts elements from the range [first, last).
-complexity: Linear in N if the range [first, last) is already sorted using comp and otherwise N log N, where N is last - first.

23.3.2.2 multimap operations [lib.multimap.ops]

iterator find(const key_type& x);
const_iterator find(const key_type& x) const;

iterator lower_bound(const key_type& x);
const_iterator lower_bound(const key_type& x) const;

pair<iterator, iterator> lower_bound(const key_type& x);
const_pair<iterator, iterator> lower_bound(const key_type& x) const;

pair<iterator, iterator> equal_range(const key_type& x);
pair<const_iterator, const_iterator> equal_range(const key_type& x) const;
The `find`, `lower_bound`, `upper_bound`, and `equal_range` member functions each have two versions, one `const` and one non-`const`. In each case the behavior of the two versions is identical except that the `const` version returns a `const_iterator` and the non-`const` version an `iterator` (23.1.2).

### 23.3.2.3 multimap specialized algorithms

```cpp
template <class Key, class T, class Compare, class Allocator>
void swap(multimap<Key,T,Compare,Allocator>& x,
          multimap<Key,T,Compare,Allocator>& y);
```

*Effects:*

```cpp
x.swap(y);
```

### 23.3.3 Class template set

A `set` is a kind of associative container that supports unique keys (contains at most one of each key value) and provides for fast retrieval of the keys themselves. Class `set` supports bidirectional iterators.

A `set` satisfies all of the requirements of a container and of a reversible container (23.1), and of an associative container (23.1.2). A `set` also provides most operations described in (23.1.2) for unique keys. This means that a `set` supports the `a uniq` operations in (23.1.2) but not the `a_eq` operations. For a `set<Key>` both the `key_type` and `value_type` are `Key`. Descriptions are provided here only for operations on `set` that are not described in one of these tables and for operations where there is additional semantic information.

```cpp
namespace std {
    template <class Key, class Compare = less<Key>,
              class Allocator = allocator<Key> >
    class set {
        public:
            // types:
            typedef Key key_type;
            typedef Key value_type;
            typedef Compare key_compare;
            typedef Compare value_compare;
            typedef Allocator allocator_type;
            typedef typename Allocator::reference reference;
            typedef typename Allocator::const_reference const_reference;
            typedef implementation-defined iterator;
            // See 23.1
            typedef implementation-defined const_iterator; // See 23.1
            typedef implementation-defined size_type; // See 23.1
            typedef implementation-defined difference_type; // See 23.1
            typedef typename Allocator::pointer pointer;
            typedef typename Allocator::const_pointer const_pointer;
            typedef std::reverse_iterator<iterator> reverse_iterator;
            typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

            // 23.3.3.1 construct/copy/destroy:
            explicit set(const Compare& comp = Compare(),
```
const Allocator& = Allocator();

```cpp
template <class InputIterator>
set(InputIterator first, InputIterator last,
    const Compare& comp = Compare(), const Allocator& = Allocator());
```

```cpp
set(const set<Key,Compare,Allocator>& x);
```

```cpp
~set();
```

```cpp
set<Key,Compare,Allocator>& operator=(
    const set<Key,Compare,Allocator>& x);
```

```cpp
allocator_type get_allocator() const;
```

```cpp
// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
```

```cpp
reverse_iterator rbegin();
const_reverse_iterator rbeg (const);
reverse_iterator rend();
const_reverse_iterator rend() const;
```

```cpp
const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;
```

```cpp
// capacity:
bool empty() const;
size_type size() const;
size_type max_size() const;
```

```cpp
// modifiers:
pair<iterator,bool> insert(const value_type& x);
iterator insert(iterator position, const value_type& x);
template <class InputIterator>
void insert(InputIterator first, InputIterator last);
```

```cpp
iterator erase(iterator position);
size_type erase(const key_type& x);
iterator erase(iterator first, iterator last);
void swap(set<Key,Compare,Allocator>&);
void clear();
```

```cpp
// observers:
key_compare key_comp() const;
value_compare value_comp() const;
```

```cpp
// set operations:
iterator find(const key_type& x);
const_iterator find(const key_type& x) const;
```
### 23.3 Associative containers

Containers library 642

```cpp
size_type count(const key_type& x) const;
iterator lower_bound(const key_type& x);
const_iterator lower_bound(const key_type& x) const;
iterator upper_bound(const key_type& x);
const_iterator upper_bound(const key_type& x) const;
pair<iterator,iterator> equal_range(const key_type& x);
pair<const_iterator,const_iterator> equal_range(const key_type& x) const;
};
```

```cpp
template <class Key, class Compare, class Allocator>
bool operator==(const set<Key,Compare,Allocator>& x,
const set<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator<(const set<Key,Compare,Allocator>& x,
const set<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator!=(const set<Key,Compare,Allocator>& x,
const set<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator>(const set<Key,Compare,Allocator>& x,
const set<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator<=(const set<Key,Compare,Allocator>& x,
const set<Key,Compare,Allocator>& y);
template <class Key, class Compare, class Allocator>
bool operator>=(const set<Key,Compare,Allocator>& x,
const set<Key,Compare,Allocator>& y);
```
Effects: Constructs an empty set using the specified comparison object and allocator, and inserts elements from the range \([\text{first}, \text{last})\).

Complexity: Linear in \(N\) if the range \([\text{first}, \text{last})\) is already sorted using \(\text{comp}\) and otherwise \(N \log N\), where \(N\) is \(\text{last} - \text{first}\).

### 23.3.3.2 set specialized algorithms

[lib.set.special]

```cpp
template <class Key, class Compare, class Allocator>
void swap(set<Key,Compare,Allocator>& x,
    set<Key,Compare,Allocator>& y);
```

Effects:

\(x.\text{swap}(y)\);

### 23.3.4 Class template multiset

[lib.multiset]

A multiset is a kind of associative container that supports equivalent keys (possibly contains multiple copies of the same key value) and provides for fast retrieval of the keys themselves. Class `multiset` supports bidirectional iterators.

A multiset satisfies all of the requirements of a container and of a reversible container (23.1), and of an associative container (23.1.2). `multiset` also provides most operations described in (23.1.2) for duplicate keys. This means that a multiset supports the `a_eq` operations in (23.1.2) but not the `a_uniq` operations. For a `multiset<Key>` both the `key_type` and `value_type` are `Key`. Descriptions are provided here only for operations on `multiset` that are not described in one of these tables and for operations where there is additional semantic information.

```cpp
namespace std {
    template <class Key, class Compare = less<Key>,
        class Allocator = allocator<Key> >
    class multiset {
        public:
            // types:
            typedef Key key_type;
            typedef Key value_type;
            typedef Compare key_compare;
            typedef Compare value_compare;
            typedef Allocator allocator_type;
            typedef typename Allocator::reference reference;
            typedef typename Allocator::const_reference const_reference;
            typedef implementation-defined iterator;
            typedef implementation-defined const_iterator;
            typedef implementation-defined size_type; // See 23.1
            typedef implementation-defined difference_type; // See 23.1
            typedef typename Allocator::pointer pointer;
            typedef typename Allocator::const_pointer const_pointer;
            typedef std::reverse_iterator<iterator> reverse_iterator;
            typedef std::reverse_iterator<const_iterator> const_reverse_iterator;

    }
}
```

Draft
23.3 Associative containers

Containers library 644

// construct/copy/destroy:
explicit multiset(const Compare& comp = Compare(),
                  const Allocator& = Allocator());
template <class InputIterator>
multiset(InputIterator first, InputIterator last,
         const Compare& comp = Compare(),
         const Allocator& = Allocator());
multiset(const multiset<Key,Compare,Allocator>& x);
~multiset();
multiset<Key,Compare,Allocator>&
    operator=(const multiset<Key,Compare,Allocator>& x);
allocator_type get_allocator() const;

// iterators:
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
reverse_iterator rbegin();
const_reverse_iterator rbegin() const;
reverse_iterator rend();
const_reverse_iterator rend() const;

const_iterator cbegin() const;
const_iterator cend() const;
const_reverse_iterator crbegin() const;
const_reverse_iterator crend() const;

// capacity:
bool empty() const;
size_type size() const;
size_type max_size() const;

// modifiers:
iterator insert(const value_type& x);
iterator insert(iterator position, const value_type& x);
template <class InputIterator>
void insert(InputIterator first, InputIterator last);
iterator erase(iterator position);
size_type erase(const key_type& x);
iterator erase(iterator first, iterator last);
void swap(multiset<Key,Compare,Allocator>&);
void clear();

// observers:
key_compare key_comp() const;
value_compare value_comp() const;
Containers library 23.3 

Associative containers

// set operations:
iterator find(const key_type& x);
const_iterator find(const key_type& x) const;
size_type count(const key_type& x) const;
iterator lower_bound(const key_type& x);
const_iterator lower_bound(const key_type& x) const;
iterator upper_bound(const key_type& x);
const_iterator upper_bound(const key_type& x) const;
pair<iterator,iterator> equal_range(const key_type& x);
pair<const_iterator,const_iterator> equal_range(const key_type& x) const;
};

template <class Key, class Compare, class Allocator>
bool operator==(const multiset<Key,Compare,Allocator>& x,
    const multiset<Key,Compare,Allocator>& y);

template <class Key, class Compare, class Allocator>
bool operator< (const multiset<Key,Compare,Allocator>& x,
    const multiset<Key,Compare,Allocator>& y);

template <class Key, class Compare, class Allocator>
bool operator!=(const multiset<Key,Compare,Allocator>& x,
    const multiset<Key,Compare,Allocator>& y);

template <class Key, class Compare, class Allocator>
bool operator> (const multiset<Key,Compare,Allocator>& x,
    const multiset<Key,Compare,Allocator>& y);

template <class Key, class Compare, class Allocator>
bool operator>=(const multiset<Key,Compare,Allocator>& x,
    const multiset<Key,Compare,Allocator>& y);

template <class Key, class Compare, class Allocator>
bool operator<=(const multiset<Key,Compare,Allocator>& x,
    const multiset<Key,Compare,Allocator>& y);

// specialized algorithms:
template <class Key, class Compare, class Allocator>
void swap(multiset<Key,Compare,Allocator>& x,
    multiset<Key,Compare,Allocator>& y);

23.3.4.1 multiset constructors

explicit multiset(const Compare& comp = Compare(),
    const Allocator& = Allocator());

Effects: Constructs an empty set using the specified comparison object and allocator.

Complexity: Constant.

template <class InputIterator>
23.3 Associative containers

```
multiset(InputIterator first, last,
    const Compare& comp = Compare(), const Allocator& = Allocator());
```

*Effects:* Constructs an empty `multiset` using the specified comparison object and allocator, and inserts elements from the range `[first, last)`.

*Complexity:* Linear in `N` if the range `[first, last)` is already sorted using `comp` and otherwise `N log N`, where `N` is `last - first`.

23.3.4.2 `multiset` specialized algorithms

```
template <class Key, class Compare, class Allocator>
void swap(multiset<Key,Compare,Allocator>& x,
    multiset<Key,Compare,Allocator>& y);
```

*Effects:* `x.swap(y);`

23.3.5 Class template `bitset`

**Header `<bitset>` synopsis**

```
#include <cstddef>  // for size_t
#include <string>
#include <stdexcept>  // for invalid_argument, out_of_range, overflow_error
#include <iosfwd>  // for istream, ostream
namespace std {
    template <size_t N> class bitset;

    // 23.3.5.3 bitset operations:
    template <size_t N>
    bitset<N> operator&(const bitset<N>&, const bitset<N>&);
    template <size_t N>
    bitset<N> operator|(const bitset<N>&, const bitset<N>&);
    template <size_t N>
    bitset<N> operator^(const bitset<N>&, const bitset<N>&);
    template <class charT, class traits, size_t N>
    basic_istream<charT, traits>&
        operator>>(basic_istream<charT, traits>& is, bitset<N>& x);
    template <class charT, class traits, size_t N>
    basic_ostream<charT, traits>&
        operator<<(basic_ostream<charT, traits>& os, const bitset<N>& x);
}
```

The header `<bitset>` defines a class template and several related functions for representing and manipulating fixed-size sequences of bits.

Draft
namespace std {
    template<size_t N> class bitset {
    public:
        // bit reference:
        class reference {
            friend class bitset;
            reference();
            public:
                ~reference();
                reference& operator=(bool x);       // for b[i] = x;
                reference& operator=(const reference&); // for b[i] = b[j];
                bool operator~() const;            // flips the bit
                operator bool() const;             // for x = b[i];
                reference& flip();                 // for b[i].flip();
        };

        // 23.3.5.1 constructors:
        bitset();
        bitset(unsigned long val);
        template<class charT, class traits, class Allocator>
        explicit bitset(
            const basic_string<charT,traits,Allocator>& str,
            typename basic_string<charT,traits,Allocator>::size_type pos = 0,
            typename basic_string<charT,traits,Allocator>::size_type n =
            basic_string<charT,traits,Allocator>::npos);

        // 23.3.5.2 bitset operations:
        bitset<N>& operator&=(const bitset<N>& rhs);
        bitset<N>& operator|=(const bitset<N>& rhs);
        bitset<N>& operator^=(const bitset<N>& rhs);
        bitset<N>& operator<<=(size_t pos);
        bitset<N>& operator>>=(size_t pos);
        bitset<N>& set();
        bitset<N>& set(size_t pos, bool val = true);
        bitset<N>& reset();
        bitset<N>& reset(size_t pos);
        bitset<N> operator~() const;
        bitset<N>& flip();
        bitset<N>& flip(size_t pos);

        // element access:
        bool operator[](size_t pos) const;      // for b[i];
        reference operator[](size_t pos) const;  // for b[i];

        unsigned long to_ulong() const;
        template <class charT, class traits, class Allocator>
        basic_string<charT, traits, Allocator> to_string() const;
        template <class charT, class traits>
        basic_string<charT, traits, allocator<charT>> to_string() const;
        template <class charT>
    }
};
The template class `bitset<N>` describes an object that can store a sequence consisting of a fixed number of bits, \( N \).

Each bit represents either the value zero (reset) or one (set). To **toggle** a bit is to change the value zero to one, or the value one to zero. Each bit has a non-negative position \( \text{pos} \). When converting between an object of class `bitset<N>` and a value of some integral type, bit position \( \text{pos} \) corresponds to the bit value \( 1 \ll \text{pos} \). The integral value corresponding to two or more bits is the sum of their bit values.

The functions described in this subclause can report three kinds of errors, each associated with a distinct exception:

- an **invalid-argument** error is associated with exceptions of type `invalid_argument` (19.1.3);
- an **out-of-range** error is associated with exceptions of type `out_of_range` (19.1.5);
- an **overflow** error is associated with exceptions of type `overflow_error` (19.1.8).

### 23.3.5.1 `bitset` constructors

```cpp
bitset();
```

**Effects:** Constructs an object of class `bitset<N>`, initializing all bits to zero.

```cpp
bitset(unsigned long val);
```

**Effects:** Constructs an object of class `bitset<N>`, initializing the first \( M \) bit positions to the corresponding bit values in \( val \). \( M \) is the smaller of \( N \) and the number of bits in the value representation (section 3.9) of `unsigned long`. If \( M<N \), the remaining bit positions are initialized to zero.

```cpp
template <class charT, class traits, class Allocator>
explicit
bitset(const basic_string<charT, traits, Allocator>& str,
        typename basic_string<charT, traits, Allocator>::size_type pos = 0,
        typename basic_string<charT, traits, Allocator>::size_type n =
        basic_string<charT, traits, Allocator>::npos);
```

**Requires:** \( \text{pos} \leq \text{str.size()} \).

**Throws:** `out_of_range` if \( \text{pos} > \text{str.size()} \).
Effects: Determines the effective length $rlen$ of the initializing string as the smaller of $n$ and $str.size() - pos$.

The function then throws invalid_argument if any of the $rlen$ characters in $str$ beginning at position $pos$ is other than 0 or 1.

Otherwise, the function constructs an object of class bitset<N>, initializing the first $M$ bit positions to values determined from the corresponding characters in the string $str$. $M$ is the smaller of $N$ and $rlen$.

An element of the constructed string has value zero if the corresponding character in $str$, beginning at position $pos$, is 0. Otherwise, the element has the value one. Character position $pos + M - 1$ corresponds to bit position zero. Subsequent decreasing character positions correspond to increasing bit positions.

If $M < N$, remaining bit positions are initialized to zero.

23.3.5.2 bitset members

bitset<N>& operator&=(const bitset<N>& rhs);

Effects: Clears each bit in *this for which the corresponding bit in rhs is clear, and leaves all other bits unchanged.

Returns: *this.

bitset<N>& operator|=(const bitset<N>& rhs);

Effects: Sets each bit in *this for which the corresponding bit in rhs is set, and leaves all other bits unchanged.

Returns: *this.

bitset<N>& operator^=(const bitset<N>& rhs);

Effects: Toggles each bit in *this for which the corresponding bit in rhs is set, and leaves all other bits unchanged.

Returns: *this.

bitset<N>& operator<<=(size_t pos);

Effects: Replaces each bit at position $I$ in *this with a value determined as follows:

— If $I < pos$, the new value is zero;
— If $I >= pos$, the new value is the previous value of the bit at position $I - pos$.

Returns: *this.

bitset<N>& operator>>=(size_t pos);

Effects: Replaces each bit at position $I$ in *this with a value determined as follows:

— If $pos >= N - I$, the new value is zero;
— If $pos < N - I$, the new value is the previous value of the bit at position $I + pos$.
Returns: *this.

bitset<N>& set();

Effects: Sets all bits in *this.
Returns: *this.

bitset<N>& set(size_t pos, bool val = true);

Requires: pos is valid
Throws: out_of_range if pos does not correspond to a valid bit position.
Effects: Stores a new value in the bit at position pos in *this. If val is nonzero, the stored value is one, otherwise it is zero.
Returns: *this.

bitset<N>& reset();

Effects: Resets all bits in *this.
Returns: *this.

bitset<N>& reset(size_t pos);

Requires: pos is valid
Throws: out_of_range if pos does not correspond to a valid bit position.
Effects: Resets the bit at position pos in *this.
Returns: *this.

bitset<N> operator~() const;

Effects: Constructs an object x of class bitset<N> and initializes it with *this.
Returns: x.flip().

bitset<N>& flip();

Effects: Toggles all bits in *this.
Returns: *this.

bitset<N>& flip(size_t pos);

Requires: pos is valid
Throws: out_of_range if pos does not correspond to a valid bit position.
Effects: Toggles the bit at position pos in *this.
Returns: *this.

unsigned long to_ulong() const;
Throws: overflow_error if the integral value \( x \) corresponding to the bits in \(*this\) cannot be represented as type unsigned long.

Returns: \( x \).

```cpp
template <class charT, class traits, class Allocator>
basic_string<charT, traits, Allocator> to_string() const;
```

Effects: Constructs a string object of the appropriate type and initializes it to a string of length \( N \) characters. Each character is determined by the value of its corresponding bit position in \(*this\). Character position \( N - 1 \) corresponds to bit position zero. Subsequent decreasing character positions correspond to increasing bit positions. Bit value zero becomes the character 0, bit value one becomes the character 1.

Returns: The created object.

```cpp
template <class charT, class traits>
basic_string<charT, traits, allocator<charT> > to_string() const;
```

Returns: to_string<charT, traits, allocator<charT> >().

```cpp
template <class charT>
basic_string<charT, char_traits<charT>, allocator<charT> > to_string() const;
```

Returns: to_string<charT, char_traits<charT>, allocator<charT> >().

```cpp
size_t count() const;
```

Returns: A count of the number of bits set in \(*this\).

```cpp
size_t size() const;
```

Returns: \( N \).

```cpp
bool operator==(const bitset<N>& rhs) const;
```

Returns: A nonzero value if the value of each bit in \(*this\) equals the value of the corresponding bit in \( rhs \).

```cpp
bool operator!=(const bitset<N>& rhs) const;
```

Returns: A nonzero value if \(!(*this == rhs)\).

```cpp
bool test(size_t pos) const;
```

Requires: \( pos \) is valid

Throws: out_of_range if \( pos \) does not correspond to a valid bit position.

Returns: true if the bit at position \( pos \) in \(*this\) has the value one.

```cpp
bool any() const;
```

Returns: true if any bit in \(*this\) is one.
bool none() const;

    Returns: true if no bit in *this is one.

bitset<N> operator<<(size_t pos) const;

    Returns: bitset<N>(*this) <<= pos.

bitset<N> operator>>(size_t pos) const;

    Returns: bitset<N>(*this) >>= pos.

bool operator[](size_t pos) const;

    Requires: pos is valid.
    Throws: nothing.
    Returns: test(pos).

bitset<N>::reference operator[](size_t pos);

    Requires: pos is valid.
    Throws: nothing.
    Returns: An object of type bitset<N>::reference such that (*this)[pos] == this->test(pos), and such that (*this)[pos] = val is equivalent to this->set(pos, val).

23.3.5.3 bitset operators
[lib.bitset.operators]

bitset<N> operator&(const bitset<N>& lhs, const bitset<N>& rhs);

    Returns: bitset<N>(lhs) &= rhs.

bitset<N> operator|(const bitset<N>& lhs, const bitset<N>& rhs);

    Returns: bitset<N>(lhs) |= rhs.

bitset<N> operator^(const bitset<N>& lhs, const bitset<N>& rhs);

    Returns: bitset<N>(lhs) ^= rhs.

template <class charT, class traits, size_t N>
    basic_istream<charT, traits>&
    operator>>(basic_istream<charT, traits>& is, bitset<N>& x);

    A formatted input function (27.6.1.2).

    Effects: Extracts up to N characters from is. Stores these characters in a temporary object str of type basic_string<charT, traits>, then evaluates the expression x = bitset<N>(str). Characters are extracted and stored until any of the following occurs:

    — N characters have been extracted and stored;
    — end-of-file occurs on the input sequence;

Draft
Containers library

— the next input character is neither is.widen(‘0’) nor is.widen(‘1’) (in which case the input character is not extracted).

If no characters are stored in str, calls is.setstate(ios::failbit) (which may throw ios_base::failure (27.4.4.3)).

Returns: is.

template <class charT, class traits, size_t N>
basic_ostream<charT, traits>&
operator<<(basic_ostream<charT, traits>& os, const bitset<N>& x);

Returns: os << z.template to_string<charT,traits,allocator<charT> >() (27.6.2.5).

23.4 TR1: Unordered associative containers [lib.unord]

Headers <unordered_map> and <unordered_set>:

Header <unordered_map> synopsis

namespace std {
    // 23.4.1, class template unordered_map:
    template <class Key,
              class T,
              class Hash = hash<Key>,
              class Pred = std::equal_to<Key>,
              class Alloc = std::allocator<std::pair<const Key, T> > >
    class unordered_map;

    // 23.4.2, class template unordered_multimap:
    template <class Key,
              class T,
              class Hash = hash<Key>,
              class Pred = std::equal_to<Key>,
              class Alloc = std::allocator<std::pair<const Key, T> > >
    class unordered_multimap;

    template <class Key, class T, class Hash, class Pred, class Alloc>
    void swap(unordered_map<Key, T, Hash, Pred, Alloc>& x,
              unordered_map<Key, T, Hash, Pred, Alloc>& y);

    template <class Key, class T, class Hash, class Pred, class Alloc>
    void swap(unordered_multimap<Key, T, Hash, Pred, Alloc>& x,
              unordered_multimap<Key, T, Hash, Pred, Alloc>& y);
} // namespace std

Header <unordered_set> synopsis

namespace std {
    // 23.4.3, class template unordered_set:
    template <class Value,
              class Hash = hash<Value>,
              class Pred = std::equal_to<Value>,
              class Alloc = std::allocator<Value> >
    class unordered_set;

    template <class Value, class Pred, class Alloc>
    void swap(unordered_set<Value, Pred, Alloc>& x,
              unordered_set<Value, Pred, Alloc>& y);

} // namespace std

Draft
23.4 TR1: Unordered associative containers

containers library

```cpp
    class Pred = std::equal_to<Value>,
    class Alloc = std::allocator<Value> >
class unordered_set;

    // 23.4.4, class template unordered_multiset:
    template <class Value,
             class Hash = hash<Value>,
             class Pred = std::equal_to<Value>,
             class Alloc = std::allocator<Value> >
class unordered_multiset;

    template <class Value, class Hash, class Pred, class Alloc>
    void swap(unordered_set<Value, Hash, Pred, Alloc>& x,
              unordered_set<Value, Hash, Pred, Alloc>& y);

    template <class Value, class Hash, class Pred, class Alloc>
    void swap(unordered_multiset<Value, Hash, Pred, Alloc>& x,
              unordered_multiset<Value, Hash, Pred, Alloc>& y);
    } // namespace std
```

23.4.1 Class template unordered_map

An unordered_map is an unordered associative container that supports unique keys (an unordered_map contains at most one of each key value) and that associates values of another type mapped_type with the keys.

An unordered_map satisfies all of the requirements of a container and of an unordered associative container. It provides the operations described in the preceding requirements table for unique keys; that is, an unordered_map supports the a_uniq operations in that table, not the a_eq operations. For an unordered_map<Key, T> the key type is Key, the mapped type is T, and the value type is std::pair<const Key, T>.

This section only describes operations on unordered_map that are not described in one of the requirement tables, or for which there is additional semantic information.

```cpp
    template <class Key,
              class T,
              class Hash = hash<Key>,
              class Pred = std::equal_to<Key>,
              class Alloc = std::allocator<std::pair<const Key, T> > >
class unordered_map
{
public:
    // types
    typedef Key key_type;
    typedef std::pair<const Key, T> value_type;
    typedef T mapped_type;
    typedef Hash hasher;
    typedef Pred key_equal;
    typedef Alloc allocator_type;
    typedef typename allocator_type::pointer pointer;
    typedef typename allocator_type::const_pointer const_pointer;
    typedef typename allocator_type::reference reference;
}
```
typedef typename allocator_type::const_reference const_reference;
typedef implementation-defined size_type;
typedef implementation-defined difference_type;
typedef implementation-defined iterator;
typedef implementation-defined const_iterator;
typedef implementation-defined local_iterator;
typedef implementation-defined const_local_iterator;

// construct/destroy/copy
explicit unordered_map(size_type n = implementation-defined,
                        const hasher& hf = hasher(),
                        const key_equal& eql = key_equal(),
                        const allocator_type& a = allocator_type());
template <class InputIterator>
unordered_map(InputIterator f, InputIterator l,
              size_type n = implementation-defined,
              const hasher& hf = hasher(),
              const key_equal& eql = key_equal(),
              const allocator_type& a = allocator_type());
unordered_map(const unordered_map&);
~unordered_map();
unordered_map& operator=(const unordered_map&);
allocator_type get_allocator() const;

// size and capacity
bool empty() const;
size_type size() const;
size_type max_size() const;

// iterators
iterator begin();
const_iterator begin() const;
iterator end();
const_iterator end() const;
const_iterator cbegin() const;
const_iterator cend() const;

// modifiers
std::pair<iterator, bool> insert(const value_type& obj);
iterator insert(iterator hint, const value_type& obj);
const_iterator insert(const_iterator hint, const value_type& obj);
template <class InputIterator> void insert(InputIterator first, InputIterator last);
iterator erase(iterator position);
const_iterator erase(const_iterator position);
size_type erase(const key_type& k);
iterator erase(iterator first, iterator last);
const_iterator erase(const_iterator first, const_iterator last);
void clear();

Draft
23.4.1.1 unordered_map constructors

explicit unordered_map(size_type n = implementation-defined,
    const hasher& hf = hasher(),
    const key_equal& eql = key_equal(),
    const allocator_type& a = allocator_type());

Effects: Constructs an empty unordered_map using the specified hash function, key equality function, and allocator, and using at least n buckets. If n is not provided, the number of buckets is implementation defined. max_load_factor() returns 1.0.

Complexity: Constant.
template <class InputIterator>
unordered_map(InputIterator f, InputIterator l,
   size_type n = implementation-defined,
   const hasher& hf = hasher(),
   const key_equal& eql = key_equal(),
   const allocator_type& a = allocator_type());

Effects: Constructs an empty unordered_map using the specified hash function, key equality function, and allocator, and using at least n buckets. (If n is not provided, the number of buckets is implementation defined.) Then inserts elements from the range \([f, l)\). max_load_factor() returns 1.0.

Complexity: Average case linear, worst case quadratic.

23.4.1.2 unordered_map element access

mapped_type& operator[](const key_type& k);

Effects: If the unordered_map does not already contain an element whose key is equivalent to \(k\), inserts the value \(\text{std::pair<const key_type, mapped_type>}(k, \text{mapped_type}())\).

Returns: A reference to \(x.second\), where \(x\) is the (unique) element whose key is equivalent to \(k\).

23.4.1.3 unordered_map swap

template <class Key, class T, class Hash, class Pred, class Alloc>
void swap(unordered_map<Key, T, Hash, Pred, Alloc>& x,
   unordered_map<Key, T, Hash, Pred, Alloc>& y);

Effects: \(x.swap(y)\).

23.4.2 Class template unordered_multimap

An unordered_multimap is an unordered associative container that supports equivalent keys (an unordered_multimap may contain multiple copies of each key value) and that associates values of another type \(\text{mapped\_type}\) with the keys.

An unordered_multimap satisfies all of the requirements of a container and of an unordered associative container. It provides the operations described in the preceding requirements table for equivalent keys; that is, an unordered_multimap supports the \(\text{a\_eq}\) operations in that table, not the \(\text{a\_uniq}\) operations. For an unordered_multimap\(<\text{Key},\ T>\) the key type is \(\text{Key}\), the mapped type is \(\text{T}\), and the value type is \(\text{std::pair<const Key, T>}\).

This section only describes operations on unordered_multimap that are not described in one of the requirement tables, or for which there is additional semantic information.

template <class Key,
   class T,
   class Hash = hash<Key>,
   class Pred = std::equal_to<Key>,
   class Alloc = std::allocator<std::pair<const Key, T>>
>
class unordered_multimap


```cpp
{
public:
    // types
    typedef Key key_type;
    typedef std::pair<const Key, T> value_type;
    typedef T mapped_type;
    typedef Hash hasher;
    typedef Pred key_equal;
    typedef Alloc allocator_type;
    typedef typename allocator_type::pointer pointer;
    typedef typename allocator_type::const_pointer const_pointer;
    typedef typename allocator_type::reference reference;
    typedef typename allocator_type::const_reference const_reference;
    typedef implementation-defined size_type;
    typedef implementation-defined difference_type;
    typedef implementation-defined iterator;
    typedef implementation-defined const_iterator;
    typedef implementation-defined local_iterator;
    typedef implementation-defined const_local_iterator;

    // construct/destroy.copyWith
    explicit unordered_multimap(size_type n = implementation-defined,
                                  const hasher& hf = hasher(),
                                  const key_equal& eql = key_equal(),
                                  const allocator_type& a = allocator_type());
    template <class InputIterator>
    unordered_multimap(InputIterator f, InputIterator l,
                       size_type n = implementation-defined,
                       const hasher& hf = hasher(),
                       const key_equal& eql = key_equal(),
                       const allocator_type& a = allocator_type());
    unordered_multimap(const unordered_multimap&);
    ~unordered_multimap();
    unordered_multimap& operator=(const unordered_multimap&);
    allocator_type get_allocator() const;

    // size and capacity
    bool empty() const;
    size_type size() const;
    size_type max_size() const;

    // iterators
    iterator begin();
    const_iterator begin() const;
    iterator end();
    const_iterator end() const;
    const_iterator cbegin() const;
    const_iterator cend() const;
}
```

Draft
// modifiers
iterator insert(const value_type& obj);
iterator insert(iterator hint, const value_type& obj);
const_iterator insert(const_iterator hint, const value_type& obj);
template <class InputIterator> void insert(InputIterator first, InputIterator last);

iterator erase(iterator position);
const_iterator erase(const_iterator position);
size_type erase(const key_type& k);
iterator erase(iterator first, iterator last);
const_iterator erase(const_iterator first, const_iterator last);
void clear();

void swap(unordered_multimap&);

// observers
hasher hash_function() const;
key_equal key_eq() const;

// lookup
iterator find(const key_type& k);
const_iterator find(const key_type& k) const;
size_type count(const key_type& k) const;
std::pair<iterator, iterator> equal_range(const key_type& k);
std::pair<const_iterator, const_iterator> equal_range(const key_type& k) const;

// bucket interface
size_type bucket_count() const;
size_type max_bucket_count() const;
size_type bucket_size(size_type n);
size_type bucket(const key_type& k) const;
local_iterator begin(size_type n) const;
const_local_iterator begin(size_type n) const;
local_iterator end(size_type n);
const_local_iterator end(size_type n) const;

// hash policy
float load_factor() const;
float max_load_factor() const;
void max_load_factor(float z);
void rehash(size_type n);
};
const hasher& hf = hasher(),
    const key_equal& eql = key_equal(),
    const allocator_type& a = allocator_type());

Effects: Constructs an empty unordered_multimap using the specified hash function, key equality function, and allocator, and using at least \( n \) buckets. If \( n \) is not provided, the number of buckets is implementation defined. \( \text{max\_load\_factor}() \) returns 1.0.

Complexity: Constant.

template <class InputIterator>
unordered_multimap(InputIterator f, InputIterator l,
    size_type n = implementation-defined,
    const hasher& hf = hasher(),
    const key_equal& eql = key_equal(),
    const allocator_type& a = allocator_type());

Effects: Constructs an empty unordered_multimap using the specified hash function, key equality function, and allocator, and using at least \( n \) buckets. (If \( n \) is not provided, the number of buckets is implementation defined.) Then inserts elements from the range \([f, l)\). \( \text{max\_load\_factor}() \) returns 1.0.

Complexity: Average case linear, worst case quadratic.

23.4.2.2 unordered_multimap swap

[lib.unord.multimap.swap]

template <class Key, class T, class Hash, class Pred, class Alloc>
void swap(unordered_multimap<Key, T, Hash, Pred, Alloc>& x,
    unordered_multimap<Key, T, Hash, Pred, Alloc>& y);

Effects: \( x.\text{swap}(y) \).

23.4.3 Class template unordered_set

[lib.unord.set]

An unordered_set is an unordered associative container that supports unique keys (an unordered_set contains at most one of each key value) and in which the elements’ keys are the elements themselves.

An unordered_set satisfies all of the requirements of a container and of an unordered associative container. It provides the operations described in the preceding requirements table for unique keys; that is, an unordered_set supports the \( \text{a\_uniq} \) operations in that table, not the \( \text{a\_eq} \) operations. For an unordered_set<Value> the key type and the value type are both Value. The \texttt{iterator} and \texttt{const\_iterator} types are both const iterator types. It is unspecified whether they are the same type.

This section only describes operations on unordered_set that are not described in one of the requirement tables, or for which there is additional semantic information.

template <class Value,
    class Hash = hash<Value>,
    class Pred = std::equal_to<Value>,
    class Alloc = std::allocator<Value> >
class unordered_set

Draft
containers library

```cpp
public:
    // types
    typedef Value key_type;
    typedef Value value_type;
    typedef Hash hasher;
    typedef Pred key_equal;
    typedef Alloc allocator_type;
    typedef typename allocator_type::pointer pointer;
    typedef typename allocator_type::const_pointer const_pointer;
    typedef typename allocator_type::reference reference;
    typedef typename allocator_type::const_reference const_reference;
    typedef implementation-defined size_type;
    typedef implementation-defined difference_type;
    typedef implementation-defined iterator;
    typedef implementation-defined const_iterator;
    typedef implementation-defined local_iterator;
    typedef implementation-defined const_local_iterator;

    // construct/destroy/copy
    explicit unordered_set(size_type n = implementation-defined,
                            const hasher& hf = hasher(),
                            const key_equal& eql = key_equal(),
                            const allocator_type& a = allocator_type());
    template <class InputIterator>
    unordered_set(InputIterator f, InputIterator l,
                   size_type n = implementation-defined,
                   const hasher& hf = hasher(),
                   const key_equal& eql = key_equal(),
                   const allocator_type& a = allocator_type());
    unordered_set(const unordered_set&);
    ~unordered_set();
    unordered_set& operator=(const unordered_set&);
    allocator_type get_allocator() const;

    // size and capacity
    bool empty() const;
    size_type size() const;
    size_type max_size() const;

    // iterators
    iterator begin();
    const_iterator begin() const;
    iterator end();
    const_iterator end() const;
    const_iterator cbegin() const;
    const_iterator cend() const;
```

Draft
23.4 TR1: Unordered associative containers

// modifiers
std::pair<iterator, bool> insert(const value_type& obj);
iterator insert(iterator hint, const value_type& obj);
const_iterator insert(const_iterator hint, const value_type& obj);
template <class InputIterator> void insert(InputIterator first, InputIterator last);

iterator erase(iterator position);
const_iterator erase(const_iterator position);
size_type erase(const key_type& k);
iterator erase(iterator first, iterator last);
const_iterator erase(const_iterator first, const_iterator last);
void clear();
void swap(unordered_set&);

// observers
hasher hash_function() const;
key_equal key_eq() const;

// lookup
iterator find(const key_type& k);
const_iterator find(const key_type& k) const;
size_type count(const key_type& k) const;
std::pair<iterator, iterator> equal_range(const key_type& k);
std::pair<const_iterator, const_iterator> equal_range(const key_type& k) const;

// bucket interface
size_type bucket_count() const;
size_type max_bucket_count() const;
size_type bucket_size(size_type n) const;
size_type bucket(const key_type& k) const;
local_iterator begin(size_type n);
const_local_iterator begin(size_type n) const;
local_iterator end(size_type n);
const_local_iterator end(size_type n) const;

// hash policy
float load_factor() const;
float max_load_factor() const;
void max_load_factor(float z);
void rehash(size_type n);
};

template <class Value, class Hash, class Pred, class Alloc>
void swap(unordered_set<Value, Hash, Pred, Alloc>& x,
unordered_set<Value, Hash, Pred, Alloc>& y);

23.4.3.1 unordered_set constructors

explicit unordered_set(size_type n = implementation-defined,
Draft
const hasher& hf = hasher(),
const key_equal& eql = key_equal(),
const allocator_type& a = allocator_type());

Effects: Constructs an empty unordered_set using the specified hash function, key equality function, and allocator, and using at least \( n \) buckets. If \( n \) is not provided, the number of buckets is implementation defined. max_load_factor() returns 1.0.

Complexity: Constant.

template <class InputIterator>
unordered_set(InputIterator f, InputIterator l,
size_type n = implementation-defined,
const hasher& hf = hasher(),
const key_equal& eql = key_equal(),
const allocator_type& a = allocator_type());

Effects: Constructs an empty unordered_set using the specified hash function, key equality function, and allocator, and using at least \( n \) buckets. (If \( n \) is not provided, the number of buckets is implementation defined.) Then inserts elements from the range \([f, l)\). max_load_factor() returns 1.0.

Complexity: Average case linear, worst case quadratic.

23.4.3.2 unordered_set swap

template <class Value, class Hash, class Pred, class Alloc>
void swap(unordered_set<Value, Hash, Pred, Alloc>& x,
unordered_set<Value, Hash, Pred, Alloc>& y);

Effects: x.swap(y).

23.4.4 Class template unordered_multiset

An unordered_multiset is an unordered associative container that supports equivalent keys (an unordered_multiset may contain multiple copies of the same key value) and in which each element’s key is the element itself.

An unordered_multiset satisfies all of the requirements of a container and of an unordered associative container. It provides the operations described in the preceding requirements table for equivalent keys; that is, an unordered_multiset supports the a_eq operations in that table, not the a_uniq operations. For an unordered_multiset<Value> the key type and the value type are both Value. The iterator and const_iterator types are both const_iterator types. It is unspecified whether they are the same type.

This section only describes operations on unordered_multiset that are not described in one of the requirement tables, or for which there is additional semantic information.

template <class Value,
class Hash = hash<Value>,
class Pred = std::equal_to<Value>,
class Alloc = std::allocator<Value> >
class unordered_multiset
{  
public:
    // types
    typedef Value key_type;
    typedef Value value_type;
    typedef Hash hasher;
    typedef Pred key_equal;
    typedef Alloc allocator_type;
    typedef typename allocator_type::pointer pointer;
    typedef typename allocator_type::const_pointer const_pointer;
    typedef typename allocator_type::reference reference;
    typedef typename allocator_type::const_reference const_reference;
    typedef implementation-defined size_type;
    typedef implementation-defined difference_type;
    typedef implementation-defined iterator;
    typedef implementation-defined const_iterator;
    typedef implementation-defined local_iterator;
    typedef implementation-defined const_local_iterator;

    // construct/destroy/copy
    explicit unordered_multiset(size_type n = implementation-defined,
                               const hasher& hf = hasher(),
                               const key_equal& eql = key_equal(),
                               const allocator_type& a = allocator_type());
    template <class InputIterator>
    unordered_multiset(InputIterator f, InputIterator l,
                       size_type n = implementation-defined,
                       const hasher& hf = hasher(),
                       const key_equal& eql = key_equal(),
                       const allocator_type& a = allocator_type());
    unordered_multiset(const unordered_multiset&);
    ~unordered_multiset();
    unordered_multiset& operator=(const unordered_multiset&);
    allocator_type get_allocator() const;

    // size and capacity
    bool empty() const;
    size_type size() const;
    size_type max_size() const;

    // iterators
    iterator begin();
    const_iterator begin() const;
    iterator end();
    const_iterator end() const;
    const_iterator cbegin() const;
    const_iterator cend() const;

Draft
// modifiers
iterator insert(const value_type& obj);
iterator insert(iterator hint, const value_type& obj);
const_iterator insert(const_iterator hint, const value_type& obj);
template <class InputIterator> void insert(InputIterator first, InputIterator last);

iterator erase(iterator position);
const_iterator erase(const_iterator position);
size_type erase(const key_type& k);
iterator erase(iterator first, iterator last);
const_iterator erase(const_iterator first, const_iterator last);
void clear();
void swap(unordered_multiset&);

// observers
hasher hash_function() const;
key_equal key_eq() const;

// lookup
iterator find(const key_type& k);
const_iterator find(const key_type& k) const;
size_type count(const key_type& k) const;
std::pair<iterator, iterator> equal_range(const key_type& k);
std::pair<const_iterator, const_iterator> equal_range(const key_type& k) const;

// bucket interface
size_type bucket_count() const;
size_type max_bucket_count() const;
size_type bucket_size(size_type n);
size_type bucket(const key_type& k) const;
local_iterator begin(size_type n) const;
local_iterator end(size_type n);
const_local_iterator begin(size_type n) const;
const_local_iterator end(size_type n) const;

// hash policy
float load_factor() const;
float max_load_factor() const;
void max_load_factor(float z);
void rehash(size_type n);

};

template <class Value, class Hash, class Pred, class Alloc>
void swap(unordered_multiset<Value, Hash, Pred, Alloc>& x, unordered_multiset<Value, Hash, Pred, Alloc>& y);

23.4.4.1 unordered_multiset constructors

Draft
explicit unordered_multiset(size_type n = implementation-defined,
    const hasher& hf = hasher(),
    const key_equal& eql = key_equal(),
    const allocator_type& a = allocator_type());

    Effects: Constructs an empty unordered_multiset using the specified hash function, key equality function, and
    allocator, and using at least n buckets. If n is not provided, the number of buckets is implementation defined.
    max_load_factor() returns 1.0.

    Complexity: Constant.

template <class InputIterator>
    unordered_multiset(InputIterator f, InputIterator l,
        size_type n = implementation-defined,
        const hasher& hf = hasher(),
        const key_equal& eql = key_equal(),
        const allocator_type& a = allocator_type());

    Effects: Constructs an empty unordered_multiset using the specified hash function, key equality function, and
    allocator, and using at least n buckets. (If n is not provided, the number of buckets is implementation defined.)
    Then inserts elements from the range [f, l). max_load_factor() returns 1.0.

    Complexity: Average case linear, worst case quadratic.

23.4.4.2 unordered_multiset swap

    template <class Value, class Hash, class Pred, class Alloc>
        void swap(unordered_multiset<Value, Hash, Pred, Alloc>& x,
            unordered_multiset<Value, Hash, Pred, Alloc>& y);

    Effects: x.swap(y);
Chapter 24  Iterators library  [lib.iterators]

This clause describes components that C++ programs may use to perform iterations over containers (clause 23), streams (27.6), and stream buffers (27.5).

The following subclauses describe iterator requirements, and components for iterator primitives, predefined iterators, and stream iterators, as summarized in Table 87.

Table 87: Iterators library summary

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.1 Requirements</td>
<td></td>
</tr>
<tr>
<td>24.3 Iterator primitives</td>
<td>&lt;iterator&gt;</td>
</tr>
<tr>
<td>24.4 Predefined iterators</td>
<td></td>
</tr>
<tr>
<td>24.5 Stream iterators</td>
<td></td>
</tr>
</tbody>
</table>

24.1 Iterator requirements  [lib.iterator.requirements]

Iterators are a generalization of pointers that allow a C++ program to work with different data structures (containers) in a uniform manner. To be able to construct template algorithms that work correctly and efficiently on different types of data structures, the library formalizes not just the interfaces but also the semantics and complexity assumptions of iterators. All input iterators \( i \) support the expression \( *i \), resulting in a value of some class, enumeration, or built-in type \( T \), called the value type of the iterator. All output iterators support the expression \( *i = o \) where \( o \) is a value of some type that is in the set of types that are writable to the particular iterator type of \( i \). All iterators \( i \) for which the expression \( (*i).m \) is well-defined, support the expression \( i->m \) with the same semantics as \( (*i).m \). For every iterator type \( X \) for which equality is defined, there is a corresponding signed integral type called the difference type of the iterator.

Since iterators are an abstraction of pointers, their semantics is a generalization of most of the semantics of pointers in C++. This ensures that every function template that takes iterators works as well with regular pointers. This International Standard defines five categories of iterators, according to the operations defined on them: input iterators, output iterators, forward iterators, bidirectional iterators and random access iterators, as shown in Table 88.

Table 88: Relations among iterator categories

| Random Access → Bidirectional → Forward → Input → Output |

Forward iterators satisfy all the requirements of the input and output iterators and can be used whenever either kind is specified; Bidirectional iterators also satisfy all the requirements of the forward iterators and can be used whenever a
24.1 Iterator requirements

A forward iterator is specified; Random access iterators also satisfy all the requirements of bidirectional iterators and can be used whenever a bidirectional iterator is specified.

Besides its category, a forward, bidirectional, or random access iterator can also be mutable or constant depending on whether the result of the expression *i behaves as a reference or as a reference to a constant. Constant iterators do not satisfy the requirements for output iterators, and the result of the expression *i (for constant iterator i) cannot be used in an expression where an lvalue is required.

Just as a regular pointer to an array guarantees that there is a pointer value pointing past the last element of the array, so for any iterator type there is an iterator value that points past the last element of a corresponding container. These values are called past-the-end values. Values of an iterator i for which the expression *i is defined are called dereferenceable. The library never assumes that past-the-end values are dereferenceable. Iterators can also have singular values that are not associated with any container. [Example: After the declaration of an uninitialized pointer x (as with int* x), x must always be assumed to have a singular value of a pointer. —end example] Results of most expressions are undefined for singular values; the only exceptions are destroying an iterator that holds a singular value and the assignment of a non-singular value to an iterator that holds a singular value. In this case the singular value is overwritten the same way as any other value. Dereferenceable values are always non-singular.

An iterator j is called reachable from an iterator i if and only if there is a finite sequence of applications of the expression ++i that makes i == j. If j is reachable from i, they refer to the same container.

Most of the library’s algorithmic templates that operate on data structures have interfaces that use ranges. A range is a pair of iterators that designate the beginning and end of the computation. A range [i,i) is an empty range; in general, a range [i,j) refers to the elements in the data structure starting with the one pointed to by i and up to but not including the one pointed to by j. Range [i,j) is valid if and only if j is reachable from i. The result of the application of functions in the library to invalid ranges is undefined.

All the categories of iterators require only those functions that are realizable for a given category in constant time (amortized). Therefore, requirement tables for the iterators do not have a complexity column.

An invalid iterator is an iterator that may be singular.267

In the following sections, a and b denote values of type X or const X, n denotes a value of the difference type Distance, u, tmp, and m denote identifiers, r denotes a value of some type that is writable to the output iterator.

24.1.1 Input iterators

A class or a built-in type X satisfies the requirements of an input iterator for the value type T if the following expressions are valid, where U is the type of any specified member of type T, as shown in Table 89.

In Table 89, the term the domain of == is used in the ordinary mathematical sense to denote the set of values over which == is (required to be) defined. This set can change over time. Each algorithm places additional requirements on the domain of == for the iterator values it uses. These requirements can be inferred from the uses that algorithm makes of == and !=. [Example: the call find(a,b,x) is defined only if the value of a has the property p defined as follows: b has property p and a value i has property p if (*i==x) or if (*i!=x and ++i has property p). —end example]

267This definition applies to pointers, since pointers are iterators. The effect of dereferencing an iterator that has been invalidated is undefined.
Table 89: Input iterator requirements

<table>
<thead>
<tr>
<th>operation</th>
<th>type</th>
<th>semantics, pre/post-conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>X u(a);</td>
<td>X</td>
<td>post: u is a copy of a A destructor is assumed to be present and accessible.</td>
</tr>
<tr>
<td>u = a;</td>
<td>X&amp;</td>
<td>result: u post: u is a copy of a</td>
</tr>
<tr>
<td>a == b</td>
<td>convertible to bool</td>
<td>== is an equivalence relation over its domain.</td>
</tr>
<tr>
<td>a != b</td>
<td>convertible to bool</td>
<td>bool(a == b) != bool(a != b) over the domain of ==</td>
</tr>
<tr>
<td>*a</td>
<td>convertible to T</td>
<td>pre: a is dereferenceable. If a == b and (a,b) is in the domain of == then *a is equivalent to *b.</td>
</tr>
<tr>
<td>a-&gt;m</td>
<td></td>
<td>pre: (*a).m is well-defined. Equivalent to (*a).m.</td>
</tr>
<tr>
<td>++r</td>
<td>X&amp;</td>
<td>pre: r is dereferenceable. post: r is dereferenceable or r is past-the-end. post: any copies of the previous value of r are no longer required either to be dereferenceable or to be in the domain of ==.</td>
</tr>
<tr>
<td>(void)r++</td>
<td></td>
<td>equivalent to (void)++r</td>
</tr>
<tr>
<td>*r++</td>
<td>convertible to T</td>
<td>{ T tmp = *r; ++r; return tmp; }</td>
</tr>
</tbody>
</table>

3 [Note: For input iterators, a == b does not imply ++a == ++b. (Equality does not guarantee the substitution property or referential transparency.) Algorithms on input iterators should never attempt to pass through the same iterator twice. They should be single pass algorithms. Value type T is not required to be an Assignable type (23.1). These algorithms can be used with istream as the source of the input data through the istream_iterator class. — end note]

24.1.2 Output iterators

A class or a built-in type X satisfies the requirements of an output iterator if X is a CopyConstructible (20.1.3) and Assignable type (23.1) and also the following expressions are valid, as shown in Table 90.

Table 90: Output iterator requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note pre/post-condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>X(a)</td>
<td></td>
<td></td>
<td>a = t is equivalent to X(a) = t. note: a destructor is assumed.</td>
</tr>
<tr>
<td>X u(a);</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X u = a;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*r = o</td>
<td></td>
<td>result is not used</td>
<td></td>
</tr>
<tr>
<td>++r</td>
<td>X&amp;</td>
<td></td>
<td>kr == &amp;++r.</td>
</tr>
</tbody>
</table>
24.1 Iterator requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note</th>
</tr>
</thead>
<tbody>
<tr>
<td>r++</td>
<td>convertible to X &amp;</td>
<td>{ X tmp = r; ++r; return tmp; }</td>
<td></td>
</tr>
<tr>
<td>*r++ = o</td>
<td>result is not used</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 [Note: The only valid use of an operator* is on the left side of the assignment statement. Assignment through the same value of the iterator happens only once. Algorithms on output iterators should never attempt to pass through the same iterator twice. They should be single pass algorithms. Equality and inequality might not be defined. Algorithms that take output iterators can be used with ostrows as the destination for placing data through the ostream_iterator class as well as with insert iterators and insert pointers. — end note ]

24.1.3 Forward iterators

1 A class or a built-in type X satisfies the requirements of a forward iterator if the following expressions are valid, as shown in Table 91.

Table 91: Forward iterator requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note</th>
</tr>
</thead>
<tbody>
<tr>
<td>X u;</td>
<td></td>
<td>note: u might have a singular value. note: a destructor is assumed.</td>
<td></td>
</tr>
<tr>
<td>X()</td>
<td></td>
<td>note: X() might be singular.</td>
<td></td>
</tr>
<tr>
<td>X(a)</td>
<td></td>
<td>a == X(a)</td>
<td></td>
</tr>
<tr>
<td>X u(a); X u = a;</td>
<td></td>
<td>post: u == a.</td>
<td></td>
</tr>
<tr>
<td>a == b</td>
<td>convertible to bool</td>
<td>== is an equivalence relation.</td>
<td></td>
</tr>
<tr>
<td>a != b</td>
<td>convertible to bool</td>
<td>!(a == b)</td>
<td></td>
</tr>
<tr>
<td>r = a</td>
<td>X &amp;</td>
<td>post: r == a</td>
<td></td>
</tr>
<tr>
<td>*a</td>
<td>T if X is mutable, otherwise const T &amp;</td>
<td>pre: a is dereferenceable. a == b implies *a == *b. If X is mutable, *a = t is valid.</td>
<td></td>
</tr>
<tr>
<td>a-&gt;m</td>
<td>U &amp; if X is mutable, otherwise const U &amp;</td>
<td>pre: (*a).m is well-defined.</td>
<td></td>
</tr>
<tr>
<td>x-&gt;m</td>
<td>U &amp;</td>
<td>(*x).m</td>
<td></td>
</tr>
</tbody>
</table>

Draft
24.1 Iterator requirements

---

**Expression** | **Return type** | **Operational semantics** | **Assertion/Note**
---|---|---|---
++r | X& | | pre: r is dereferenceable. post: r is dereferenceable or r is past-the-end. r == s and r is dereferenceable implies ++r == ++s. \&r == &++r.

---

r++ | convertible to | { X tmp = r; ++r; return tmp; } | | |

---

*r++ | T& if X is mutable, otherwise const T& | | | |

---

2 If a and b are equal, then either a and b are both dereferenceable or else neither is dereferenceable.

---

2 Note: The condition that a == b implies ++a == ++b (which is not true for input and output iterators) and the removal of the restrictions on the number of the assignments through the iterator (which applies to output iterators) allows the use of multi-pass one-directional algorithms with forward iterators. --- end note ---

24.1.4 Bidirectional iterators [lib.bidirectional.iterators]

A class or a built-in type X satisfies the requirements of a bidirectional iterator if, in addition to satisfying the requirements for forward iterators, the following expressions are valid as shown in Table 92.

Table 92: Bidirectional iterator requirements (in addition to forward iterator)

---

**Expression** | **Return type** | **Operational semantics** | **Assertion/Note**
---|---|---|---
--r | X& | | pre: there exists s such that r == ++s. post: r is dereferenceable. --(++r) == r. --r == --s implies r == s. \&r == &--r.

---

r-- | convertible to | { X tmp = r; --r; return tmp; } | |

---

*r-- | convertible to T | | | |

---

Draft
A class or a built-in type \( X \) satisfies the requirements of a random access iterator if, in addition to satisfying the requirements for bidirectional iterators, the following expressions are valid as shown in Table 93.

**Table 93: Random access iterator requirements (in addition to bidirectional iterator)**

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note</th>
<th>pre/post-condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r += n )</td>
<td>( X &amp; )</td>
<td>{ Distance ( m = n; )&lt;br&gt;( \text{if} (m &gt; 0) )&lt;br&gt;( \text{while} (m--) )&lt;br&gt;( ++r; )&lt;br&gt;( \text{else} )&lt;br&gt;( \text{while} (m++) )&lt;br&gt;( --r; )&lt;br&gt;( \text{return} r; } )</td>
<td>( a + n == n + a. )</td>
<td></td>
</tr>
<tr>
<td>( a + n )</td>
<td>( X )</td>
<td>{ ( X \text{ tmp } = a; )&lt;br&gt;( \text{return} \text{ tmp } += n; } )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( n + a )</td>
<td>( X &amp; )</td>
<td>( \text{return} r += -n; )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( r -= n )</td>
<td>( X &amp; )</td>
<td>{ ( X \text{ tmp } = a; )&lt;br&gt;( \text{return} \text{ tmp } -= n; } )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( a - n )</td>
<td>( X )</td>
<td>( { X \text{ tmp } = a; )&lt;br&gt;( \text{return} \text{ tmp } -= n; } )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( b - a )</td>
<td>Distance</td>
<td>( (a &lt; b) ? \text{distance}(a,b) :)&lt;br&gt;( -\text{distance}(b,a) )</td>
<td>pre: there exists a value ( n ) of Distance such that ( a + n == b. )&lt;br&gt;( b == a + (b - a). )</td>
<td></td>
</tr>
<tr>
<td>( a[n] )</td>
<td>convertible to ( const T &amp; )</td>
<td>( *(a + n) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( a &lt; b )</td>
<td>convertible to bool</td>
<td>( b - a &gt; 0 )</td>
<td>&lt; is a total ordering relation</td>
<td></td>
</tr>
<tr>
<td>( a &gt; b )</td>
<td>convertible to bool</td>
<td>( b &lt; a )</td>
<td>&gt; is a total ordering relation opposite to &lt;.</td>
<td></td>
</tr>
<tr>
<td>( a &gt;= b )</td>
<td>convertible to bool</td>
<td>( !(a &lt; b) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( a &lt;= b )</td>
<td>convertible to bool</td>
<td>( !(a &gt; b) )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

24.2 Header `<iterator> synopsis`
template<class Category, class T, class Distance = ptrdiff_t, 
    class Pointer = T*, class Reference = T&> struct iterator;

struct input_iterator_tag {};  
struct output_iterator_tag {};  
struct forward_iterator_tag: public input_iterator_tag {};  
struct bidirectional_iterator_tag: public forward_iterator_tag {};  
struct random_access_iterator_tag: public bidirectional_iterator_tag {};

// 24.3.4, iterator operations:
template <class InputIterator, class Distance>  
void advance(InputIterator& i, Distance n);
template <class InputIterator>  
typename iterator_traits<InputIterator>::difference_type 
    distance(InputIterator first, InputIterator last);

// 24.4, predefined iterators:
class reverse_iterator;

template <class Iterator> class reverse_iterator;

template <class Iterator>  
bool operator==(const reverse_iterator<Iterator>& x, 
    const reverse_iterator<Iterator>& y);

template <class Iterator>  
bool operator<(const reverse_iterator<Iterator>& x, 
    const reverse_iterator<Iterator>& y);

template <class Iterator>  
bool operator!=(const reverse_iterator<Iterator>& x, 
    const reverse_iterator<Iterator>& y);

template <class Iterator>  
bool operator>(const reverse_iterator<Iterator>& x, 
    const reverse_iterator<Iterator>& y);

template <class Iterator>  
bool operator>=(const reverse_iterator<Iterator>& x, 
    const reverse_iterator<Iterator>& y);

template <class Iterator>  
bool operator<=(const reverse_iterator<Iterator>& x, 
    const reverse_iterator<Iterator>& y);

template <class Iterator>  
typename reverse_iterator<Iterator>::difference_type 
    operator-(const reverse_iterator<Iterator>& x, 
        const reverse_iterator<Iterator>& y);
reverse_iterator<Iterator>
operator+(typename reverse_iterator<Iterator>::difference_type n, const reverse_iterator<Iterator>& x);

template <class Container> class back_insert_iterator;
template <class Container>
back_insert_iterator<Container> back_inserter(Container& x);

template <class Container> class front_insert_iterator;
template <class Container>
front_insert_iterator<Container> front_inserter(Container& x);

template <class Container> class insert_iterator;
template <class Container, class Iterator>
insert_iterator<Container> inserter(Container& x, Iterator i);

// 24.5, stream iterators:
template <class T, class charT = char, class traits = char_traits<charT>,
class Distance = ptrdiff_t>
class istream_iterator;
template <class T, class charT, class traits, class Distance>
bool operator==(const istream_iterator<T,charT,traits,Distance>& x, const istream_iterator<T,charT,traits,Distance>& y);
template <class T, class charT, class traits, class Distance>
bool operator!=(const istream_iterator<T,charT,traits,Distance>& x, const istream_iterator<T,charT,traits,Distance>& y);

template <class T, class charT = char, class traits = char_traits<charT>>
class ostream_iterator;
template<class charT, class traits = char_traits<charT>>
class istreambuf_iterator;
template <class charT, class traits>
bool operator==(const istreambuf_iterator<charT,traits>& a, const istreambuf_iterator<charT,traits>& b);
template <class charT, class traits>
bool operator!=(const istreambuf_iterator<charT,traits>& a, const istreambuf_iterator<charT,traits>& b);

template <class charT, class traits = char_traits<charT>>
class ostreambuf_iterator;
}
To simplify the task of defining iterators, the library provides several classes and functions:

### 24.3.1 Iterator traits

To implement algorithms only in terms of iterators, it is often necessary to determine the value and difference types that correspond to a particular iterator type. Accordingly, it is required that if `Iterator` is the type of an iterator, the types

```
iterator_traits<Iterator>::difference_type
iterator_traits<Iterator>::value_type
iterator_traits<Iterator>::iterator_category
```

be defined as the iterator’s difference type, value type and iterator category, respectively. In addition, the types

```
iterator_traits<Iterator>::reference
iterator_traits<Iterator>::pointer
```

shall be defined as the iterator’s reference and pointer types, that is, for an iterator object `a`, the same type as the type of `*a` and `a->`, respectively. In the case of an output iterator, the types

```
iterator_traits<Iterator>::difference_type
iterator_traits<Iterator>::value_type
iterator_traits<Iterator>::reference
iterator_traits<Iterator>::pointer
```

may be defined as `void`.

The template `iterator_traits<Iterator>` is defined as

```
namespace std {
  template<class Iterator> struct iterator_traits {
    typedef typename Iterator::difference_type difference_type;
    typedef typename Iterator::value_type value_type;
    typedef typename Iterator::iterator_category iterator_category;
    typedef void difference_type;
    typedef void value_type;
    typedef void reference;
    typedef void pointer;
  };
}
```

It is specialized for pointers as

```
namespace std {
  template<class T> struct iterator_traits<T*> {
    typedef ptrdiff_t difference_type;
    typedef T value_type;
    typedef T* pointer;
    typedef T& reference;
    typedef random_access_iterator_tag iterator_category;
  };
}
```

and for pointers to const as
namespace std {
    template<class T> struct iterator_traits<const T*> {
        typedef ptrdiff_t difference_type;
        typedef T value_type;
        typedef const T* pointer;
        typedef const T& reference;
        typedef random_access_iterator_tag iterator_category;
    };
}

/* end note */

Example: To implement a generic reverse function, a C++ program can do the following:

```cpp
template <class BidirectionalIterator>
void reverse(BidirectionalIterator first, BidirectionalIterator last) {
    typename iterator_traits<BidirectionalIterator>::difference_type n =
    distance(first, last);
    --n;
    while(n > 0) {
        typename iterator_traits<BidirectionalIterator>::value_type
        tmp = *first;
        *first++ = *--last;
        *last = tmp;
        n -= 2;
    }
}
/* end example */

24.3.2 Basic iterator

The iterator template may be used as a base class to ease the definition of required types for new iterators.

namespace std {
    template<
class Category, class T, class Distance = ptrdiff_t,
class Pointer = T*, class Reference = T&>
    struct iterator {
        typedef T value_type;
        typedef Distance difference_type;
        typedef Pointer pointer;
```
typedef Reference reference;
typedef Category iterator_category;
};
}

### 24.3.3 Standard iterator tags

It is often desirable for a function template specialization to find out what is the most specific category of its iterator argument, so that the function can select the most efficient algorithm at compile time. To facilitate this, the library introduces *category tag* classes which are used as compile time tags for algorithm selection. They are: `input_iterator_tag`, `output_iterator_tag`, `forward_iterator_tag`, `bidirectional_iterator_tag` and `random_access_iterator_tag`. For every iterator of type `Iterator`, `iterator_traits<Iterator>::iterator_category` shall be defined to be the most specific category tag that describes the iterator’s behavior.

```cpp
namespace std {
    struct input_iterator_tag {}
    struct output_iterator_tag {}
    struct forward_iterator_tag : public input_iterator_tag {}
    struct bidirectional_iterator_tag : public forward_iterator_tag {}
    struct random_access_iterator_tag : public bidirectional_iterator_tag {}
}
```

**Example:** For a program-defined iterator `BinaryTreeIterator`, it could be included into the bidirectional iterator category by specializing the `iterator_traits` template:

```cpp
template<class T> struct iterator_traits<BinaryTreeIterator<T> > {
    typedef std::ptrdiff_t difference_type;
    typedef T value_type;
    typedef T* pointer;
    typedef T& reference;
    typedef bidirectional_iterator_tag iterator_category;
};
```

Typically, however, it would be easier to derive `BinaryTreeIterator<T>` from `iterator<bidirectional_iterator_tag,T,T*,T&>`. — *end example*

**Example:** If `evolve()` is well defined for bidirectional iterators, but can be implemented more efficiently for random access iterators, then the implementation is as follows:

```cpp
template <class BidirectionalIterator>
inline void
evolve(BidirectionalIterator first, BidirectionalIterator last) {
    evolve(first, last,
        typename iterator_traits<BidirectionalIterator>::iterator_category());
}

template <class BidirectionalIterator>
void evolve(BidirectionalIterator first, BidirectionalIterator last,
    bidirectional_iterator_tag) {
    //... more generic, but less efficient algorithm
}
```

Draft
template <class RandomAccessIterator>
void evolve(RandomAccessIterator first, RandomAccessIterator last,
random_access_iterator_tag) {
    //... more efficient, but less generic algorithm
}

/* end example */

/* Example: If a C++ program wants to define a bidirectional iterator for some data structure containing double and such that it works on a large memory model of the implementation, it can do so with:
   
   class MyIterator :
       public iterator<bidirectional_iterator_tag, double, long, T*, T&> {
       // code implementing ++, etc.
   };

Then there is no need to specialize the iterator_traits template.  — end example */

24.3.4 Iterator operations [lib.iterator.operations]

1 Since only random access iterators provide + and - operators, the library provides two function templates advance and distance. These function templates use + and - for random access iterators (and are, therefore, constant time for them); for input, forward and bidirectional iterators they use ++ to provide linear time implementations.

    template <class InputIterator, class Distance>
    void advance(InputIterator& i, Distance n);

2 Requires: n may be negative only for random access and bidirectional iterators.

3 Effects: Increments (or decrements for negative n) iterator reference i by n.

    template<class InputIterator>
    typename iterator_traits<InputIterator>::difference_type
distance(InputIterator first, InputIterator last);

4 Effects: Returns the number of increments or decrements needed to get from first to last.

5 Requires: last shall be reachable from first.

24.4 Predefined iterators [lib.predef.iterators]

24.4.1 Reverse iterators [lib.reverse.iterators]

1 Bidirectional and random access iterators have corresponding reverse iterator adaptors that iterate through the data structure in the opposite direction. They have the same signatures as the corresponding iterators. The fundamental relation between a reverse iterator and its corresponding iterator i is established by the identity: &*(reverse_iterator(i)) == &*(i - 1).

2 This mapping is dictated by the fact that while there is always a pointer past the end of an array, there might not be a valid pointer before the beginning of an array.

24.4.1.1 Class template reverse_iterator [lib.reverse.iterator]

Draft
namespace std {
    template <class Iterator>
    class reverse_iterator : public
        iterator<typename iterator_traits<Iterator>::iterator_category,
            typename iterator_traits<Iterator>::value_type,
            typename iterator_traits<Iterator>::difference_type,
            typename iterator_traits<Iterator>::pointer,
            typename iterator_traits<Iterator>::reference> {

protected:
    Iterator current;

public:
    typedef Iterator
        iterator_type;
    typedef typename iterator_traits<Iterator>::difference_type
        difference_type;
    typedef typename iterator_traits<Iterator>::reference
        reference;
    typedef typename iterator_traits<Iterator>::pointer
        pointer;

    reverse_iterator();
    explicit reverse_iterator(Iterator x);
    template <class U> reverse_iterator(const reverse_iterator<U>& u);
    template <class U> reverse_iterator operator=(const reverse_iterator<U>& u);

    Iterator base() const;  // explicit
    reference operator*() const;
    pointer operator->() const;

    reverse_iterator& operator++();
    reverse_iterator operator++(int);
    reverse_iterator& operator--();
    reverse_iterator operator--(int);

    reverse_iterator operator+ (difference_type n) const;
    reverse_iterator& operator+=(difference_type n);
    reverse_iterator operator- (difference_type n) const;
    reverse_iterator& operator-=(difference_type n);

    unspecified operator[](difference_type n) const;
};

template <class Iterator1, class Iterator2>
bool operator=(
    const reverse_iterator<Iterator1>& x,
    const reverse_iterator<Iterator2>& y);

template <class Iterator1, class Iterator2>
bool operator<(const reverse_iterator<Iterator1>& x,
    const reverse_iterator<Iterator2>& y);
24.4 Predefined iterators

24.4.1.2 reverse_iterator requirements

1 The template parameter Iterator shall meet all the requirements of a Bidirectional Iterator (24.1.4).

2 Additionally, Iterator shall meet the requirements of a Random Access Iterator (24.1.5) if any of the members operator+ (24.4.1.3.8), operator- (24.4.1.3.10), operator+= (24.4.1.3.9), operator-= (24.4.1.3.11), operator [] (24.4.1.3.12), or the global operators operator< (24.4.1.3.14), operator> (24.4.1.3.16), operator <= (24.4.1.3.18), operator>= (24.4.1.3.17), operator~ (24.4.1.3.19) or operator+ (24.4.1.3.20). is referenced in a way that requires instantiation (14.7.1).

24.4.1.3 reverse_iterator operations

24.4.1.3.1 reverse_iterator constructor

reverse_iterator();

1 Effects: Default initializes current. Iterator operations applied to the resulting iterator have defined behavior if and only if the corresponding operations are defined on a default constructed iterator of type Iterator.
explicit reverse_iterator(Iterator x);

*Effects:* Initializes current with x.

template<class U> reverse_iterator(const reverse_iterator&amp; u);

*Effects:* Initializes current with u . current.

### 24.4.1.3.2 reverse_iterator::operator=

```cpp
template<class U>
reverse_iterator&amp; operator=(const reverse_iterator&amp; u);
```

*Effects:* Assigns u . base() to current.

*Returns:* *this.

### 24.4.1.3.3 Conversion

```cpp
Iterator base() const; // explicit
```

*Returns:* current.

### 24.4.1.3.4 operator*

```cpp
reference operator*() const;
```

*Effects:

this->tmp = current;
--this->tmp;
return *this->tmp;

*Note:* This operation must use an auxiliary member variable, rather than a temporary variable, to avoid returning a reference that persists beyond the lifetime of its associated iterator. (See 24.1.) The name of this member variable is shown for exposition only. — end note

### 24.4.1.3.5 operator->

```cpp
pointer operator->() const;
```

*Effects:

return &(operator*());
### 24.4.1.3.6 operator++

```cpp
type reverse_iterator& operator++();
```

1. **Effects:** --current;
2. **Returns:** *this.

```cpp
type reverse_iterator operator++(int);
```

1. **Effects:**
   - reverse_iterator tmp = *this;
   - --current;
   - return tmp;

### 24.4.1.3.7 operator--

```cpp
type reverse_iterator& operator--();
```

1. **Effects:** ++current
2. **Returns:** *this.

```cpp
type reverse_iterator operator--(int);
```

1. **Effects:**
   - reverse_iterator tmp = *this;
   - ++current;
   - return tmp;

### 24.4.1.3.8 operator+

```cpp
type reverse_iterator operator+(typename reverse_iterator<Iterator>::difference_type n) const;
```

1. **Returns:** reverse_iterator(current-n).

### 24.4.1.3.9 operator+=

```cpp
type reverse_iterator& operator+=(typename reverse_iterator<Iterator>::difference_type n);
```

1. **Effects:** current -= n;
2. **Returns:** *this.
24.4.1.3.10 operator-  

reverse_iterator  
operator-((typename reverse_iterator<Iterator>::difference_type n) const;  
1  
   Returns: reverse_iterator(current+n).

24.4.1.3.11 operator-=  

reverse_iterator&  
operator-=(typename reverse_iterator<Iterator>::difference_type n);  
1  
   Effects: current += n;  
2  
   Returns: *this.

24.4.1.3.12 operator[]  

\textit{unspecified}  
operator[](typename reverse_iterator<Iterator>::difference_type n) const;  
1  
   Returns: current[-n-1].

24.4.1.3.13 operator==  

\texttt{template} <\texttt{class} Iterator1,\texttt{class} Iterator2>  
bool operator==(
   const reverse_iterator<Iterator1>& x,  
   const reverse_iterator<Iterator2>& y);  
1  
   Returns: x.current == y.current.

24.4.1.3.14 operator<  

\texttt{template} <\texttt{class} Iterator1,\texttt{class} Iterator2>  
bool operator<(
   const reverse_iterator<Iterator1>& x,  
   const reverse_iterator<Iterator2>& y);  
1  
   Returns: x.current > y.current.

24.4.1.3.15 operator!=  

\texttt{template} <\texttt{class} Iterator1,\texttt{class} Iterator2>  
bool operator!=(
   const reverse_iterator<Iterator1>& x,  
   const reverse_iterator<Iterator2>& y);
 Returns: \(x\.current \neq y\.current\).

### 24.4.1.3.16 operator>  

[lib.reverse.iter.op>]

\[
\text{template <class Iterator1, class Iterator2>}
\text{bool operator>}(  
  \text{const reverse_iterator<Iterator1>& x,}
  \text{const reverse_iterator<Iterator2>& y});
\]

Returns: \(x\.current < y\.current\).

### 24.4.1.3.17 operator>=(  

[lib.reverse.iter.op>=]

\[
\text{template <class Iterator1, class Iterator2>}
\text{bool operator>=(  }
  \text{const reverse_iterator<Iterator1>& x,}
  \text{const reverse_iterator<Iterator2>& y});
\]

Returns: \(x\.current \leq y\.current\).

### 24.4.1.3.18 operator<=  

[lib.reverse.iter.op<=]

\[
\text{template <class Iterator1, class Iterator2>}
\text{bool operator<=(  }
  \text{const reverse_iterator<Iterator1>& x,}
  \text{const reverse_iterator<Iterator2>& y});
\]

Returns: \(x\.current \geq y\.current\).

### 24.4.1.3.19 operator-  

[lib.reverse.iter.opdiff]

\[
\text{template <class Iterator1, class Iterator2>}
\text{typename reverse_iterator<Iterator>::difference_type operator-}(  
  \text{const reverse_iterator<Iterator1>& x,}
  \text{const reverse_iterator<Iterator2>& y});
\]

Returns: \(y\.current - x\.current\).

### 24.4.1.3.20 operator+  

[lib.reverse.iter.opsum]

\[
\text{template <class Iterator>}
\text{reverse_iterator<Iterator> operator+}(  
  \text{typename reverse_iterator<Iterator>::difference_type n,}
  \text{const reverse_iterator<Iterator>& x});
\]

Returns: \(\text{reverse_iterator<Iterator> (x\.current - n)}\).
24.4.2 Insert iterators

To make it possible to deal with insertion in the same way as writing into an array, a special kind of iterator adaptors, called insert iterators, are provided in the library. With regular iterator classes,

```cpp
while (first != last) *result++ = *first++;
```

causes a range \([\text{first}, \text{last})\) to be copied into a range starting with result. The same code with result being an insert iterator will insert corresponding elements into the container. This device allows all of the copying algorithms in the library to work in the insert mode instead of the regular overwrite mode.

An insert iterator is constructed from a container and possibly one of its iterators pointing to where insertion takes place if it is neither at the beginning nor at the end of the container. Insert iterators satisfy the requirements of output iterators. \texttt{operator*} returns the insert iterator itself. The assignment \texttt{operator=(\texttt{const T} & x)} is defined on insert iterators to allow writing into them, it inserts \(x\) right before where the insert iterator is pointing. In other words, an insert iterator is like a cursor pointing into the container where the insertion takes place. \texttt{back_insert_iterator} inserts elements at the end of a container, \texttt{front_insert_iterator} inserts elements at the beginning of a container, and \texttt{insert_iterator} inserts elements where the iterator points to in a container. \texttt{back_inserter}, \texttt{front_inserter}, and \texttt{inserter} are three functions making the insert iterators out of a container.

24.4.2.1 Class template back_insert_iterator

```cpp
namespace std {
    template <class Container>
    class back_insert_iterator :
        public iterator<output_iterator_tag,void,void,void,void> {
            protected:
                Container* container;

            public:
                typedef Container container_type;
                explicit back_insert_iterator(Container& x);
                back_insert_iterator<Container>&
                    operator=(typename Container::const_reference value);

                back_insert_iterator<Container>& operator*();
                back_insert_iterator<Container>& operator++();
                back_insert_iterator<Container>    operator++(int);

            };

    template <class Container>
    back_insert_iterator<Container> back_inserter(Container& x);
}
```

24.4.2.2 back_insert_iterator operations

**24.4.2.2.1 back_insert_iterator constructor**

```cpp
explicit back_insert_iterator(Container& x);
```

*Effects:* Initializes container with &\(x\).*

Draft
24.4 Predefined iterators

24.4.2.2 back_insert_iterator::operator=

back_insert_iterator<Container>&
operator=(typename Container::const_reference value);

1 Effects: container->push_back(value);
2 Returns: *this.

24.4.2.2.3 back_insert_iterator::operator*

back_insert_iterator<Container>& operator*();

1 Returns: *this.

24.4.2.2.4 back_insert_iterator::operator++

back_insert_iterator<Container>& operator++();
back_insert_iterator<Container> operator++(int);

1 Returns: *this.

24.4.2.2.5 back_inserter

template <class Container>
back_insert_iterator<Container> back_inserter(Container& x);

1 Returns: back_insert_iterator<Container>(x).

24.4.2.3 Class template front_insert_iterator

namespace std {
  template <class Container>
  class front_insert_iterator :
    public iterator<input_iterator_tag,void,void,void,void> {
    protected:
      Container* container;

    public:
      typedef Container container_type;
      explicit front_insert_iterator(Container& x);
      front_insert_iterator<Container>&
      operator=(typename Container::const_reference value);

      front_insert_iterator<Container>& operator*();
      front_insert_iterator<Container>& operator++();
      front_insert_iterator<Container> operator++(int);
    };

Draft
template <class Container>
    front_insert_iterator<Container> front_inserter(Container& x);
}

24.4.2.4 front_insert_iterator operations

24.4.2.4.1 front_insert_iterator constructor

explicit front_insert_iterator(Container& x);

Effects: Initializes container with &x.

24.4.2.4.2 front_insert_iterator::operator=

front_insert_iterator<Container>&
    operator=(typename Container::const_reference value);

Effects: container->push_front(value);

Returns: *this.

24.4.2.4.3 front_insert_iterator::operator*

front_insert_iterator<Container>& operator*();

Returns: *this.

24.4.2.4.4 front_insert_iterator::operator++

front_insert_iterator<Container>& operator++();
    front_insert_iterator<Container> operator++(int);

Returns: *this.

24.4.2.5 front_inserter

template <class Container>
    front_insert_iterator<Container> front_inserter(Container& x);

Returns: front_insert_iterator<Container>(x).

24.4.2.5 Class template insert_iterator

namespace std {
    template <class Container>
        class insert_iterator :
            public iterator<input_iterator_tag, void, void, void, void> {

Draft
24.4 Predefined iterators

protected:
    Container* container;
    typename Container::iterator iter;

public:
    typedef Container container_type;
    insert_iterator(Container& x, typename Container::iterator i);
    insert_iterator<Container>&
        operator=(typename Container::const_reference value);
    insert_iterator<Container>&
        operator*();
    insert_iterator<Container>&
        operator++();
    insert_iterator<Container>&
        operator++(int);
};

template <class Container, class Iterator>
    insert_iterator<Container> inserter(Container& x, Iterator i);

24.4.2.6 insert_iterator operations

24.4.2.6.1 insert_iterator constructor

    insert_iterator(Container& x, typename Container::iterator i);

    Effects: Initializes container with &x and iter with i.

24.4.2.6.2 insert_iterator::operator=

    insert_iterator<Container>&
        operator=(typename Container::const_reference value);

    Effects:
        iter = container->insert(iter, value);
        ++iter;

    Returns: *this.

24.4.2.6.3 insert_iterator::operator*

    insert_iterator<Container>&
        operator*();

    Returns: *this.

24.4.2.6.4 insert_iterator::operator++

    insert_iterator<Container>&
        operator++();
    insert_iterator<Container>&
        operator++(int);
1 Returns: *this.

### 24.4.2.6.5 inserter

```
template <class Container, class Inserter>
insert_iterator<Container> inserter(Container& x, Inserter i);
```

1 Returns: `insert_iterator<Container>(x,typename Container::iterator(i))`.

### 24.5 Stream iterators

To make it possible for algorithmic templates to work directly with input/output streams, appropriate iterator-like class templates are provided.

[Example:
```
partial_sum_copy(istream_iterator<double, char>(cin),
                istream_iterator<double, char>(),
                ostream_iterator<double, char>(cout, "\n"));
```
reads a file containing floating point numbers from `cin`, and prints the partial sums onto `cout`. —end example]

### 24.5.1 Class template `istream_iterator`

`istream_iterator` reads (using `operator>>`) successive elements from the input stream for which it was constructed. After it is constructed, and every time `++` is used, the iterator reads and stores a value of `T`. If the end of stream is reached (`operator void*()` on the stream returns `false`), the iterator becomes equal to the *end-of-stream* iterator value. The constructor with no arguments `istream_iterator()` always constructs an end of stream input iterator object, which is the only legitimate iterator to be used for the end condition. The result of `operator*` on an end of stream is not defined. For any other iterator value a `const T&` is returned. The result of `operator->` on an end of stream is not defined. For any other iterator value a `const T*` is returned. It is impossible to store things into istream iterators. The main peculiarity of the istream iterators is the fact that `++` operators are not equality preserving, that is, `i == j` does not guarantee at all that `++i == ++j`. Every time `++` is used a new value is read.

1 The practical consequence of this fact is that istream iterators can be used only for one-pass algorithms, which actually makes perfect sense, since for multi-pass algorithms it is always more appropriate to use in-memory data structures.

2 Two end-of-stream iterators are always equal. An end-of-stream iterator is not equal to a non-end-of-stream iterator. Two non-end-of-stream iterators are equal when they are constructed from the same stream.

```
namespace std {
    template <class T, class charT = char, class traits = char_traits<charT>,
              class Distance = ptrdiff_t>
    class istream_iterator:
    public iterator<input_iterator_tag, T, Distance, const T*, const T&> {
        public:
            typedef charT char_type;
            typedef traits traits_type;
            typedef basic_istream<charT,traits> istream_type;
            istream_iterator();
```
24.5 Stream iterators

`istream_iterator(istream_type& s);`
`istream_iterator(const istream_iterator<T,charT,traits,Distance>& x);`
`~istream_iterator();`

`const T& operator*() const;`
`const T* operator->() const;`
`istream_iterator<T,charT,traits,Distance>& operator++();`
`istream_iterator<T,charT,traits,Distance> operator++(int);`

private:
// basic_istream<charT,traits>* in_stream;  
// T value;  
{

};

template <class T, class charT, class traits, class Distance>
bool operator==(const istream_iterator<T,charT,traits,Distance>& x,
const istream_iterator<T,charT,traits,Distance>& y);

template <class T, class charT, class traits, class Distance>
bool operator!=(const istream_iterator<T,charT,traits,Distance>& x,
const istream_iterator<T,charT,traits,Distance>& y);

24.5.1.1 istream_iterator constructors and destructor

`istream_iterator();`

1. **Effects:** Constructs the end-of-stream iterator.

`istream_iterator(istream_type& s);`

2. **Effects:** Initializes `in_stream` with `s`. `value` may be initialized during construction or the first time it is referenced.

`istream_iterator(const istream_iterator<T,charT,traits,Distance>& x);`

3. **Effects:** Constructs a copy of `x`.

`~istream_iterator();`

4. **Effects:** The iterator is destroyed.

24.5.1.2 istream_iterator operations

`const T& operator*() const;`

1. **Returns:** `value`.

`const T* operator->() const;`

2. **Returns:** `&(operator*())`.

`istream_iterator<T,charT,traits,Distance>& operator++();`

3. **Effects:** `*in_stream >> value`. 

Draft
Returns: *this.

```cpp
istream_iterator<T, charT, traits, Distance> operator++(int);
```

Effects:

```cpp
istream_iterator<T, charT, traits, Distance> tmp = *this;
*in_stream >> value;
return (tmp);
```

```cpp
template <class T, class charT, class traits, class Distance>
bool operator==(const istream_iterator<T, charT, traits, Distance> &x,
const istream_iterator<T, charT, traits, Distance> &y);
```

Returns: `(x.in_stream == y.in_stream)`.

```cpp
template <class T, class charT, class traits, class Distance>
bool operator!=(const istream_iterator<T, charT, traits, Distance> &x,
const istream_iterator<T, charT, traits, Distance> &y);
```

Returns: !(x == y)

### 24.5.2 Class template `ostream_iterator`

`ostream_iterator<T, charT, traits, Distance>` writes (using `operator<<`) successive elements onto the output stream from which it was constructed. If it was constructed with `char*` as a constructor argument, this string, called a **delimiter string**, is written to the stream after every `T` is written. It is not possible to get a value out of the output iterator. Its only use is as an output iterator in situations like

```cpp
while (first != last) *result++ = *first++;
```

`ostream_iterator` is defined as:

```cpp
namespace std {
    template <class T, class charT = char, class traits = char_traits<charT> >
    class ostream_iterator {
        public:
            iterator<output_iterator_tag, void, void, void, void> { public:
                typedef charT char_type;
                typedef traits traits_type;
                typedef basic_ostream<charT, traits> ostream_type;
                ostream_iterator(ostream_type& s);
                ostream_iterator(ostream_type& s, const charT* delimiter);
                ostream_iterator(const ostream_iterator<T, charT, traits>& x);
                ~ostream_iterator();
                ostream_iterator& operator=(const T& value);
                ostream_iterator& operator*();
                ostream_iterator& operator++();
            }
        private:
    }
}
```

Draft
24.5 Stream iterators

Iterators library 692

// basic_ostream<charT,traits>* out_stream;
// const charT* delim;
};

24.5.2.1 ostream_iterator constructors and destructor

ostream_iterator(ostream_type& s);

Effects: Initializes out_stream with s and delim with null.

ostream_iterator(ostream_type& s, const charT* delimiter);

Effects: Initializes out_stream with s and delim with delimiter.

ostream_iterator(const ostream_iterator& x);

Effects: Constructs a copy of x.

~ostream_iterator();

Effects: The iterator is destroyed.

24.5.2.2 ostream_iterator operations

ostream_iterator& operator=(const T& value);

Effects:
*out_stream << value;
if(delim != 0) *out_stream << delim;
return (*this);

ostream_iterator& operator*();

Returns: *this.

ostream_iterator& operator++();
ostream_iterator& operator++(int);

Returns: *this.

24.5.3 Class template istreambuf_iterator

namespace std {
    template<class charT, class traits = char_traits<charT> >
    class istreambuf_iterator :
    public iterator<input_iterator_tag, charT,
        typename traits::off_type, charT*, charT> {

public:
    typedef charT char_type;
    typedef traits traits_type;

Draft
The class template `istreambuf_iterator` reads successive `characters` from the streambuf for which it was constructed. `operator*` provides access to the current input character, if any. Each time `operator++` is evaluated, the iterator advances to the next input character. If the end of stream is reached (streambuf_type::sgetc() returns traits::eof()), the iterator becomes equal to the end of stream iterator value. The default constructor `istreambuf_iterator()` and the constructor `istreambuf_iterator(0)` both construct an end of stream iterator object suitable for use as an end-of-range.

1 The result of `operator*()` on an end of stream is undefined. For any other iterator value a `char_type` value is returned. It is impossible to assign a character via an input iterator.

2 Note that in the input iterators, ++ operators are not equality preserving, that is, i == j does not guarantee at all that ++i == ++j. Every time ++ is evaluated a new value is used.

3 The practical consequence of this fact is that an `istreambuf_iterator` object can be used only for one-pass algorithms. Two end of stream iterators are always equal. An end of stream iterator is not equal to a non-end-of-stream iterator.

24.5.3.1 Class template `istreambuf_iterator::proxy` [lib.istreambuf.iterator::proxy]

```c++
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class istreambuf_iterator<charT, traits>::proxy {
        charT keep_;
};
```
24.5 Stream iterators

basic_streambuf<charT,traits>* sbuf_;
proxy(charT c,
    basic_streambuf<charT,traits>* sbuf);
    : keep_(c), sbuf_(sbuf) {}}
public:
    charT operator*() { return keep_; }
};

Class istreambuf_iterator<charT,traits>::proxy is for exposition only. An implementation is permitted to provide equivalent functionality without providing a class with this name. Class istreambuf_iterator<charT, traits>::proxy provides a temporary placeholder as the return value of the post-increment operator (operator++). It keeps the character pointed to by the previous value of the iterator for some possible future access to get the character.

24.5.3.2 istreambuf_iterator constructors

istreambuf_iterator() throw();

Effects: Constructs the end-of-stream iterator.

istreambuf_iterator(basic_istream<charT,traits>& s) throw();
istreambuf_iterator(basic_streambuf<charT,traits>* s) throw();

Effects: Constructs an istreambuf_iterator<> that uses the basic_streambuf<> object *(s.rdbuf()), or *s, respectively. Constructs an end-of-stream iterator if s.rdbuf() is null.

istreambuf_iterator(const proxy& p) throw();

Effects: Constructs a istreambuf_iterator<> that uses the basic_streambuf<> object pointed to by the proxy object's constructor argument p.

24.5.3.3 istreambuf_iterator::operator*

charT operator*() const

Returns: The character obtained via the streambuf member sbuf_->sgetc().

24.5.3.4 istreambuf_iterator::operator++

istreambuf_iterator<charT,traits>&
    istreambuf_iterator<charT,traits>::operator++();

Effects: sbuf_->sbumpc().

Returns: *this.

proxy istreambuf_iterator<charT,traits>::operator++(int);

Returns: proxy(sbuf_->sbumpc(), sbuf_).
24.5.3.5  istreambuf_iterator::equal

    bool equal(istreambuf_iterator<charT,traits>& b) const;

Returns: true if and only if both iterators are at end-of-stream, or neither is at end-of-stream, regardless of what
streambuf object they use.

24.5.3.6  operator==

    template <class charT, class traits>
    bool operator==(const istreambuf_iterator<charT,traits>& a,
                   const istreambuf_iterator<charT,traits>& b);

Returns: a.equal(b).

24.5.3.7  operator!=

    template <class charT, class traits>
    bool operator!=(const istreambuf_iterator<charT,traits>& a,
                   const istreambuf_iterator<charT,traits>& b);

Returns: !a.equal(b).

24.5.4  Class template ostreambuf_iterator

namespace std {
    template <class charT, class traits = char_traits<charT>>
    class ostreambuf_iterator:
        public iterator<output_iterator_tag, void, void, void, void> {
        public:
            typedef charT char_type;
            typedef traits traits_type;
            typedef basic_streambuf<charT,traits> streambuf_type;
            typedef basic_ostream<charT,traits> ostream_type;

        public:
            ostreambuf_iterator(ostream_type& s) throw();
            ostreambuf_iterator(streambuf_type* s) throw();
            ostreambuf_iterator& operator=(charT c);
            ostreambuf_iterator& operator*();
            ostreambuf_iterator& operator++();
            ostreambuf_iterator& operator++(int);
            bool failed() const throw();

        private:
            // streambuf_type* sbuf; exposition only

    Draft
The class template `ostreambuf_iterator` writes successive `characters` onto the output stream from which it was constructed. It is not possible to get a character value out of the output iterator.

### 24.5.4.1 `ostreambuf_iterator` constructors

```cpp
ostreambuf_iterator(ostream_type& s) throw();
```

**Requires**: `s.rdbuf()` is not null.

**Effects**: `sbuf_((s.rdbuf()))`.

```cpp
ostreambuf_iterator(streambuf_type* s) throw();
```

**Requires**: `s` is not null.

**Effects**: `sbuf_((s))`.

### 24.5.4.2 `ostreambuf_iterator` operations

```cpp
ostreambuf_iterator<charT,traits>& operator=(charT c);
```

**Effects**: If `failed()` yields `false`, calls `sbuf_->sputc(c)`; otherwise has no effect.

**Returns**: `*this`.

```cpp
ostreambuf_iterator<charT,traits>& operator*();
```

**Returns**: `*this`.

```cpp
ostreambuf_iterator<charT,traits>& operator++();
ostreambuf_iterator<charT,traits>& operator++(int);
```

**Returns**: `*this`.

```cpp
bool failed() const throw();
```

**Returns**: `true` if in any prior use of member `operator=`, the call to `sbuf_->sputc()` returned `traits::eof()`; or `false` otherwise.

Draft
Chapter 25  Algorithms library  [lib.algorithms]

1. This clause describes components that C++ programs may use to perform algorithmic operations on containers (clause 23) and other sequences.

2. The following subclauses describe components for non-modifying sequence operation, modifying sequence operations, sorting and related operations, and algorithms from the ISO C library, as summarized in Table 94.

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.1 Non-modifying sequence operations</td>
<td>&lt;algorithm&gt;</td>
</tr>
<tr>
<td>25.2 Mutating sequence operations</td>
<td>&lt;algorithm&gt;</td>
</tr>
<tr>
<td>25.3 Sorting and related operations</td>
<td>&lt;algorithm&gt;</td>
</tr>
<tr>
<td>25.4 C library algorithms</td>
<td>&lt;cstdlib&gt;</td>
</tr>
</tbody>
</table>

Header <algorithm> synopsis

namespace std {

  // 25.1, non-modifying sequence operations:
  template<class InputIterator, class Function>
      Function for_each(InputIterator first, InputIterator last, Function f);
  template<class InputIterator, class T>
      InputIterator find(InputIterator first, InputIterator last, const T& value);
  template<class InputIterator, class Predicate>
      InputIterator find_if(InputIterator first, InputIterator last, Predicate pred);
  template<class ForwardIterator1, class ForwardIterator2, class BinaryPredicate>
      ForwardIterator1
          find_end(ForwardIterator1 first1, ForwardIterator1 last1,
                   ForwardIterator2 first2, ForwardIterator2 last2);
  template<class ForwardIterator1, class ForwardIterator2, class BinaryPredicate>
      ForwardIterator1
          find_end(ForwardIterator1 first1, ForwardIterator1 last1,
                   ForwardIterator2 first2, ForwardIterator2 last2,
                   BinaryPredicate pred);

  template<class ForwardIterator1, class ForwardIterator2>
      ForwardIterator1
          find_end(ForwardIterator1 first1, ForwardIterator1 last1,
                   ForwardIterator2 first2, ForwardIterator2 last2,
                   BinaryPredicate pred);

  template<class ForwardIterator1, class ForwardIterator2>
      ForwardIterator1
          find_end(ForwardIterator1 first1, ForwardIterator1 last1,
                   ForwardIterator2 first2, ForwardIterator2 last2,
                   BinaryPredicate pred);

  template<class ForwardIterator1, class ForwardIterator2>
Algorithms library 698

```cpp

find_first_of(ForwardIterator1 first1, ForwardIterator1 last1,
              ForwardIterator2 first2, ForwardIterator2 last2);

template<class ForwardIterator1, class ForwardIterator2,
         class BinaryPredicate>
ForwardIterator1
find_first_of(ForwardIterator1 first1, ForwardIterator1 last1,
              ForwardIterator2 first2, ForwardIterator2 last2,
              BinaryPredicate pred);

template<class ForwardIterator>
ForwardIterator1 adjacent_find(ForwardIterator first,
                               ForwardIterator last);

template<class ForwardIterator, class BinaryPredicate>
ForwardIterator1 adjacent_find(ForwardIterator first,
                               ForwardIterator last,
                               BinaryPredicate pred);

template<class InputIterator, class T>
typename iterator_traits<InputIterator>::difference_type
count(InputIterator first, InputIterator last, const T& value);

template<class InputIterator, class Predicate>
typename iterator_traits<InputIterator>::difference_type
count_if(InputIterator first, InputIterator last, Predicate pred);

template<class InputIterator1, class InputIterator2>
pair<InputIterator1, InputIterator2>
mismatch(InputIterator1 first1, InputIterator1 last1,
          InputIterator2 first2);

template<class InputIterator1, class InputIterator2, class BinaryPredicate>
pair<InputIterator1, InputIterator2>
mismatch(InputIterator1 first1, InputIterator1 last1,
          InputIterator2 first2, BinaryPredicate pred);

bool equal(InputIterator1 first1, InputIterator1 last1,
           InputIterator2 first2);

template<class InputIterator1, class InputIterator2, class BinaryPredicate>
bool equal(InputIterator1 first1, InputIterator1 last1,
           InputIterator2 first2, BinaryPredicate pred);

template<class ForwardIterator1, class ForwardIterator2>
ForwardIterator1 search
(ForwardIterator1 first1, ForwardIterator1 last1,
 ForwardIterator2 first2, ForwardIterator2 last2);

template<class ForwardIterator1, class ForwardIterator2,
         class BinaryPredicate>
ForwardIterator1 search
(ForwardIterator1 first1, ForwardIterator1 last1,
 ForwardIterator2 first2, ForwardIterator2 last2,

Draft
template<class ForwardIterator, class Size, class T>
ForwardIterator search_n(ForwardIterator first, ForwardIterator last,
    Size count, const T& value);

template<class ForwardIterator, class Size, class T, class BinaryPredicate>
ForwardIterator1 search_n(ForwardIterator first, ForwardIterator last,
    Size count, const T& value,
    BinaryPredicate pred);

// 25.2. modifying sequence operations:
// 25.2.1. copy:

template<class InputIterator, class OutputIterator>
OutputIterator copy(InputIterator first, InputIterator last,
    OutputIterator result);

template<class BidirectionalIterator1, class BidirectionalIterator2>
BidirectionalIterator2
    copy_backward
    (BidirectionalIterator1 first, BidirectionalIterator1 last,
     BidirectionalIterator1 result);

// 25.2.2. swap:

template<class T> void swap(T& a, T& b);

template<class ForwardIterator1, class ForwardIterator2>
ForwardIterator2 swap_ranges(ForwardIterator1 first1,
    ForwardIterator1 last1, ForwardIterator2 first2);

template<class ForwardIterator1, class ForwardIterator2>
void iter_swap(ForwardIterator1 a, ForwardIterator2 b);

template<class InputIterator, class OutputIterator, class UnaryOperation>
OutputIterator transform(InputIterator first, InputIterator last,
    OutputIterator result, UnaryOperation op);

template<class InputIterator1, class InputIterator2, class OutputIterator,
    class BinaryOperation>
OutputIterator transform(InputIterator1 first1, InputIterator1 last1,
    InputIterator2 first2, OutputIterator result,
    BinaryOperation binary_op);

template<class ForwardIterator, class T>
void replace(ForwardIterator first, ForwardIterator last,
    const T& old_value, const T& new_value);

template<class ForwardIterator, class Predicate, class T>
void replace_if(ForwardIterator first, ForwardIterator last,
    Predicate pred, const T& new_value);

template<class InputIterator, class OutputIterator, class T>
OutputIterator replace_copy(InputIterator first, InputIterator last,
    OutputIterator result,
    const T& old_value, const T& new_value);

template<class InputIterator, class OutputIterator, class Predicate, class T>
OutputIterator replace_copy_if(InputIterator first, InputIterator last,
Algorithms library
700

OutputIterator result,
Predicate pred, const T& new_value);

template<class ForwardIterator, class T>
void fill(ForwardIterator first, ForwardIterator last, const T& value);

template<class OutputIterator, class T>
void fill_n(OutputIterator first, Size n, const T& value);

template<class ForwardIterator, class Generator>
void generate(ForwardIterator first, ForwardIterator last,
Generator gen);

template<class OutputIterator, class Size, class Generator>
void generate_n(OutputIterator first, Size n, Generator gen);

template<class ForwardIterator, class T>
ForwardIterator remove(ForwardIterator first, ForwardIterator last,
const T& value);

template<class ForwardIterator, class Predicate>
ForwardIterator remove_if(ForwardIterator first, ForwardIterator last,
Predicate pred);

template<class InputIterator, class OutputIterator, class T>
OutputIterator remove_copy(InputIterator first, InputIterator last,
OutputIterator result, const T& value);

template<class InputIterator, class OutputIterator, class Predicate>
OutputIterator remove_copy_if(InputIterator first, InputIterator last,
OutputIterator result, Predicate pred);

template<class BidirectionalIterator>
void reverse(BidirectionalIterator first, BidirectionalIterator last);

template<class BidirectionalIterator, class OutputIterator>
OutputIterator reverse_copy(BidirectionalIterator first,
BidirectionalIterator last, OutputIterator result);

template<class ForwardIterator>
void rotate(ForwardIterator first, ForwardIterator middle,
ForwardIterator last);

Draft
OutputIterator rotate_copy
  (ForwardIterator first, ForwardIterator middle,
   ForwardIterator last, OutputIterator result);

template<class RandomAccessIterator>
void random_shuffle(RandomAccessIterator first,
                    RandomAccessIterator last);

template<class RandomAccessIterator, class RandomNumberGenerator>
void random_shuffle(RandomAccessIterator first,
                    RandomAccessIterator last,
                    RandomNumberGenerator& rand);

// 25.2.12, partitions:
template<class BidirectionalIterator, class Predicate>
BidirectionalIterator partition(BidirectionalIterator first,
                                BidirectionalIterator last,
                                Predicate pred);

template<class BidirectionalIterator, class Predicate>
BidirectionalIterator stable_partition(BidirectionalIterator first,
                                        BidirectionalIterator last,
                                        Predicate pred);

// 25.3, sorting and related operations:
// 25.3.1, sorting:

template<class RandomAccessIterator>
void sort(RandomAccessIterator first, RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
void sort(RandomAccessIterator first, RandomAccessIterator last,
          Compare comp);

template<class RandomAccessIterator>
void stable_sort(RandomAccessIterator first, RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
void stable_sort(RandomAccessIterator first, RandomAccessIterator last,
                 Compare comp);

template<class RandomAccessIterator>
partial_sort(RandomAccessIterator first,
             RandomAccessIterator middle,
             RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
partial_sort(RandomAccessIterator first,
             RandomAccessIterator middle,
             RandomAccessIterator last, Compare comp);

template<class InputIterator, class RandomAccessIterator>
RandomAccessIterator
  partial_sort_copy(InputIterator first, InputIterator last,
                    RandomAccessIterator result_first,
                    RandomAccessIterator result_last);
RandomAccessIterator

partial_sort_copy(InputIterator first, InputIterator last,
RandomAccessIterator result_first,
RandomAccessIterator result_last,
Compare comp);

template<class RandomAccessIterator>
void nth_element(RandomAccessIterator first, RandomAccessIterator nth,
RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
void nth_element(RandomAccessIterator first, RandomAccessIterator nth,
RandomAccessIterator last, Compare comp);

// 25.3.3, binary search:
template<class ForwardIterator, class T>
ForwardIterator lower_bound(ForwardIterator first, ForwardIterator last,
const T& value);

template<class ForwardIterator, class T, class Compare>
ForwardIterator lower_bound(ForwardIterator first, ForwardIterator last,
const T& value, Compare comp);

template<class ForwardIterator, class T>
ForwardIterator upper_bound(ForwardIterator first, ForwardIterator last,
const T& value);

template<class ForwardIterator, class T, class Compare>
ForwardIterator upper_bound(ForwardIterator first, ForwardIterator last,
const T& value, Compare comp);

template<class ForwardIterator, class T>
pair<ForwardIterator, ForwardIterator>
equal_range(ForwardIterator first, ForwardIterator last,
const T& value);

template<class ForwardIterator, class T, class Compare>
pair<ForwardIterator, ForwardIterator>
equal_range(ForwardIterator first, ForwardIterator last,
const T& value, Compare comp);

template<class ForwardIterator, class T>
bool binary_search(ForwardIterator first, ForwardIterator last,
const T& value);

template<class ForwardIterator, class T, class Compare>
bool binary_search(ForwardIterator first, ForwardIterator last,
const T& value, Compare comp);

// 25.3.4, merge:
template<class InputIterator1, class InputIterator2, class OutputIterator>
OutputIterator merge(InputIterator1 first1, InputIterator1 last1,
InputIterator2 first2, InputIterator2 last2,
OutputIterator result);

template<class InputIterator1, class InputIterator2, class OutputIterator,
class Compare>
  OutputIterator merge(InputIterator1 first1, InputIterator1 last1,
                         InputIterator2 first2, InputIterator2 last2,
                         OutputIterator result, Compare comp);

template<class BidirectionalIterator>
  void inplace_merge(BidirectionalIterator first,
                     BidirectionalIterator middle,
                     BidirectionalIterator last);

template<class BidirectionalIterator, class Compare>
  void inplace_merge(BidirectionalIterator first,
                     BidirectionalIterator middle,
                     BidirectionalIterator last, Compare comp);

// 25.3.5, set operations:
template<class InputIterator1, class InputIterator2>
  bool includes(InputIterator1 first1, InputIterator1 last1,
                 InputIterator2 first2, InputIterator2 last2);

template<class InputIterator1, class InputIterator2, class Compare>
  bool includes
    (InputIterator1 first1, InputIterator1 last1,
     InputIterator2 first2, InputIterator2 last2, Compare comp);

template<class InputIterator1, class InputIterator2, class OutputIterator>
  OutputIterator set_union(InputIterator1 first1, InputIterator1 last1,
                            InputIterator2 first2, InputIterator2 last2,
                            OutputIterator result);

template<class InputIterator1, class InputIterator2, class OutputIterator,
         class Compare>
  OutputIterator set_union(InputIterator1 first1, InputIterator1 last1,
                            InputIterator2 first2, InputIterator2 last2,
                            OutputIterator result, Compare comp);

template<class InputIterator1, class InputIterator2, class OutputIterator>
  OutputIterator set_intersection
    (InputIterator1 first1, InputIterator1 last1,
     InputIterator2 first2, InputIterator2 last2,
     OutputIterator result);

template<class InputIterator1, class InputIterator2, class OutputIterator,
         class Compare>
  OutputIterator set_intersection
    (InputIterator1 first1, InputIterator1 last1,
     InputIterator2 first2, InputIterator2 last2,
     OutputIterator result, Compare comp);

template<class InputIterator1, class InputIterator2, class OutputIterator>
  OutputIterator set_difference
    (InputIterator1 first1, InputIterator1 last1,
     InputIterator2 first2, InputIterator2 last2,
     OutputIterator result);
template<class InputIterator1, class InputIterator2, class OutputIterator,
class Compare>
OutputIterator set_difference
(InputIterator1 first1, InputIterator1 last1,
InputIterator2 first2, InputIterator2 last2,
OutputIterator result, Compare comp);

template<class InputIterator1, class InputIterator2, class OutputIterator>
OutputIterator set_symmetric_difference(InputIterator1 first1, InputIterator1 last1,
InputIterator2 first2, InputIterator2 last2,
OutputIterator result);

template<class InputIterator1, class InputIterator2, class OutputIterator,
class Compare>
OutputIterator set_symmetric_difference(InputIterator1 first1, InputIterator1 last1,
InputIterator2 first2, InputIterator2 last2,
OutputIterator result, Compare comp);

// 25.3.6, heap operations:
template<class RandomAccessIterator>
void push_heap(RandomAccessIterator first, RandomAccessIterator last);
template<class RandomAccessIterator, class Compare>
void push_heap(RandomAccessIterator first, RandomAccessIterator last,
Compare comp);

template<class RandomAccessIterator>
void pop_heap(RandomAccessIterator first, RandomAccessIterator last);
template<class RandomAccessIterator, class Compare>
void pop_heap(RandomAccessIterator first, RandomAccessIterator last,
Compare comp);

template<class RandomAccessIterator>
void make_heap(RandomAccessIterator first, RandomAccessIterator last);
template<class RandomAccessIterator, class Compare>
void make_heap(RandomAccessIterator first, RandomAccessIterator last,
Compare comp);

template<class RandomAccessIterator>
void sort_heap(RandomAccessIterator first, RandomAccessIterator last);
template<class RandomAccessIterator, class Compare>
void sort_heap(RandomAccessIterator first, RandomAccessIterator last,
Compare comp);

// 25.3.7, minimum and maximum:
template<class T> const T& min(const T& a, const T& b);
template<class T, class Compare>
const T& min(const T& a, const T& b, Compare comp);
template<class T> const T& max(const T& a, const T& b);
template<class T, class Compare>
const T& max(const T& a, const T& b, Compare comp);
const T& max(const T& a, const T& b, Compare comp);
template<class T> pair<const T&, const T&> minmax(const T& a, const T& b);
template<class T, class Compare>
  pair<const T&, const T&> minmax(const T& a, const T& b, Compare comp);

template<class ForwardIterator>
ForwardIterator min_element
  (ForwardIterator first, ForwardIterator last);
template<class ForwardIterator, class Compare>
  ForwardIterator min_element(ForwardIterator first, ForwardIterator last,
                               Compare comp);

template<class ForwardIterator>
ForwardIterator max_element
  (ForwardIterator first, ForwardIterator last);
template<class ForwardIterator, class Compare>
  ForwardIterator max_element(ForwardIterator first, ForwardIterator last,
                               Compare comp);

pair<ForwardIterator, ForwardIterator>
minmax_element(ForwardIterator first, ForwardIterator last);
template<class ForwardIterator, class Compare>
  pair<ForwardIterator, ForwardIterator>
    minmax_element(ForwardIterator first, ForwardIterator last, Compare comp);

template<class InputIterator1, class InputIterator2>
bool lexicographical_compare
  (InputIterator1 first1, InputIterator1 last1,
   InputIterator2 first2, InputIterator2 last2);
template<class InputIterator1, class InputIterator2, class Compare>
  bool lexicographical_compare
    (InputIterator1 first1, InputIterator1 last1,
     InputIterator2 first2, InputIterator2 last2, Compare comp);

// 25.3.9, permutations:
template<class BidirectionalIterator>
bool next_permutation(BidirectionalIterator first,
                      BidirectionalIterator last);
template<class BidirectionalIterator, class Compare>
  bool next_permutation(BidirectionalIterator first,
                        BidirectionalIterator last, Compare comp);
template<class BidirectionalIterator>
bool prev_permutation(BidirectionalIterator first,
                      BidirectionalIterator last);
template<class BidirectionalIterator, class Compare>
  bool prev_permutation(BidirectionalIterator first,
                        BidirectionalIterator last, Compare comp);

3 All of the algorithms are separated from the particular implementations of data structures and are parameterized by
iterator types. Because of this, they can work with program-defined data structures, as long as these data structures have iterator types satisfying the assumptions on the algorithms.

Throughout this clause, the names of template parameters are used to express type requirements. If an algorithm’s template parameter is `InputIterator`, `InputIterator1`, or `InputIterator2`, the actual template argument shall satisfy the requirements of an input iterator (24.1.1). If an algorithm’s template parameter is `OutputIterator`, `OutputIterator1`, or `OutputIterator2`, the actual template argument shall satisfy the requirements of an output iterator (24.1.2). If an algorithm’s template parameter is `ForwardIterator`, `ForwardIterator1`, or `ForwardIterator2`, the actual template argument shall satisfy the requirements of a forward iterator (24.1.3). If an algorithm’s template parameter is `BidirectionalIterator`, `BidirectionalIterator1`, or `BidirectionalIterator2`, the actual template argument shall satisfy the requirements of a bidirectional iterator (24.1.4). If an algorithm’s template parameter is `RandomAccessIterator`, `RandomAccessIterator1`, or `RandomAccessIterator2`, the actual template argument shall satisfy the requirements of a random-access iterator (24.1.5).

If an algorithm’s Effects section says that a value pointed to by any iterator passed as an argument is modified, then that algorithm has an additional type requirement: The type of that argument shall satisfy the requirements of a mutable iterator (24.1). [Note: this requirement does not affect arguments that are declared as `OutputIterator`, `OutputIterator1`, or `OutputIterator2`, because output iterators must always be mutable. — end note]

Both in-place and copying versions are provided for certain algorithms. When such a version is provided for algorithm it is called algorithm_copy. Algorithms that take predicates end with the suffix _if (which follows the suffix _copy).

The Predicate parameter is used whenever an algorithm expects a function object that when applied to the result of dereferencing the corresponding iterator returns a value testable as true. In other words, if an algorithm takes `Predicate pred` as its argument and `first` as its iterator argument, it should work correctly in the construct `if (pred(*first)){...}`. The function object `pred` shall not apply any non-constant function through the dereferenced iterator. This function object may be a pointer to function, or an object of a type with an appropriate function call operator.

The BinaryPredicate parameter is used whenever an algorithm expects a function object that when applied to the result of dereferencing two corresponding iterators or to dereferencing an iterator and type `T` when `T` is part of the signature returns a value testable as true. In other words, if an algorithm takes `BinaryPredicate binary_pred` as its argument and `first1` and `first2` as its iterator arguments, it should work correctly in the construct `if (binary_pred(*first1, *first2)){...}`. BinaryPredicate always takes the first iterator type as its first argument, that is, in those cases when `T` value is part of the signature, it should work correctly in the context of `if (binary_pred(*first1, value)){...}`. `binary_pred` shall not apply any non-constant function through the dereferenced iterators.

[Note: Unless otherwise specified, algorithms that take function objects as arguments are permitted to copy those function objects freely. Programmers for whom object identity is important should consider using a wrapper class that points to a noncopied implementation object, or some equivalent solution. — end note]

When the description of an algorithm gives an expression such as `*first == value` for a condition, the expression shall evaluate to either true or false in boolean contexts.

268 The decision whether to include a copying version was usually based on complexity considerations. When the cost of doing the operation dominates the cost of copy, the copying version is not included. For example, `sort_copy` is not included because the cost of sorting is much more significant, and users might as well do `copy` followed by `sort`. 
In the description of the algorithms operators + and − are used for some of the iterator categories for which they do not have to be defined. In these cases the semantics of a+n is the same as that of

```
{ X tmp = a;
  advance(tmp, n);
  return tmp;
}
```

and that of b−a is the same as of

```
return distance(a, b);
```

### 25.1 Non-modifying sequence operations

#### 25.1.1 For each

```
template<class InputIterator, class Function>
Function for_each(InputIterator first, InputIterator last, Function f);
```

1. **Effects:** Applies f to the result of dereferencing every iterator in the range [first, last), starting from first and proceeding to last − 1. [Note: If the type of first satisfies the requirements of a mutable iterator, f may apply nonconstant functions through the dereferenced iterator. — end note]

2. **Returns:** f.

3. **Complexity:** Applies f exactly last − first times.

4. **Remarks:** If f returns a result, the result is ignored.

#### 25.1.2 Find

```
template<class InputIterator, class T>
InputIterator find(InputIterator first, InputIterator last, const T& value);
```

```
template<class InputIterator, class Predicate>
InputIterator find_if(InputIterator first, InputIterator last, Predicate pred);
```

1. **Returns:** The first iterator i in the range [first, last) for which the following corresponding conditions hold: *i == value, pred(*i) != false. Returns last if no such iterator is found.

2. **Complexity:** At most last − first applications of the corresponding predicate.

#### 25.1.3 Find End

```
template<class ForwardIterator1, class ForwardIterator2>
ForwardIterator1
find_end(ForwardIterator1 first1, ForwardIterator1 last1,
         ForwardIterator2 first2, ForwardIterator2 last2);
```
25.1 Non-modifying sequence operations

```
template<class ForwardIterator1, class ForwardIterator2,
         class BinaryPredicate>
ForwardIterator1
    find_end(ForwardIterator1 first1, ForwardIterator1 last1,
             ForwardIterator2 first2, ForwardIterator2 last2,
             BinaryPredicate pred);
```

1  **Effects:** Finds a subsequence of equal values in a sequence.
2  **Returns:** The last iterator \( i \) in the range \([first1, last1 - (last2 - first2))\) such that for any non-negative integer \( n < (last2 - first2) \), the following corresponding conditions hold: \( *(i + n) == *(first2 + n) \), \( \text{pred}(*(i + n), *(first2 + n)) != \text{false} \). Returns \( last1 \) if no such iterator is found.
3  **Complexity:** At most \((last2 - first2) * (last1 - first1 - (last2 - first2) + 1)\) applications of the corresponding predicate.

25.1.4 Find First
[lib.alg.find.first.of]

```
template<class ForwardIterator1, class ForwardIterator2>
ForwardIterator1
    find_first_of(ForwardIterator1 first1, ForwardIterator1 last1,
                  ForwardIterator2 first2, ForwardIterator2 last2);

template<class ForwardIterator1, class ForwardIterator2,
         class BinaryPredicate>
ForwardIterator1
    find_first_of(ForwardIterator1 first1, ForwardIterator1 last1,
                  ForwardIterator2 first2, ForwardIterator2 last2,
                  BinaryPredicate pred);
```

1  **Effects:** Finds an element that matches one of a set of values.
2  **Returns:** The first iterator \( i \) in the range \([first1, last1)\) such that for some iterator \( j \) in the range \([first2, last2)\) the following conditions hold: \( \ast i == \ast j \), \( \text{pred}(\ast i, \ast j) != \text{false} \). Returns \( last1 \) if no such iterator is found.
3  **Complexity:** At most \((last2 - first2) * (last1 - first1)\) applications of the corresponding predicate.

25.1.5 Adjacent find
[lib.alg.adjacent.find]

```
template<class ForwardIterator>
    ForwardIterator adjacent_find(ForwardIterator first, ForwardIterator last);

template<class ForwardIterator, class BinaryPredicate>
    ForwardIterator adjacent_find(ForwardIterator first, ForwardIterator last,
                                   BinaryPredicate pred);
```

Draft
Returns: The first iterator \(i\) such that both \(i\) and \(i + 1\) are in the range \([first, last)\) for which the following corresponding conditions hold: \(*i == *(i + 1)\), \(\text{pred}(\*i, \*\text{(i + 1)}) \neq \text{false}\). Returns \(last\) if no such iterator is found.

Complexity: For a nonempty range, exactly \(\min((i - first) + 1, (last - first) - 1)\) applications of the corresponding predicate, where \(i\) is adjacent_find’s return value.

25.1.6 Count

\[\text{count}\]

```
template<class InputIterator, class T>
  typename iterator_traits<InputIterator>::difference_type
  count(InputIterator first, InputIterator last, const T& value);
```

\[\text{count_if}\]

```
template<class InputIterator, class Predicate>
  typename iterator_traits<InputIterator>::difference_type
  count_if(InputIterator first, InputIterator last, Predicate pred);
```

Effects: Returns the number of iterators \(i\) in the range \([first, last)\) for which the following corresponding conditions hold: \(*i == value, \text{pred}(\*i) \neq \text{false}\.

Complexity: Exactly \(last - first\) applications of the corresponding predicate.

25.1.7 Mismatch

\[\text{mismatch}\]

```
template<class InputIterator1, class InputIterator2>
  pair<InputIterator1, InputIterator2>
  mismatch(InputIterator1 first1, InputIterator1 last1,
            InputIterator2 first2);
```

```
template<class InputIterator1, class InputIterator2,
         class BinaryPredicate>
  pair<InputIterator1, InputIterator2>
  mismatch(InputIterator1 first1, InputIterator1 last1,
            InputIterator2 first2, BinaryPredicate pred);
```

Returns: A pair of iterators \(i\) and \(j\) such that \(j == first2 + (i - first1)\) and \(i\) is the first iterator in the range \([first1, last1)\) for which the following corresponding conditions hold:

\(!(*i == *(first2 + (i - first1)))\)
\(\text{pred}(\*i, *(first2 + (i - first1))) == \text{false}\)

Returns the pair \(last1\) and \(first2 + (last1 - first1)\) if such an iterator \(i\) is not found.

Complexity: At most \(last1 - first1\) applications of the corresponding predicate.

25.1.8 Equal

\[\text{equal}\]

```
Draft
25.1 Non-modifying sequence operations

Algorithm library

\[
\text{template}\langle\text{class InputIterator1, class InputIterator2}\rangle
\]
\[
\text{bool equal(InputIterator1 first1, InputIterator1 last1, InputIterator2 first2);}\]

\[
\text{template}\langle\text{class InputIterator1, class InputIterator2, class BinaryPredicate}\rangle
\]
\[
\text{bool equal(InputIterator1 first1, InputIterator1 last1, InputIterator2 first2, BinaryPredicate pred);}\]

Returns: true if for every iterator \(i\) in the range \([first1, last1)\) the following corresponding conditions hold:
\[i == *(first2 + (i - first1)), \text{pred}(*i, *(first2 + (i - first1))) \neq \text{false} \]
Otherwise, returns false.

Complexity: At most \(last1 - first1\) applications of the corresponding predicate.

25.1.9 Search

\[
\text{template}\langle\text{class ForwardIterator1, class ForwardIterator2}\rangle
\]
\[
\text{ForwardIterator1 search(ForwardIterator1 first1, ForwardIterator1 last1, ForwardIterator2 first2, ForwardIterator2 last2);}\]

\[
\text{template}\langle\text{class ForwardIterator1, class ForwardIterator2, class BinaryPredicate}\rangle
\]
\[
\text{ForwardIterator1 search(ForwardIterator1 first1, ForwardIterator1 last1, ForwardIterator2 first2, ForwardIterator2 last2, BinaryPredicate pred);}\]

Effects: Finds a subsequence of equal values in a sequence.

Returns: The first iterator \(i\) in the range \([first1, last1 - (last2-first2))\) such that for any non-negative integer \(n\) less than \(last2 - first2\) the following corresponding conditions hold:
\[*(i + n) == *(first2 + n), \text{pred}(*(i + n), *(first2 + n)) \neq \text{false} \]
Returns \(last1\) if no such iterator is found.

Complexity: At most \((last1 - first1) \times (last2 - first2)\) applications of the corresponding predicate.

\[
\text{template}\langle\text{class ForwardIterator, class Size, class T}\rangle
\]
\[
\text{ForwardIterator search_n(ForwardIterator first, ForwardIterator last, Size count, const T& value);}\]

\[
\text{template}\langle\text{class ForwardIterator, class Size, class T, class BinaryPredicate}\rangle
\]
\[
\text{ForwardIterator search_n(ForwardIterator first, ForwardIterator last, Size count, const T& value, BinaryPredicate pred);}\]

Requires: The type Size is convertible to integral type (4.7, 12.3).

Effects: Finds a subsequence of equal values in a sequence.
Returns: The first iterator \( i \) in the range \([first, last - count)\) such that for any non-negative integer \( n \) less than \( count \) the following corresponding conditions hold: \( *(i + n) == value, \text{ pred}(*(i + n),value) != false \). Returns \( last \) if no such iterator is found.

Complexity: At most \((last - first) \times count\) applications of the corresponding predicate if \( count \) is positive, or 0 otherwise.

25.2 Mutating sequence operations [lib.alg.modifying.operations]

25.2.1 Copy [lib.alg.copy]

```cpp
template<class InputIterator, class OutputIterator>
OutputIterator copy(InputIterator first, InputIterator last, OutputIterator result);
```

Effects: Copies elements in the range \([first, last)\) into the range \([result, result + (last - first))\) starting from \( first \) and proceeding to \( last \). For each non-negative integer \( n < (last - first) \), performs \( *(result + n) = *(first + n) \).

Returns: \( result + (last - first) \).

Requires: \( result \) shall not be in the range \([first, last)\).

Complexity: Exactly \( last - first \) assignments.

```cpp
template<class BidirectionalIterator1, class BidirectionalIterator2>
BidirectionalIterator2
copy_backward(BidirectionalIterator1 first,
BidirectionalIterator1 last,
BidirectionalIterator2 result);
```

Effects: Copies elements in the range \([first, last)\) into the range \([result - (last - first),result)\) starting from \( last - 1 \) and proceeding to \( first \). For each positive integer \( n <= (last - first) \), performs \( *(result - n) = *(last - n) \).

Requires: \( result \) shall not be in the range \([first, last)\).

Returns: \( result - (last - first) \).

Complexity: Exactly \( last - first \) assignments.

25.2.2 Swap [lib.alg.swap]

```cpp
template<class T> void swap(T& a, T& b);
```

Requires: Type \( T \) is CopyConstructible (20.1.3) and Assignable (23.1).

Effects: Exchanges values stored in two locations.

\(^{269}\) copy_backward should be used instead of copy when \( last \) is in the range \([result - (last - first),result)\).
25.2 Mutating sequence operations

template<class ForwardIterator1, class ForwardIterator2>
ForwardIterator2
swap_ranges(ForwardIterator1 first1, ForwardIterator1 last1,
ForwardIterator2 first2);

Effects: For each non-negative integer n < (last1 - first1) performs: swap(*(first1 + n), *(first2 + n)).

Requires: The two ranges [first1, last1) and [first2, first2 + (last1 - first1)) shall not overlap. The type of *first1 shall be the same as the type of *first2 and that type shall satisfy the Swappable requirements (20.1.4).

Returns: first2 + (last1 - first1).

Complexity: Exactly last1 - first1 swaps.

template<class ForwardIterator1, class ForwardIterator2>
void iter_swap(ForwardIterator1 a, ForwardIterator2 b);


Requires: The type of *a shall be the same as the type of *b and that type shall satisfy the Swappable requirements (20.1.4).

25.2.3 Transform

template<class InputIterator, class OutputIterator,
class UnaryOperation>
OutputIterator
transform(InputIterator first, InputIterator last,
OutputIterator result, UnaryOperation op);

template<class InputIterator1, class InputIterator2,
class OutputIterator, class BinaryOperation>
OutputIterator
transform(InputIterator1 first1, InputIterator1 last1,
InputIterator2 first2, OutputIterator result,
BinaryOperation binary_op);

Effects: Assigns through every iterator i in the range [result, result + (last1 - first1)) a new corresponding value equal to op(*(first1 + (i - result)) or binary_op(*(first1 + (i - result)), *(first2 + (i - result))).

Requires: op and binary_op shall not invalidate iterators or subranges, or modify elements in the ranges [first1, last1), [first2, first2 + (last1 - first1)], and [result, result + (last1 - first1)].

Returns: result + (last1 - first1).

Complexity: Exactly last1 - first1 applications of op or binary_op.

[lib.alg.transform]

Draft
5 Remarks: result may be equal to first in case of unary transform, or to first1 or first2 in case of binary transform.

25.2.4 Replace

template<class ForwardIterator, class T>
void replace(ForwardIterator first, ForwardIterator last,
const T& old_value, const T& new_value);

template<class ForwardIterator, class Predicate, class T>
void replace_if(ForwardIterator first, ForwardIterator last,
Predicatelpred, const T& new_value);

Requires: The expression *first = new_value must be valid.

Effects: Substitutes elements referred by the iterator i in the range [first, last) with new_value, when the following corresponding conditions hold: *i == old_value, pred(*i) != false.

Complexity: Exactly last - first applications of the corresponding predicate.

25.2.5 Fill

template<class ForwardIterator, class T>
void fill(ForwardIterator first, ForwardIterator last, const T& value);
25.2 Mutating sequence operations

```cpp
template<class OutputIterator, class Size, class T>
void fill_n(OutputIterator first, Size n, const T& value);
```

1. **Requires**: The expression `value` shall be writable to the output iterator. The type `Size` shall be convertible to an integral type (4.7, 12.3).

2. **Effects**: The first algorithm assigns `value` through all the iterators in the range `[first, last)`. The second algorithm assigns `value` through all the iterators in the range `[first, first + n)` if `n` is positive, otherwise it does nothing.

3. **Complexity**: Exactly `last - first`, `n`, or 0 assignments, respectively.

25.2.6 Generate

```cpp
template<class ForwardIterator, class Generator>
void generate(ForwardIterator first, ForwardIterator last, Generator gen);
```

```cpp
template<class OutputIterator, class Size, class Generator>
void generate_n(OutputIterator first, Size n, Generator gen);
```

1. **Effects**: The first algorithm invokes the function object `gen` and assigns the return value of `gen` through all the iterators in the range `[first, last)`. The second algorithm invokes the function object `gen` and assigns the return value of `gen` through all the iterators in the range `[first, first + n)` if `n` is positive, otherwise it does nothing.

2. **Requires**: `gen` takes no arguments, `Size` is convertible to an integral type (4.7, 12.3).

3. **Complexity**: Exactly `last - first`, `n`, or 0 invocations of `gen` and assignments, respectively.

25.2.7 Remove

```cpp
template<class ForwardIterator, class T>
ForwardIterator remove(ForwardIterator first, ForwardIterator last, const T& value);
```

```cpp
template<class ForwardIterator, class Predicate>
ForwardIterator remove_if(ForwardIterator first, ForwardIterator last, Predicate pred);
```

1. **Requires**: The type of `*first` shall satisfy the Assignable requirements (23.1).

2. **Effects**: Eliminates all the elements referred to by iterator `i` in the range `[first, last)` for which the following corresponding conditions hold: `*i == value, pred(*i) != false`.

3. **Returns**: The end of the resulting range.

4. **Remarks**: Stable.

5. **Complexity**: Exactly `last - first` applications of the corresponding predicate.
template<class InputIterator, class OutputIterator, class T>
OutputIterator
remove_copy(InputIterator first, InputIterator last,
OutputIterator result, const T& value);

OutputIterator
remove_copy_if(InputIterator first, InputIterator last,
OutputIterator result, Predicate pred);

Requires: Type T is EqualityComparable (20.1.1). The ranges [first, last) and [result, result +
(last - first)) shall not overlap.
Effects: Copies all the elements referred to by the iterator \( i \) in the range [first, last) for which the following
 corresponding conditions do not hold: \( *i == \text{value}, \text{pred}(\ast i) \neq \text{false} \).
Returns: The end of the resulting range.
Remarks: Exactly last - first applications of the corresponding predicate.

25.2.8 Unique [lib.alg.unique]

template<class ForwardIterator>
ForwardIterator unique(ForwardIterator first, ForwardIterator last);

ForwardIterator unique(ForwardIterator first, ForwardIterator last,
BinaryPredicate pred);

Effects: For a nonempty range, eliminates all but the first element from every consecutive group of equivalent
elements referred to by the iterator \( i \) in the range [first + 1, last) for which the following conditions hold:
\( *(i - 1) == *i \) or \( \text{pred}(*(i - 1), *i) != \text{false} \).
Requires: The comparison function shall be an equivalence relation.
Returns: The end of the resulting range.
Complexity: For nonempty ranges, exactly \( last - first) - 1 \) applications of the corresponding predicate.
25.2 Mutating sequence operations

Requires: The ranges \([first, last)\) and \([result, result+(last-first))\) shall not overlap. The expression \(*result = *first\) shall be valid. If neither InputIterator nor OutputIterator meets the requirements of forward iterator then the value type of InputIterator shall be CopyConstructible (20.1.3). Otherwise CopyConstructible is not required.

Effects: Copies only the first element from every consecutive group of equal elements referred to by the iterator \(i\) in the range \([first, last)\) for which the following corresponding conditions hold: \(*i == *(i - 1)\) or \(\text{pred}(*i, *(i - 1)) != false\).

Returns: The end of the resulting range.

Complexity: For nonempty ranges, exactly \(last - first - 1\) applications of the corresponding predicate.

25.2.9 Reverse [lib.alg.reverse]

\[
\text{template}<\text{class BidirectionalIterator}>
\]
\[
\text{void reverse(BidirectionalIterator first, BidirectionalIterator last);};
\]

Effects: For each non-negative integer \(i \leq \frac{last - first}{2}\), applies \text{iter_swap} to all pairs of iterators \(first + i, (last - i) - 1\).

Requires: The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).

Complexity: Exactly \(\frac{last - first}{2}\) swaps.

\[
\text{template}<\text{class BidirectionalIterator, class OutputIterator}>
\]
\[
\text{OutputIterator reverse_copy(BidirectionalIterator first, BidirectionalIterator last, OutputIterator result);};
\]

Effects: Copies the range \([first, last)\) to the range \([result, result+(last-first))\) such that for any non-negative integer \(i < (last - first)\) the following assignment takes place: \(*\text{result} + (last - first) - i) = *(first + i)\).

Requires: The ranges \([first, last)\) and \([result, result+(last-first))\) shall not overlap.

Returns: \(\text{result} + (last - first)\).

Complexity: \(\text{result} + (last - first)\).

25.2.10 Rotate [lib.alg.rotate]

\[
\text{template}<\text{class ForwardIterator}>
\]
\[
\text{void rotate(ForwardIterator first, ForwardIterator middle, ForwardIterator last);};
\]

Effects: For each non-negative integer \(i < (last - first)\), places the element from the position \(first + i\) into position \(first + (i + (last - middle)) \% (last - first)\).

Remarks: This is a left rotate.
3 Requires: \([first, middle)\) and \([middle, last)\) are valid ranges. The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).

4 Complexity: At most \(last - first\) swaps.

5 template<class ForwardIterator, class OutputIterator>
   OutputIterator
   rotate_copy(ForwardIterator \(first\), ForwardIterator \(middle\),
               ForwardIterator \(last\), OutputIterator \(result\));

6 Effects: Copies the range \([first, last)\) to the range \([result, result + (last - first))\) such that for each non-negative integer \(i < (last - first)\) the following assignment takes place: \(*(result + i) = *(first + (i + (middle - first)) \% (last - first)).\

7 Returns: \(result + (last - first)\).

8 Requires: The ranges \([first, last)\) and \([result, result + (last - first))\) shall not overlap.

9 Complexity: Exactly \(last - first\) assignments.

25.2.11 Random shuffle

[lib.alg.random.shuffle]

1 template<class RandomAccessIterator>
   void random_shuffle(RandomAccessIterator \(first\),
                       RandomAccessIterator \(last\));

2 template<class RandomAccessIterator, class RandomNumberGenerator>
   void random_shuffle(RandomAccessIterator \(first\),
                       RandomAccessIterator \(last\),
                       RandomNumberGenerator& \(rand\));

3 Effects: Shuffles the elements in the range \([first, last)\) with uniform distribution.

4 Requires: The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).

5 Complexity: Exactly \((last - first) - 1\) swaps.

6 Remarks: The underlying source of random numbers for the first form of the function is implementation-defined. An implementation may use the \(rand\) function from the standard C library. The second form of the function takes a random number generating function object \(rand\) such that if \(n\) is an argument for \(rand\), with a positive value, that has type \(\text{iterator_traits<RandomAccessIterator>::difference_type}\), then \(rand(n)\) returns a randomly chosen value, which lies in the interval \([0, n)\), and which has a type that is convertible to \(\text{iterator_traits<RandomAccessIterator>::difference_type}\).

25.2.12 Partitions

[lib.alg.partitions]

1 template<class BidirectionalIterator, class Predicate>
   BidirectionalIterator
   partition(BidirectionalIterator \(first\),
             BidirectionalIterator \(last\), Predicate \(pred\));

Draft
25.3 Sorting and related operations

1 Effects: Places all the elements in the range \([\textit{first}, \textit{last})\) that satisfy \textit{pred} before all the elements that do not satisfy it.

2 Returns: An iterator \(i\) such that for any iterator \(j\) in the range \([\textit{first}, i)\), \(\textit{pred}(\ast j) \neq \textit{false}\), and for any iterator \(k\) in the range \([i, \textit{last})\), \(\textit{pred}(\ast k) = \textit{false}\).

3 Requires: The type of \(*\textit{first}\) shall satisfy the Swappable requirements (20.1.4).

4 Complexity: At most \((\textit{last} - \textit{first})/2\) swaps. Exactly \(\textit{last} - \textit{first}\) applications of the predicate are done.

\[
\text{template<class BidirectionalIterator, class Predicate>}
\]

\[
\text{BidirectionalIterator}
\]

\[
\text{stable\_partition(BidirectionalIterator } \textit{first}, \text{ BidirectionalIterator } \textit{last}, \text{ Predicate } \textit{pred});
\]

5 Effects: Places all the elements in the range \([\textit{first}, \textit{last})\) that satisfy \textit{pred} before all the elements that do not satisfy it.

6 Returns: An iterator \(i\) such that for any iterator \(j\) in the range \([\textit{first}, i), \textit{pred}(\ast j) \neq \textit{false}\), and for any iterator \(k\) in the range \([i, \textit{last})\), \(\textit{pred}(\ast k) = \textit{false}\). The relative order of the elements in both groups is preserved.

7 Requires: The type of \(*\textit{first}\) shall satisfy the Swappable requirements (20.1.4).

8 Complexity: At most \((\textit{last} - \textit{first}) \ast \log(\textit{last} - \textit{first})\) swaps, but only linear number of swaps if there is enough extra memory. Exactly \(\textit{last} - \textit{first}\) applications of the predicate.

25.3 Sorting and related operations

1 All the operations in 25.3 have two versions: one that takes a function object of type \texttt{Compare} and one that uses an \texttt{operator\textless}.

2 \texttt{Compare} is used as a function object which returns \texttt{true} if the first argument is less than the second, and \texttt{false} otherwise. \texttt{Compare comp} is used throughout for algorithms assuming an ordering relation. It is assumed that \texttt{comp} will not apply any non-constant function through the dereferenced iterator.

3 For all algorithms that take \texttt{Compare}, there is a version that uses \texttt{operator\textless} instead. That is, \(\texttt{comp}(\ast i, \ast j) \neq \texttt{false}\) defaults to \(*i < *j \neq \text{false}\). For algorithms other than those described in 25.3.3 to work correctly, \texttt{comp} has to induce a strict weak ordering on the values.

4 The term \textit{strict} refers to the requirement of an irreflexive relation (\(\neg \texttt{comp}(x, x)\) for all \(x\), and the term \textit{weak} to requirements that are not as strong as those for a total ordering, but stronger than those for a partial ordering. If we define \texttt{equiv}(a, b) as \(\neg \texttt{comp}(a, b) \&\& \neg \texttt{comp}(b, a)\), then the requirements are that \texttt{comp} and \texttt{equiv} both be transitive relations:

- \(\texttt{comp}(a, b) \&\& \texttt{comp}(b, c)\) implies \(\texttt{comp}(a, c)\)
- \(\texttt{equiv}(a, b) \&\& \texttt{equiv}(b, c)\) implies \(\texttt{equiv}(a, c)\) \[\text{Note: Under these conditions, it can be shown that}

- \texttt{equiv} is an equivalence relation
- \texttt{comp} induces a well-defined relation on the equivalence classes determined by \texttt{equiv}\]
The induced relation is a strict total ordering. [end note]}

A sequence is *sorted with respect to a comparator* `comp` if for any iterator `i` pointing to the sequence and any non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, `comp(*(i + n), *i) == false`.

A sequence `[start, finish)` is *partitioned with respect to an expression* `f(e)` if there exists an integer `n` such that for all `0 <= i < distance(start, finish), f(*(begin + i))` is true if and only if `i < n`.

In the descriptions of the functions that deal with ordering relationships we frequently use a notion of equivalence to describe concepts such as stability. The equivalence to which we refer is not necessarily an `operator==`, but an equivalence relation induced by the strict weak ordering. That is, two elements `a` and `b` are considered equivalent if and only if `!(a < b) && !(b < a)`.

### 25.3.1 Sorting

#### 25.3.1.1 `sort`

```cpp
template<class RandomAccessIterator>
void sort(RandomAccessIterator first, RandomAccessIterator last);
```

```cpp
template<class RandomAccessIterator, class Compare>
void sort(RandomAccessIterator first, RandomAccessIterator last, Compare comp);
```

*Effects:* Sorts the elements in the range `[first, last)`.

*Requires:* The type of `*first` shall satisfy the Swappable requirements (20.1.4).

*Complexity:* Approximately `N log(N)` (where `N == last - first`) comparisons on the average.\(^{271}\)

#### 25.3.1.2 `stable_sort`

```cpp
template<class RandomAccessIterator>
void stable_sort(RandomAccessIterator first, RandomAccessIterator last);
```

```cpp
template<class RandomAccessIterator, class Compare>
void stable_sort(RandomAccessIterator first, RandomAccessIterator last, Compare comp);
```

*Effects:* Sorts the elements in the range `[first, last)`.

*Requires:* The type of `*first` shall satisfy the Swappable requirements (20.1.4).

*Complexity:* It does at most `N log^2(N)` (where `N == last - first`) comparisons; if enough extra memory is available, it is `N log(N)`.

*Remarks:* Stable.

\(^{271}\) If the worst case behavior is important `stable_sort()` (25.3.1.2) or `partial_sort()` (25.3.1.3) should be used.
25.3 Sorting and related operations

25.3.1.3 partial_sort

```
#include <algorithm>

template<class RandomAccessIterator>
void partial_sort(RandomAccessIterator first, 
                  RandomAccessIterator middle, 
                  RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
void partial_sort(RandomAccessIterator first, 
                  RandomAccessIterator middle, 
                  RandomAccessIterator last, 
                  Compare comp);
```

1. **Effects:** Places the first \(middle - first\) sorted elements from the range \([first, last)\) into the range \([first, middle)\). The rest of the elements in the range \([middle, last)\) are placed in an unspecified order.

2. **Requires:** The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).

3. **Complexity:** It takes approximately \((last - first) \times \log(middle - first)\) comparisons.

25.3.1.4 partial_sort_copy

```
#include <algorithm>

template<class InputIterator, class RandomAccessIterator>
RandomAccessIterator partial_sort_copy(InputIterator first, InputIterator last, 
                                       RandomAccessIterator result_first, 
                                       RandomAccessIterator result_last);

template<class InputIterator, class RandomAccessIterator, class Compare>
RandomAccessIterator partial_sort_copy(InputIterator first, InputIterator last, 
                                       RandomAccessIterator result_first, 
                                       RandomAccessIterator result_last, 
                                       Compare comp);
```

1. **Effects:** Places the first \(\min(last - first, result_last - result_first)\) sorted elements into the range \([result_first, result_first + \min(last - first, result_last - result_first))\).

2. **Returns:** The smaller of: \(result_last\) or \(result_first + (last - first)\).

3. **Requires:** The type of \(*result_first\) shall satisfy the Swappable requirements (20.1.4).

4. **Complexity:** Approximately \((last - first) \times \log(\min(last - first, result_last - result_first))\) comparisons.

25.3.2 Nth element

```
#include <algorithm>

Draft
```
template<class RandomAccessIterator>
void nth_element(RandomAccessIterator first, RandomAccessIterator nth,
RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
void nth_element(RandomAccessIterator first, RandomAccessIterator nth,
RandomAccessIterator last, Compare comp);

After nth_element the element in the position pointed to by nth is the element that would be in that position if
the whole range were sorted. Also for any iterator i in the range [first,nth) and any iterator j in the range
[nth,last) it holds that: !(i > j) or comp (*j, *i) == false.

Requires: The type of *first shall satisfy the Swappable requirements (20.1.4).

Complexity: Linear on average.

25.3.3 Binary search

All of the algorithms in this section are versions of binary search and assume that the sequence being searched is
partitioned with respect to an expression formed by binding the search key to an argument of the implied or explicit
comparison function. They work on non-random access iterators minimizing the number of comparisons, which will
be logarithmic for all types of iterators. They are especially appropriate for random access iterators, because these
algorithms do a logarithmic number of steps through the data structure. For non-random access iterators they execute a
linear number of steps.

25.3.3.1 lower_bound

template<class ForwardIterator, class T>
ForwardIterator
lower_bound(ForwardIterator first, ForwardIterator last,
const T& value);

template<class ForwardIterator, class T, class Compare>
ForwardIterator
lower_bound(ForwardIterator first, ForwardIterator last,
const T& value, Compare comp);

Requires: The elements e of [first,last) are partitioned with respect to the expression e < value or comp (e,
value).

Returns: The furthermost iterator i in the range [first,last] such that for any iterator j in the range [first,
i) the following corresponding conditions hold: *j < value or comp (*j, value) != false.

Complexity: At most log(last - first) + 1 + log2(last - first) + O(1) comparisons.

25.3.3.2 upper_bound

template<class ForwardIterator, class T>
ForwardIterator
upper_bound(ForwardIterator first, ForwardIterator last,

Draft
25.3 Sorting and related operations

const T& value);

template<class ForwardIterator, class T, class Compare>
ForwardIterator
upper_bound(ForwardIterator first, ForwardIterator last,
const T& value, Compare comp);

1  Requires: The elements e of \([first, last)\) are partitioned with respect to the expression \(! (value < e) \) or \(! \text{comp}(value, e)\).

2  Returns: The furthermost iterator i in the range \([first, last)\) such that for any iterator j in the range \([first, i)\) the following corresponding conditions hold: \(! (value < *j) \) or \(\text{comp}(value, \*j) == \text{false}\).

3  Complexity: At most \(\log(last - first) + \log_2(last - first) + \mathcal{O}(1)\) comparisons.

25.3.3.3 equal_range

Draft
template<class ForwardIterator, class T, class Compare>
bool binary_search(ForwardIterator first, ForwardIterator last, 
const T& value, Compare comp);

Requires: The elements e of [first, last) are partitioned with respect to the expressions e < value and
!(value < e) or comp(e, value) and !comp(value, e). Also, for all elements e of [first, last), e
< value implies !(value < e) or comp(e, value) implies !comp(value, e).

Returns: true if there is an iterator i in the range [first, last) that satisfies the corresponding condi-
tions: !(i < value) && (value < i) or comp(*i, value) == false && comp(value, *i) ==
false.

Complexity: At most log(last - first) + 2 comparisons.

25.3.4 Merge [lib.alg.merge]

template<class InputIterator1, class InputIterator2, 
class OutputIterator>
OutputIterator
merge(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result);

template<class InputIterator1, class InputIterator2, 
class OutputIterator, class Compare>
OutputIterator
merge(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result, Compare comp);

Effects: Merges two sorted ranges [first1, last1) and [first2, last2) into the range [result, result + (last1 - first1) + (last2 - first2)).

The resulting range shall not overlap with either of the original ranges. The list will be sorted in non-decreasing
order according to the ordering defined by comp; that is, for every iterator i in [first, last) other than first,
the condition *i < *(i - 1) or comp(*i, *(i - 1)) will be false.

Returns: result + (last1 - first1) + (last2 - first2).

Complexity: At most (last1 - first1) + (last2 - first2) - 1 comparisons.

Remarks: Stable.

template<class BidirectionalIterator>
void inplace_merge(BidirectionalIterator first, 
BidirectionalIterator middle, 
BidirectionalIterator last);

template<class BidirectionalIterator, class Compare>
void inplace_merge(BidirectionalIterator first, 
BidirectionalIterator middle,
25.3 Sorting and related operations

BidirectionalIterator last, Compare comp);

6 Effects: Merges two sorted consecutive ranges \([first, middle)\) and \([middle, last)\), putting the result of the merge into the range \([first, last)\). The resulting range will be in non-decreasing order; that is, for every iterator \(i\) in \([first, last)\) other than \(first\), the condition \(*i < *(i - 1)\) or, respectively, \(comp(*i, *(i - 1))\) will be false.

7 Requires: The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).

8 Complexity: When enough additional memory is available, \((last - first) - 1\) comparisons. If no additional memory is available, an algorithm with complexity \(N \log(N)\) (where \(N\) is equal to \(last - first\)) may be used.

9 Remarks: Stable.

25.3.5 Set operations on sorted structures

This section defines all the basic set operations on sorted structures. They also work with multisets (23.3.4) containing multiple copies of equivalent elements. The semantics of the set operations are generalized to multisets in a standard way by defining \(set\_union()\) to contain the maximum number of occurrences of every element, \(set\_intersection()\) to contain the minimum, and so on.

25.3.5.1 includes

 template<class InputIterator1, class InputIterator2, class OutputIterator>
   OutputIterator set_union(InputIterator1 first1, InputIterator1 last1,
                            InputIterator2 first2, InputIterator2 last2,
                            OutputIterator result);

 template<class InputIterator1, class InputIterator2, class Compare>
   OutputIterator set_union(InputIterator1 first1, InputIterator1 last1,
                            InputIterator2 first2, InputIterator2 last2,
                            Compare comp);

1 Returns: true if every element in the range \([first2, last2)\) is contained in the range \([first1, last1)\). Returns false otherwise.

2 Complexity: At most \(2 \times ((last1 - first1) + (last2 - first2)) - 1\) comparisons.
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result, Compare comp);  

Effects: Constructs a sorted union of the elements from the two ranges; that is, the set of elements that are present in one or both of the ranges.

Requires: The resulting range shall not overlap with either of the original ranges.

Returns: The end of the constructed range.

Complexity: At most \(2 \times ((\text{last1} - \text{first1}) + (\text{last2} - \text{first2})) - 1\) comparisons.

Remarks: If \([\text{first1}, \text{last1})\) contains \(m\) elements that are equivalent to each other and \([\text{first2}, \text{last2})\) contains \(n\) elements that are equivalent to them, then all \(m\) elements from the first range shall be copied to the output range, in order, and then \(\max(n - m, 0)\) elements from the second range shall be copied to the output range, in order.

25.3.5.3 set_intersection

```cpp
template<class InputIterator1, class InputIterator2, 
class OutputIterator>
OutputIterator
set_intersection(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result);
```

```cpp
template<class InputIterator1, class InputIterator2, 
class OutputIterator, class Compare>
OutputIterator
set_intersection(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result, Compare comp);
```

Effects: Constructs a sorted intersection of the elements from the two ranges; that is, the set of elements that are present in both of the ranges.

Requires: The resulting range shall not overlap with either of the original ranges.

Returns: The end of the constructed range.

Complexity: At most \(2 \times ((\text{last1} - \text{first1}) + (\text{last2} - \text{first2})) - 1\) comparisons.

Remarks: If \([\text{first1}, \text{last1})\) contains \(m\) elements that are equivalent to each other and \([\text{first2}, \text{last2})\) contains \(n\) elements that are equivalent to them, then all \(\min(m, n)\) elements shall be copied from the first range to the output range, in order.

25.3.5.4 set_difference

```cpp
template<class InputIterator1, class InputIterator2, 
class OutputIterator>
OutputIterator
```

Draft
set_difference(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result);

template<class InputIterator1, class InputIterator2, 
class OutputIterator, class Compare>
OutputIterator 
set_difference(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result, Compare comp);

Effects: Copies the elements of the range \([first1, last1)\) which are not present in the range \([first2, last2)\) to the range beginning at result. The elements in the constructed range are sorted.

Requires: The resulting range shall not overlap with either of the original ranges.

Returns: The end of the constructed range.

Complexity: At most \(2 \times ((last1 - first1) + (last2 - first2)) - 1\) comparisons.

Remarks: If \([first1, last1)\) contains \(m\) elements that are equivalent to each other and \([first2, last2)\) contains \(n\) elements that are equivalent to them, the last \(\max(m - n, 0)\) elements from \([first1, last1)\) shall be copied to the output range.

25.3.5.5 set_symmetric_difference

set_symmetric_difference(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result);

template<class InputIterator1, class InputIterator2, 
class OutputIterator, class Compare>
OutputIterator 
set_symmetric_difference(InputIterator1 first1, InputIterator1 last1, 
InputIterator2 first2, InputIterator2 last2, 
OutputIterator result, Compare comp);

Effects: Copies the elements of the range \([first1, last1)\) which are not present in the range \([first2, last2)\), and the elements of the range \([first2, last2)\) which are not present in the range \([first1, last1)\) to the range beginning at result. The elements in the constructed range are sorted.

Requires: The resulting range shall not overlap with either of the original ranges.

Returns: The end of the constructed range.

Complexity: At most \(2 \times ((last1 - first1) + (last2 - first2)) - 1\) comparisons.

Remarks: If \([first1, last1)\) contains \(m\) elements that are equivalent to each other and \([first2, last2)\) contains \(n\) elements that are equivalent to them, then \(|m - n|\) of those elements shall be copied to the output range.
the last \( m - n \) of these elements from \([\text{first1}, \text{last1})\) if \( m > n \), and the last \( n - m \) of these elements from \([\text{first2}, \text{last2})\) if \( m < n \).

25.3.6 Heap operations

A heap is a particular organization of elements in a range between two random access iterators \([a, b)\). Its two key properties are:

1. There is no element greater than \(*a\) in the range and
2. \(*a\) may be removed by \text{pop\_heap()}\), or a new element added by \text{push\_heap()}\), in \(O(\log(N))\) time.

These properties make heaps useful as priority queues.

\text{make\_heap()}\) converts a range into a heap and \text{sort\_heap()}\) turns a heap into a sorted sequence.

25.3.6.1 push\_heap

\text{template<class RandomAccessIterator>}
\begin{verbatim}
  void push_heap(RandomAccessIterator first, RandomAccessIterator last);
\end{verbatim}

\text{template<class RandomAccessIterator, class Compare>}
\begin{verbatim}
  void push_heap(RandomAccessIterator first, RandomAccessIterator last,
                 Compare comp);
\end{verbatim}

1 Effects: Places the value in the location \(last - 1\) into the resulting heap \([first, last)\).
2 Requires: The range \([first, last - 1)\) shall be a valid heap.
3 Complexity: At most \(\log(last - first)\) comparisons.

25.3.6.2 pop\_heap

\text{template<class RandomAccessIterator>}
\begin{verbatim}
  void pop_heap(RandomAccessIterator first, RandomAccessIterator last);
\end{verbatim}

\text{template<class RandomAccessIterator, class Compare>}
\begin{verbatim}
  void pop_heap(RandomAccessIterator first, RandomAccessIterator last,
                Compare comp);
\end{verbatim}

1 Effects: Swaps the value in the location \(first\) with the value in the location \(last - 1\) and makes \([first, last - 1)\) into a heap.
2 Requires: The range \([first, last)\) shall be a valid heap. The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).
3 Complexity: At most \(2 \times \log(last - first)\) comparisons.
25.3 Sorting and related operations

25.3.6.3 make_heap

```cpp
template<class RandomAccessIterator>
void make_heap(RandomAccessIterator first, RandomAccessIterator last);
```

```cpp
template<class RandomAccessIterator, class Compare>
void make_heap(RandomAccessIterator first, RandomAccessIterator last, Compare comp);
```

1. **Effects:** Constructs a heap out of the range \([first, last)\).
2. **Complexity:** At most \(3 \times (last - first)\) comparisons.

25.3.6.4 sort_heap

```cpp
template<class RandomAccessIterator>
void sort_heap(RandomAccessIterator first, RandomAccessIterator last);
```

```cpp
template<class RandomAccessIterator, class Compare>
void sort_heap(RandomAccessIterator first, RandomAccessIterator last, Compare comp);
```

1. **Effects:** Sorts elements in the heap \([first, last)\).
2. **Requires:** The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).
3. **Complexity:** At most \(N \log(N)\) comparisons (where \(N = last - first\)).

25.3.7 Minimum and maximum

```cpp
template<class T> const T& min(const T& a, const T& b);
template<class T, class Compare>
const T& min(const T& a, const T& b, Compare comp);
```

1. **Requires:** Type \(T\) is LessThanComparable (20.1.2).
2. **Returns:** The smaller value.

3. **Remarks:** Returns the first argument when the arguments are equivalent.

```cpp
template<class T> const T& max(const T& a, const T& b);
template<class T, class Compare>
const T& max(const T& a, const T& b, Compare comp);
```

4. **Requires:** Type \(T\) is LessThanComparable (20.1.2).
5. **Returns:** The larger value.

6. **Remarks:** Returns the first argument when the arguments are equivalent.

```cpp
template<class T> pair<const T&, const T&> minmax(const T& a, const T& b);
template<class T, class Compare>
```

Draft
pair<const T&, const T&> minmax(const T& a, const T& b, Compare comp);

Requires: Type T shall be LessThanComparable (20.1.2).

Returns: pair<const T&, const T&>(b, a) if b is smaller than a, and pair<const T&, const T&>(a, b) otherwise.

Remarks: Returns <pair<const T&, const T&>(a, b) when the arguments are equivalent.

Complexity: Exactly one comparison.

template<class ForwardIterator>
ForwardIterator min_element(ForwardIterator first, ForwardIterator last);

template<class ForwardIterator, class Compare>
ForwardIterator min_element(ForwardIterator first, ForwardIterator last, Compare comp);

Returns: The first iterator i in the range [first, last) such that for any iterator j in the range [first, last)
the following corresponding conditions hold: !(\*j < \*i) or comp (\*j, \*i) == false. Returns last if first == last.

Complexity: Exactly max((last - first) - 1, 0) applications of the corresponding comparisons.

template<class ForwardIterator>
ForwardIterator max_element(ForwardIterator first, ForwardIterator last);

template<class ForwardIterator, class Compare>
ForwardIterator max_element(ForwardIterator first, ForwardIterator last, Compare comp);

Returns: The first iterator i in the range [first, last) such that for any iterator j in the range [first, last)
the following corresponding conditions hold: !(\*i < \*j) or comp (\*i, \*j) == false. Returns last if first == last.

Complexity: Exactly max((last - first) - 1, 0) applications of the corresponding comparisons.

template<class ForwardIterator>
pair<ForwardIterator, ForwardIterator> minmax_element(ForwardIterator first, ForwardIterator last);

template<class ForwardIterator, class Compare>
pair<ForwardIterator, ForwardIterator> minmax_element(ForwardIterator first, ForwardIterator last, Compare comp);

Returns: make_pair(m, M), where m is min_element(first, last) or min_element(first, last, comp)
and M is max_element(first, last) or max_element(first, last, comp).

Complexity: At most max(2 * (last - first) - 2, 0) applications of the corresponding comparisons.

25.3.8 Lexicographical comparison [lib.alg.lex.comparison]

template<class InputIterator1, class InputIterator2>
bool
25.3 Sorting and related operations

```
lexicographical_compare(InputIterator1 first1, InputIterator1 last1,
                        InputIterator2 first2, InputIterator2 last2);
```

```
template<class InputIterator1, class InputIterator2, class Compare>
bool
lexicographical_compare(InputIterator1 first1, InputIterator1 last1,
                        InputIterator2 first2, InputIterator2 last2,
                        Compare comp);
```

1 Returns: true if the sequence of elements defined by the range \([first1, last1)\) is lexicographically less than the sequence of elements defined by the range \([first2, last2)\).

Returns false otherwise.

2 Complexity: At most \(2 \times \min((last1 - first1), (last2 - first2))\) applications of the corresponding comparison.

3 Remarks: If two sequences have the same number of elements and their corresponding elements are equivalent, then neither sequence is lexicographically less than the other. If one sequence is a prefix of the other, then the shorter sequence is lexicographically less than the longer sequence. Otherwise, the lexicographical comparison of the sequences yields the same result as the comparison of the first corresponding pair of elements that are not equivalent.

```
for ( ; first1 != last1 && first2 != last2 ; ++first1, ++first2) {
    if (*first1 < *first2) return true;
    if (*first2 < *first1) return false;
} return first1 == last1 && first2 != last2;
```

25.3.9 Permutation generators

```
template<class BidirectionalIterator>
bool next_permutation(BidirectionalIterator first, BidirectionalIterator last);
```

```
template<class BidirectionalIterator, class Compare>
bool next_permutation(BidirectionalIterator first, BidirectionalIterator last, Compare comp);
```

1 Effects: Takes a sequence defined by the range \([first, last)\) and transforms it into the next permutation. The next permutation is found by assuming that the set of all permutations is lexicographically sorted with respect to \(\text{operator<}\) or \(\text{comp}\). If such a permutation exists, it returns true. Otherwise, it transforms the sequence into the smallest permutation, that is, the ascendingly sorted one, and returns false.

2 Requires: The type of \(*\text{first}\) shall satisfy the Swappable requirements (20.1.4).

3 Complexity: At most \((last - first)/2\) swaps.

```
template<class BidirectionalIterator>
bool prev_permutation(BidirectionalIterator first, BidirectionalIterator last);
```

Draft
template<class BidirectionalIterator, class Compare>
bool prev_permutation(BidirectionalIterator first,
                       BidirectionalIterator last, Compare comp);

Effects: Takes a sequence defined by the range \([first, last)\) and transforms it into the previous permutation.
The previous permutation is found by assuming that the set of all permutations is lexicographically sorted with
respect to \(\text{operator<}\) or \(\text{comp}\).

Returns: true if such a permutation exists. Otherwise, it transforms the sequence into the largest permutation,
that is, the descendingly sorted one, and returns false.

Requires: The type of \(*first\) shall satisfy the Swappable requirements (20.1.4).

Complexity: At most \((last - first)/2\) swaps.

25.4 C library algorithms

Header <cstdlib> (partial, Table 95).

Table 95: Header <cstdlib> synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>size_t</td>
</tr>
<tr>
<td>Functions:</td>
<td>bsearch qsort</td>
</tr>
</tbody>
</table>

The contents are the same as the Standard C library header <stdlib.h> with the following exceptions:

The function signature:

\[
\text{bsearch(const void *, const void *, size_t, size_t,}
\int (*)\text{(const void *, const void *)});
\]

is replaced by the two declarations:

\[
\text{extern "C" void *bsearch(const void *key, const void *base,}
\text{size_t nmemb, size_t size,}
\int (*compar)(const void *, const void *)});
\]

\[
\text{extern "C++" void *bsearch(const void *key, const void *base,}
\text{size_t nmemb, size_t size,}
\int (*compar)(const void *, const void *)});
\]

both of which have the same behavior as the original declaration.

The function signature:

\[
\text{qsort(void *, size_t, size_t,}
\int (*)\text{(const void *, const void *)});
\]

is replaced by the two declarations:
both of which have the same behavior as the original declaration. The behavior is undefined unless the objects in the array pointed to by `base` are of POD type.

[Note: Because the function argument `compar()` may throw an exception, `bsearch()` and `qsort()` are allowed to propagate the exception (17.4.4.8). — end note]

See also: ISO C subclause 7.10.5.
Chapter 26  Numerics library

This clause describes components that C++ programs may use to perform seminumerical operations.

The following subclauses describe components for complex number types, random number generation, numeric (n-at-a-time) arrays, generalized numeric algorithms, and facilities included from the ISO C library, as summarized in Table 96.

Table 96: Numerics library summary

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.1 Requirements</td>
<td>&lt;complex&gt;</td>
</tr>
<tr>
<td>26.3 Complex Numbers</td>
<td>&lt;complex&gt;</td>
</tr>
<tr>
<td>26.4 Random number generation</td>
<td>&lt;random&gt;</td>
</tr>
<tr>
<td>26.5 Numeric arrays</td>
<td>&lt;valarray&gt;</td>
</tr>
<tr>
<td>26.6 Generalized numeric operations</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>26.7 C library</td>
<td>&lt;cmath&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;ctgmath&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;tgmath.h&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;cstdlib&gt;</td>
</tr>
</tbody>
</table>

26.1 Numeric type requirements

The complex and valarray components are parameterized by the type of information they contain and manipulate. A C++ program shall instantiate these components only with a type \( T \) that satisfies the following requirements:

- \( T \) is not an abstract class (it has no pure virtual member functions);
- \( T \) is not a reference type;
- \( T \) is not cv-qualified;
- If \( T \) is a class, it has a public default constructor;
- If \( T \) is a class, it has a public copy constructor with the signature \( T::T(\text{const} \ T&) \)
- If \( T \) is a class, it has a public destructor;
- If \( T \) is a class, it has a public assignment operator whose signature is either \( T& \ T::\text{operator}=(\text{const} \ T&) \) or \( T& \ T::\text{operator}=(T) \)

\[\text{(272)}\] In other words, value types. These include built-in arithmetic types, pointers, the library class complex, and instantiations of valarray for value types.
— If \( T \) is a class, its assignment operator, copy and default constructors, and destructor shall correspond to each other in the following sense: Initialization of raw storage using the default constructor, followed by assignment, is semantically equivalent to initialization of raw storage using the copy constructor. Destruction of an object, followed by initialization of its raw storage using the copy constructor, is semantically equivalent to assignment to the original object.

[Note: This rule states that there shall not be any subtle differences in the semantics of initialization versus assignment. This gives an implementation considerable flexibility in how arrays are initialized.]

[Example: An implementation is allowed to initialize a `valarray` by allocating storage using the `new` operator (which implies a call to the default constructor for each element) and then assigning each element its value. Or the implementation can allocate raw storage and use the copy constructor to initialize each element. — end example]

If the distinction between initialization and assignment is important for a class, or if it fails to satisfy any of the other conditions listed above, the programmer should use `vector` (23.2.5) instead of `valarray` for that class; — end note]

— If \( T \) is a class, it does not overload unary `operator&`. 

If any operation on \( T \) throws an exception the effects are undefined.

3 In addition, many member and related functions of `valarray<T>` can be successfully instantiated and will exhibit well-defined behavior if and only if \( T \) satisfies additional requirements specified for each such member or related function.

4 [Example: It is valid to instantiate `valarray<complex>`, but `operator()` will not be successfully instantiated for `valarray<complex>` operands, since `complex` does not have any ordering operators. — end example]

26.2 TR1: The floating-point environment

26.2.1 Header `<cfenv>` synopsis

```cpp
namespace std {
    // types
    typedef object type fenv_t;
    typedef integer type fexcept_t;

    // functions
    int feclearexcept(int except);
    int fegetexceptflag(fexcept_t *pflag, int except);
    int feraiseexcept(int except);
    int fesetexceptflag(const fexcept_t *pflag, int except);
    int fetestexcept(int except);
    int fegetround(void);
    int fesetround(int mode);

    int fegetenv(fenv_t *penv);
    int feholdexcept(fenv_t *penv);
    int fesetenv(const fenv_t *penv);
    int feupdateenv(const fenv_t *penv);
} // namespace std
```

Draft
The header also defines the macros:

```
FE_ALL_EXCEPT
FE_DIVBYZERO
FE_INEXACT
FE_INVALID
FE_OVERFLOW
FE_UNDERFLOW

FE_DOWNWARD
FE_TONEAREST
FE_TOWARDZERO
FE_UPWARD

FE_DFL_ENV
```

The header defines all functions, types, and macros the same as C99 subclause 7.6.

### 26.2.2 Header `<fenv.h>`

The header behaves as if it includes the header `<cfenv>`, and provides sufficient `using` declarations to declare in the global namespace all function and type names declared or defined in the header `<cfenv>`.

### 26.3 Complex numbers

The header `<complex>` defines a class template, and numerous functions for representing and manipulating complex numbers.

The effect of instantiating the template `complex` for any type other than float, double or long double is unspecified.

If the result of a function is not mathematically defined or not in the range of representable values for its type, the behavior is undefined.

### 26.3.1 Header `<complex>` synopsis

```cpp
namespace std {
    template<class T> class complex;
    template<> class complex<float>;
    template<> class complex<double>;
    template<> class complex<long double>;

    // 26.3.6 operators:
    template<class T>
        complex<T> operator+(const complex<T>&, const complex<T>&);
    template<class T> complex<T> operator+(const complex<T>&, const T&);
    template<class T> complex<T> operator+(const T&, const complex<T>&);

    template<class T> complex<T> operator-(const complex<T>&, const complex<T>&);
    template<class T> complex<T> operator-(const complex<T>&, const T&);
    template<class T> complex<T> operator-(const T&, const complex<T>&);
}```
26.3 Complex numbers

template<class T> complex<T> operator*
    (const complex<T>&, const complex<T>&);
template<class T> complex<T> operator*(const complex<T>&, const T&);
template<class T> complex<T> operator*(const T&, const complex<T>&);

template<class T> complex<T> operator/
    (const complex<T>&, const complex<T>&);
template<class T> complex<T> operator/(const complex<T>&, const T&);
template<class T> complex<T> operator/(const T&, const complex<T>&);

template<class T> complex<T> operator+(const complex<T>&);
template<class T> complex<T> operator-(const complex<T>&);

template<class T> bool operator==
    (const complex<T>&, const complex<T>&);
template<class T> bool operator==(const complex<T>&, const T&);
template<class T> bool operator==(const T&, const complex<T>&);

template<class T, class charT, class traits>
    basic_istream<charT, traits>&
    operator>>(basic_istream<charT, traits>&, complex<T>&);

template<class T, class charT, class traits>
    basic_ostream<charT, traits>&
    operator<<(basic_ostream<charT, traits>&, const complex<T>&);

// 26.3.7 values:

    template<class T> T real(const complex<T>&);
    template<class T> T imag(const complex<T>&);

    template<class T> T abs(const complex<T>&);
    template<class T> T arg(const complex<T>&);
    template<class T> T norm(const complex<T>&);

    template<class T> complex<T> conj(const complex<T>&);

    TR1:    template<class T> complex<T> fabs(const complex<T>&);

    TR1:    template<class T> complex<T> polar(const T&, const T& = 0);

// 26.3.8 transcendental:

    TR1:    template<class T> complex<T> acos(const complex<T>&);
    TR1:    template<class T> complex<T> asin(const complex<T>&);
    TR1:    template<class T> complex<T> atan(const complex<T>&);

    TR1:    template<class T> complex<T> acosh(const complex<T>&);
    TR1:    template<class T> complex<T> asinh(const complex<T>&);
    TR1:    template<class T> complex<T> atanh(const complex<T>&);
26.3 Complex numbers

namespace std {
    template<class T> class complex {
        public:
            typedef T value_type;

            complex(const T& re = T(), const T& im = T());
            complex(const complex&);  
            template<class X> complex(const complex<X>&);  

            T real() const;
            T imag() const;

            complex<T>& operator=(const T&);
            complex<T>& operator+=(const T&);
            complex<T>& operator-=(const T&);
            complex<T>& operator*=(const T&);
            complex<T>& operator/=(const T&);
            template<class X> complex<T>& operator= (const complex<X>&);
            template<class X> complex<T>& operator+=(const complex<X>&);
            template<class X> complex<T>& operator-=(const complex<X>&);
            template<class X> complex<T>& operator*=(const complex<X>&);
            template<class X> complex<T>& operator/=(const complex<X>&);
    };
}
The class complex describes an object that can store the Cartesian components, real() and imag(), of a complex number.

### 26.3.3 complex specializations

```cpp
template<> class complex<float> {
    public:
        typedef float value_type;

        complex(float re = 0.0f, float im = 0.0f);
        explicit complex(const complex<double>&);
        explicit complex(const complex<long double>&);

        float real() const;
        float imag() const;

        complex<float>& operator= (float);
        complex<float>& operator+=(float);
        complex<float>& operator-=(float);
        complex<float>& operator*=(float);
        complex<float>& operator/=(float);
}
```

```cpp
template<> class complex<double> {
    public:
        typedef double value_type;

        complex(double re = 0.0, double im = 0.0);
        complex(const complex<float>&);
        explicit complex(const complex<long double>&);

        double real() const;
        double imag() const;

        complex<double>& operator= (double);
        complex<double>& operator+=(double);
        complex<double>& operator-=(double);
        complex<double>& operator*=(double);
        complex<double>& operator/=(double);
}
```
```cpp
template<class X> complex<double>& operator-=(const complex<X>&);
template<class X> complex<double>& operator*=(const complex<X>&);
template<class X> complex<double>& operator/=(const complex<X>&);
}

template<> class complex<long double> {
public:
    typedef long double value_type;
    complex(long double re = 0.0L, long double im = 0.0L);
    complex(const complex<float>&);
    complex(const complex<double>&);

    long double real() const;
    long double imag() const;

    complex<long double>& operator=(const complex<long double>&);
    complex<long double>& operator=(long double);
    complex<long double>& operator+=(long double);
    complex<long double>& operator-=(long double);
    complex<long double>& operator*=(long double);
    complex<long double>& operator/=(long double);
}

26.3.4 complex member functions

template<class T> complex(const T& re = T(), const T& im = T());
1      Effects: Constructs an object of class complex.
2      Postcondition: real() == re && imag() == im.

26.3.5 complex member operators

template <class T> complex<T>& operator+= (const T& rhs);
1      Effects: Adds the scalar value rhs to the real part of the complex value *this and stores the result in the real part of *this, leaving the imaginary part unchanged.
2      Returns: *this.

template <class T> complex<T>& operator-=(const T& rhs);
3      Effects: Subtracts the scalar value rhs from the real part of the complex value *this and stores the result in the real part of *this, leaving the imaginary part unchanged.
```

Draft
26.3 Complex numbers

Returns: *this.

```cpp
template <class T> complex<T>& operator*=(const T& rhs);
```

Effects: Multiplies the scalar value \( rhs \) by the complex value \( \ast \text{this} \) and stores the result in \( \ast \text{this} \).

Returns: *this.

```cpp
template <class T> complex<T>& operator/=(const T& rhs);
```

Effects: Divides the scalar value \( rhs \) into the complex value \( \ast \text{this} \) and stores the result in \( \ast \text{this} \).

Returns: *this.

```cpp
template <class T> complex<T>& operator+=(const T& rhs);
```

Effects: Adds the complex value \( rhs \) to the complex value \( \ast \text{this} \) and stores the sum in \( \ast \text{this} \).

Returns: *this.

```cpp
template <class T> complex<T>& operator-=(const T& rhs);
```

Effects: Subtracts the complex value \( rhs \) from the complex value \( \ast \text{this} \) and stores the difference in \( \ast \text{this} \).

Returns: *this.

```cpp
template <class T> complex<T>& operator*=(const complex<T>& rhs);
```

Effects: Multiplies the complex value \( rhs \) by the complex value \( \ast \text{this} \) and stores the product in \( \ast \text{this} \).

Returns: *this.

```cpp
template <class T> complex<T>& operator/=(const complex<T>& rhs);
```

Effects: Divides the complex value \( rhs \) into the complex value \( \ast \text{this} \) and stores the quotient in \( \ast \text{this} \).

Returns: *this.

### 26.3.6 complex non-member operations

#### Remarks: unary operator.

```
template<class T> complex<T> operator+(const complex<T>& lhs);
```

Returns: \( \text{complex}<T>(\text{lhs}) \).

```
template<class T> complex<T> operator+(const complex<T>& lhs, const complex<T>& rhs);
template<class T> complex<T> operator+(const complex<T>& lhs, const T& rhs);
template<class T> complex<T> operator+(const T& lhs, const complex<T>& rhs);
```

Returns: \( \text{complex}<T>(\text{lhs}) + \text{rhs} \).

```
template<class T> complex<T> operator-(const complex<T>& lhs);
```

Draft
Remarks: unary operator.

Returns: \( \text{complex}\langle T\rangle(-\text{lhs}.\text{real}(),-\text{lhs}.\text{imag}()) \).

```cpp
template<class T>
  complex<T> operator-(const complex<T>& lhs, const complex<T>& rhs);
template<class T> complex<T> operator-(const complex<T>& lhs, const T& rhs);
template<class T> complex<T> operator-(const T& lhs, const complex<T>& rhs);
```

Returns: \( \text{complex}\langle T\rangle(lhs) -= rhs \).

```cpp
template<class T>
  complex<T> operator*(const complex<T>& lhs, const complex<T>& rhs);
template<class T> complex<T> operator*(const complex<T>& lhs, const T& rhs);
template<class T> complex<T> operator*(const T& lhs, const complex<T>& rhs);
```

Returns: \( \text{complex}\langle T\rangle(lhs) *= rhs \).

```cpp
template<class T>
  bool operator==(const complex<T>& lhs, const complex<T>& rhs);
template<class T> bool operator==(const complex<T>& lhs, const T& rhs);
template<class T> bool operator==(const T& lhs, const complex<T>& rhs);
```

Returns: \( \text{lhs}.\text{real}() == rhs.\text{real}() && \text{lhs}.\text{imag}() == rhs.\text{imag}() \).

Remarks: The imaginary part is assumed to be \( T() \), or 0.0, for the \( T \) arguments.

```cpp
template<class T>
  bool operator!=(const complex<T>& lhs, const complex<T>& rhs);
template<class T> bool operator!=(const complex<T>& lhs, const T& rhs);
template<class T> bool operator!=(const T& lhs, const complex<T>& rhs);
```

Returns: \( rhs.\text{real}() != lhs.\text{real}() || rhs.\text{imag}() != lhs.\text{imag}() \).

Effects: Extracts a complex number \( z \) of the form: \( u, (u) \), or \( (u,v) \), where \( u \) is the real part and \( v \) is the imaginary part (27.6.1.2).

Requires: The input values be convertible to \( T \).

If bad input is encountered, calls \( \text{is}.\text{setstate}(\text{ios::failbit}) \) (which may throw \( \text{ios::failure} \) (27.4.4.3).

Returns: \( \text{is} \).
26.3 Complex numbers Numerics library 742

Remarks: This extraction is performed as a series of simpler extractions. Therefore, the skipping of whitespace is specified to be the same for each of the simpler extractions.

\[
\begin{align*}
\text{template} & \langle \text{class } T, \text{ class charT, class traits}\rangle \\
\text{basic ostream} & \langle \text{charT, traits}\rangle \\
\text{operator} & \langle\langle (\text{basic ostream} \langle \text{charT, traits}\rangle & o, \text{ const complex}<T>& x) \\
\end{align*}
\]

Effects: inserts the complex number \(x\) onto the stream \(o\) as if it were implemented as follows:

\[
\begin{align*}
\text{template} & \langle \text{class } T, \text{ class charT, class traits}\rangle \\
\text{basic ostream} & \langle \text{charT, traits}\rangle \\
\text{operator} & \langle\langle (\text{basic ostream} \langle \text{charT, traits}\rangle & o, \text{ const complex}<T>& x) \\
\end{align*}
\]

\[
\begin{align*}
\{ & \\
\text{basic ostringstream} & \langle \text{charT, traits}\rangle s; \\
\text{s.flags} & (o.flags()); \\
\text{s.imbue} & (o.getloc()); \\
\text{s.precision} & (o.precision()); \\
\text{s} & \langle\langle (\text{'} \langle\langle x.\text{real}() \langle\langle \text{',} \langle\langle x.\text{imag}() \langle\langle \text{'}\rangle\rangle\rangle\rangle\rangle\rangle\rangle\rangle\rangle\rangle; \\
\text{return} & \langle\langle o \langle\langle s.\text{str}()\rangle\rangle\rangle; \\
\}
\end{align*}
\]

26.3.7 complex value operations [lib.complex.value.ops]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ T \text{ real}(\text{const complex}<T>& x); \\
\text{Returns} & : x.\text{real}() . \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ T \text{ imag}(\text{const complex}<T>& x); \\
\text{Returns} & : x.\text{imag}() . \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ T \text{ abs}(\text{const complex}<T>& x); \\
\text{Returns} & : \text{the magnitude of } x . \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ T \text{ arg}(\text{const complex}<T>& x); \\
\text{Returns} & : \text{the phase angle of } x, \text{ or } \text{atan2}(\text{imag}(x), \text{real}(x)). \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ T \text{ norm}(\text{const complex}<T>& x); \\
\text{Returns} & : \text{the squared magnitude of } x . \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ \text{complex}<T> \ \text{conj}(\text{const complex}<T>& x); \\
\text{Returns} & : \text{the complex conjugate of } x. \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ \text{complex}<T> \ \text{fabs}(\text{const complex}<T>& x); \\
\text{Effects} & : \text{Behaves the same as C99 function } \text{cabs, defined in subclause 7.3.8.1}. \\
\end{align*}
\]

\[
\begin{align*}
\text{template} & \langle \text{class } T\rangle \ \text{complex}<T> \ \text{polar}(\text{const } T& \text{ rho}, \text{ const } T& \text{ theta} = 0); \\
\end{align*}
\]

Draft
26.3 Complex numbers

Returns: the complex value corresponding to a complex number whose magnitude is $\rho$ and whose phase angle is $\theta$.

26.3.8 complex transcendentals

TR1: template<typename T> complex<T> acos(const complex<T>& x);

Effects: Behaves the same as C99 function acos, defined in subclause 7.3.5.1.

TR1: template<typename T> complex<T> asin(const complex<T>& x);

Effects: Behaves the same as C99 function asin, defined in subclause 7.3.5.2.

TR1: template<typename T> complex<T> atan(const complex<T>& x);

Effects: Behaves the same as C99 function atan, defined in subclause 7.3.5.3.

TR1: template<typename T> complex<T> acosh(const complex<T>& x);

Effects: Behaves the same as C99 function acosh, defined in subclause 7.3.6.1.

TR1: template<typename T> complex<T> asinh(const complex<T>& x);

Effects: Behaves the same as C99 function asinh, defined in subclause 7.3.6.2.

TR1: template<typename T> complex<T> atanh(const complex<T>& x);

Effects: Behaves the same as C99 function atanh, defined in subclause 7.3.6.3.

template<typename T> complex<T> cos(const complex<T>& x);

Returns: the complex cosine of $x$.

template<typename T> complex<T> cosh(const complex<T>& x);

Returns: the complex hyperbolic cosine of $x$.

template<typename T> complex<T> exp(const complex<T>& x);

Returns: the complex base e exponential of $x$.

template<typename T> complex<T> log(const complex<T>& x);

Remarks: the branch cuts are along the negative real axis.

Returns: the complex natural (base e) logarithm of $x$, in the range of a strip mathematically unbounded along the real axis and in the interval $[-i \times \pi, i \times \pi]$ along the imaginary axis. When $x$ is a negative real number, $\text{imag}(\log(x))$ is $\pi$.

template<typename T> complex<T> log10(const complex<T>& x);

Remarks: the branch cuts are along the negative real axis.

Returns: the complex common (base 10) logarithm of $x$, defined as $\log(x)/\log(10)$.
26.3 Complex numbers

\begin{verbatim}
template<class T> complex<T> pow(const complex<T>& x, int y);
template<class T> complex<T> pow(const complex<T>& x, const complex<T>& y);
template<class T> complex<T> pow(const complex<T>& x, const T& y);
template<class T> complex<T> pow(const T& x, const complex<T>& y);

Remarks: the branch cuts are along the negative real axis.

Returns: the complex power of base \( x \) raised to the \( y \)-th power, defined as \( \exp(y \cdot \log(x)) \). The value returned for \( \text{pow}(0,0) \) is implementation-defined.
\end{verbatim}

\begin{verbatim}
template<class T> complex<T> sin (const complex<T>& x);

Returns: the complex sine of \( x \).
\end{verbatim}

\begin{verbatim}
template<class T> complex<T> sinh (const complex<T>& x);

Returns: the complex hyperbolic sine of \( x \).
\end{verbatim}

\begin{verbatim}
template<class T> complex<T> sqrt (const complex<T>& x);

Remarks: the branch cuts are along the negative real axis.

Returns: the complex square root of \( x \), in the range of the right half-plane. If the argument is a negative real number, the value returned lies on the positive imaginary axis.
\end{verbatim}

\begin{verbatim}
template<class T> complex<T> tan (const complex<T>& x);

Returns: the complex tangent of \( x \).
\end{verbatim}

\begin{verbatim}
template<class T> complex<T> tanh (const complex<T>& x);

Returns: the complex hyperbolic tangent of \( x \).
\end{verbatim}

26.3.9 TR1: Additional Overloads

The following function templates shall have additional overloads:

\begin{verbatim}
arg norm
conj polar
imag real
\end{verbatim}

The additional overloads shall be sufficient to ensure:

1. If the argument has type \( \text{long double} \), then it is effectively cast to \( \text{complex<long double>} \).
2. Otherwise, if the argument has type \( \text{double} \) or an integer type, then it is effectively cast to \( \text{complex<double>} \).
3. Otherwise, if the argument has type \( \text{float} \), then it is effectively cast to \( \text{complex<float>} \).

Function template \( \text{pow} \) shall have additional overloads sufficient to ensure, for a call with at least one argument of type \( \text{complex<T>} \):

1. If either argument has type \( \text{complex<long double>} \) or type \( \text{long double} \), then both arguments are effectively cast to \( \text{complex<long double>} \).
2. Otherwise, if either argument has type `complex<double>`, `double`, or an integer type, then both arguments are effectively cast to `complex<double>`.

3. Otherwise, if either argument has type `complex<float>` or `float`, then both arguments are effectively cast to `complex<float>`.

26.3.10 TR1: Header `<ccomplex>` [lib.ccmplx]

The header behaves as if it simply includes the header `<complex>`.

26.3.11 TR1: Header `<complex.h>` [lib.cmplxh]

The header behaves as if it includes the header `<ccomplex>`, and provides sufficient `using` declarations to declare in the global namespace all function and type names declared or defined in the header `<complex>`.

26.4 TR1: Random number generation [lib.rand]

This subclause defines a facility for generating random numbers.

26.4.1 Requirements [lib.rand.req]

In table 97, \( X \) denotes a uniform random number generator class returning objects of type \( T \), \( u \) is a value of \( X \), and \( v \) is a (possibly const) value of \( X \).

Table 97: Uniform random number generator requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X::\text{result_type} )</td>
<td>( T )</td>
<td>( T ) is an arithmetic type [basic.fundamental]</td>
<td>compile-time</td>
</tr>
<tr>
<td>( u() )</td>
<td>( T )</td>
<td>—</td>
<td>amortized constant</td>
</tr>
<tr>
<td>( v.\text{min}() )</td>
<td>( T )</td>
<td>Returns a value that is less than or equal to all values potentially returned by ( \text{operator()} ). The return value of this function shall not change during the lifetime of ( v ).</td>
<td>constant</td>
</tr>
<tr>
<td>( v.\text{max}() )</td>
<td>( T )</td>
<td>If `std::numeric_limits&lt;( T )&gt;&gt;::is_integer, returns a value that is greater than or equal to all values potentially returned by ( \text{operator()} ), otherwise, returns a value that is strictly greater than all values potentially returned by ( \text{operator()} ). In any case, the return value of this function shall not change during the lifetime of ( v ).</td>
<td>constant</td>
</tr>
</tbody>
</table>

2 In table 98, \( X \) denotes a pseudo-random number engine class returning objects of type \( T \), \( t \) is a value of \( T \), \( u \) is a value

Draft
of $X$, $v$ is an lvalue of $X$, $s$ is a value of integral type, $g$ is an lvalue of a type other than $X$ that defines a zero-argument function object returning values of unsigned integral type, $x$ and $y$ are (possibly const) values of $X$, $os$ is an lvalue of the type of some class template specialization `basic_ostream<charT, traits>`, and $is$ is an lvalue of the type of some class template specialization `basic_istream<charT, traits>`, where `charT` and `traits` are constrained according to [lib.strings] and [lib.input.output].

A pseudo-random number engine $x$ has a state $x(i)$ at any given time. The specification of each pseudo-random number engine defines the size of its state in multiples of the size of its `result_type`, given as an integral constant expression.

Table 98: Pseudo-random number engine requirements (in addition to uniform random number generator, CopyConstructible, and Assignable)

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X()$</td>
<td>—</td>
<td>creates an engine with the same initial state as all other default-constructed engines of type $X$ in the program.</td>
<td>$O$(size of state)</td>
</tr>
<tr>
<td>$X(s)$</td>
<td>—</td>
<td>creates an engine with the initial internal state determined by $s$</td>
<td>$O$(size of state)</td>
</tr>
<tr>
<td>$X(g)$</td>
<td>—</td>
<td>creates an engine with the initial internal state given by the results of successive invocations of $g$. Throws what and when $g$ throws.</td>
<td>$O$(size of state)</td>
</tr>
<tr>
<td>$u.seed()$</td>
<td>void</td>
<td>post: $u == X()$</td>
<td>$O$(size of state)</td>
</tr>
<tr>
<td>$u.seed(s)$</td>
<td>void</td>
<td>sets the internal state of $u$ so that $u == X(s)$.</td>
<td>same as $X(s)$</td>
</tr>
<tr>
<td>$u.seed(g)$</td>
<td>void</td>
<td>post: The internal state of $u$ is the same as if $u$ had been newly constructed by $X u(g)$. If an invocation of $g$ throws an exception, that exception is rethrown. Further use of $u$ (except destruction) is undefined until a <code>seed</code> member function has been executed without throwing an exception.</td>
<td>same as $X(g)$</td>
</tr>
<tr>
<td>$u()$</td>
<td>$T$</td>
<td>given the state $u(i)$ of the engine, computes $u(i+1)$, sets the state to $u(i+1)$, and returns some output dependent on $u(i+1)$</td>
<td>amortized constant</td>
</tr>
<tr>
<td>$x == y$</td>
<td>bool</td>
<td>Given the current state $x(i)$ of $x$ and the current state $y(j)$ of $y$, returns true if $x(i+k)$ is equal to $y(j+k)$ for all integer $k &gt;= 0$, false otherwise.</td>
<td>$O$(size of state)</td>
</tr>
</tbody>
</table>
### TR1: Random number generation

#### Numerics library

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>x != y</td>
<td>bool</td>
<td>!(x == y)</td>
<td>(O)(size of state)</td>
</tr>
<tr>
<td>os &lt;&lt; x</td>
<td>reference to the type of os set to os.fmtflags and fill character set to space character. In the output, adjacent numbers are separated by one or more space characters. post: The os.fmtflags and fill character are unchanged.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>is &gt;&gt; v</td>
<td>reference to the type of is sets the state (v(i)) of (v) as determined by reading its textual representation from (is). pre: The textual representation was previously written using an os whose imbued locale and whose type’s template specialization arguments (\text{charT}) and (\text{traits}) were the same as those of (is). post: The (is.fmtflags) are unchanged.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Additional requirements:

- The complexity of both copy construction and assignment is \(O\)(size of state).
- The constructor \(\text{template<class Gen> X(Gen& g)}\) shall have the same effect as \(X(\text{static\_cast<Gen>(g)})\) if \(Gen\) is a fundamental type.
- The member function of the form \(\text{template<class Gen> void seed(Gen& g)}\) shall have the same effect as \(X(\text{static\_cast<Gen>(g)})\) if \(Gen\) is a fundamental type.

[Note: The casts make \(g\) an rvalue, unsuitable for binding to a reference, to ensure that overload resolution will select the version of \(seed\) that takes a single integer argument instead of the version that takes a reference to a function object.]

end note

5 If a textual representation was written by \(os << x\) and that representation was read by \(is >> v\), then \(x == v\), provided that no intervening invocations of \(x\) or \(v\) have occurred.

6 In table 99, \(X\) denotes a random distribution class returning objects of type \(T\), \(u\) is a value of \(X\), \(x\) is a (possibly const) value of \(X\), \(e\) is an lvalue of an arbitrary type that meets the requirements of a uniform random number generator, returning values of type \(U\), \(os\) is an lvalue of the type of some class template specialization \(\text{basic\_ostream<charT, traits>}\), and is an lvalue of the type of some class template specialization \(\text{basic\_istream<charT, traits>}\), where \(\text{charT}\) and \(\text{traits}\) are constrained according to \[lib.strings\] and \[lib.input.output\].

Draft
Table 99: Random distribution requirements (in addition to CopyConstructible, and Assignable)

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>pre/post-condition</th>
<th>complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>X::input_type</code></td>
<td>U</td>
<td>—</td>
<td>compile-time</td>
</tr>
<tr>
<td><code>X::result_type</code></td>
<td>T</td>
<td>—</td>
<td>compile-time</td>
</tr>
<tr>
<td><code>u.reset()</code></td>
<td>void</td>
<td>subsequent uses of u do not depend on values produced by e prior to invoking reset.</td>
<td>constant</td>
</tr>
<tr>
<td><code>u(e)</code></td>
<td>T</td>
<td>the sequence of numbers returned by successive invocations with the same object e is randomly distributed with some probability density function <code>p(x)</code></td>
<td>amortized constant number of invocations of e</td>
</tr>
<tr>
<td><code>os &lt;&lt; x</code></td>
<td>reference to the type of os</td>
<td>writes a textual representation for the parameters and additional internal data of the distribution x to os. post: The os.fmtflags and fill character are unchanged.</td>
<td><code>O(size of state)</code></td>
</tr>
<tr>
<td><code>is &gt;&gt; u</code></td>
<td>reference to the type of is</td>
<td>restores the parameters and additional internal data of the distribution u. pre: is provides a textual representation that was previously written using an os whose imbued locale and whose type’s template specialization arguments charT and traits were the same than those of is. post: The is.fmtflags are unchanged.</td>
<td><code>O(size of state)</code></td>
</tr>
</tbody>
</table>

7 Additional requirements: The sequence of numbers produced by repeated invocations of `x(e)` does not change whether or not `os << x` is invoked between any of the invocations `x(e)`. If a textual representation is written using `os << x` and that representation is restored into the same or a different object `y` of the same type using `is >> y`, repeated invocations of `y(e)` produce the same sequence of random numbers as would repeated invocations of `x(e)`.

8 In the following subclauses, a template parameter named `UniformRandomNumberGenerator` shall denote a type that satisfies all the requirements of a uniform random number generator. Moreover, a template parameter named `Distribution` shall denote a type that satisfies all the requirements of a random distribution.

9 The effect of instantiating a template that has a template type parameter named `RealType` is undefined unless that type is one of `float`, `double`, or `long double`. If `std::numeric_limits<X::input_type>::is_integer` is `false`, the value of `e.min()` shall be 0 and the value of `e.max()` shall be 1.

10 The effect of instantiating a template that has a template type parameter named `IntType` is undefined unless that type is one of `short`, `int`, `long`, or their unsigned variants.

11 The effect of instantiating a template that has a template type parameter named `UIntType` is undefined unless that type is one of `short`, `int`, `long`, or their unsigned variants.

Draft
is one of unsigned short, unsigned int, or unsigned long.

26.4.2 Header <random> synopsis

nenamespace std {

  // 26.4.3, class template variate_generator:
  template<class UniformRandomNumberGenerator, class Distribution>
  class variate_generator;

  // 26.4.4.1, class template linear_congruential:
  template<class IntType, IntType a, IntType c, IntType m>
  class linear_congruential;

  // 26.4.4.2, class template mersenne_twister:
  template<class UIntType, int w, int n, int m, int r,
           UIntType a, int u, int s, UIntType b, int t, UIntType c, int l>
  class mersenne_twister;

  // 26.4.4.3, class template subtract_with_carry:
  template<class IntType, IntType m, int s, int r>
  class subtract_with_carry;

  // 26.4.4.4, class template subtract_with_carry_01:
  template<class RealType, int w, int s, int r>
  class subtract_with_carry_01;

  // 26.4.4.5, class template discard_block:
  template<class UniformRandomNumberGenerator, int p, int r>
  class discard_block;

  // 26.4.4.6, class template xor_combine:
  template<class UniformRandomNumberGenerator1, int s1,
           class UniformRandomNumberGenerator2, int s2>
  class xor_combine;

  // 26.4.6, class random_device:
  class random_device;

  // 26.4.7.1, class template uniform_int:
  template<class IntType = int>
  class uniform_int;

  // 26.4.7.2, class bernoulli_distribution:
  class bernoulli_distribution;

  // 26.4.7.3, class template geometric_distribution:
  template<class IntType = int, class RealType = double>
  class geometric_distribution;

Draft
26.4 Class template variate_generator

A variate_generator produces random numbers, drawing randomness from an underlying uniform random number generator and shaping the distribution of the numbers corresponding to a distribution function.

```cpp
class variate_generator
{
public:
    typedef Engine engine_type;
    typedef see below engine_value_type;
    typedef Distribution distribution_type;
    typedef typename Distribution::result_type result_type;

    variate_generator(engine_type eng, distribution_type d);

    result_type operator()();
    template<class T> result_type operator()(T value);

    engine_value_type& engine();
    const engine_value_type& engine() const;

    distribution_type& distribution();
    const distribution_type& distribution() const;
};
```
```cpp
result_type min() const;
result_type max() const;
};

The template argument for the parameter Engine shall be of the form U, U&, or U*, where U denotes a class that satisfies all the requirements of a uniform random number generator. The member engine_value_type shall name U.

Specializations of variate_generator satisfy the requirements of CopyConstructible and Assignable.

Except where specified otherwise, the complexity of all functions specified in this section is constant. No function described in this section except the constructor throws an exception.

variate_generator(engine_type eng, distribution_type d)

Effects: Constructs a variate_generator object with the associated uniform random number generator eng and the associated random distribution d.

Complexity: Sum of the complexities of the copy constructors of engine_type and distribution_type.

Throws: If and what the copy constructor of Engine or Distribution throws.

result_type operator()()

Returns: distribution()(e)

Complexity: Amortized constant.

Remarks: The sequence of numbers produced by the uniform random number generator e, se, is obtained from the sequence of numbers produced by the associated uniform random number generator eng, seng, as follows: Consider the values of numeric_limits<T>::is_integer for T both Distribution::input_type and engine_value_type::result_type. If the values for both types are true, then se is identical to seng. Otherwise, if the values for both types are false, then the numbers in seng are divided by engine().max() - engine().min() to obtain the numbers in se. Otherwise, if the value for engine_value_type::result_type is true and the value for Distribution::input_type is false, then the numbers in seng are divided by engine().max() - engine().min() + 1 to obtain the numbers in se. Otherwise, the mapping from seng to se is implementation-defined. In all cases, an implicit conversion from engine_value_type::result_type to Distribution::input_type is performed. If such a conversion does not exist, the program is ill-formed.

template<class T> result_type operator()(T value)

Precondition: distribution().operator()(e, value) shall be well-formed.

Returns: distribution()(e, value). For the semantics of e, see the description of operator().

engine_value_type& engine()

Returns: A reference to the associated uniform random number generator.

const engine_value_type& engine() const

Returns: A reference to the associated uniform random number generator.

distribution_type& distribution()
```
Returns: A reference to the associated random distribution.

const distribution_type& distribution() const

Returns: A reference to the associated random distribution.

result_type min() const

Precondition: distribution().min() is well-formed.

Returns: distribution().min()

result_type max() const

Precondition: distribution().max() is well-formed

Returns: distribution().max()

26.4.4 Random number engine class templates

Except where specified otherwise, the complexity of all functions specified in the following sections is constant. No function described in this section, except the constructor and seed functions taking a zero-argument function object, throws an exception.

The class templates specified in this section satisfy all the requirements of a pseudo-random number engine (given in table 98), except where specified otherwise. Descriptions are provided here only for operations on the engines that are not described in one of these tables or for operations where there is additional semantic information.

All members declared static const in any of the following class templates shall be defined in such a way that they are usable as integral constant expressions.

26.4.4.1 Class template linear_congruential

A linear_congruential engine produces random numbers using a linear function \(x(i+1) := (a \cdot x(i) + c) \mod m\).

namespace tr1 {
    template<class UIntType, UIntType a, UIntType c, UIntType m>
    class linear_congruential
    {
    public:
        // types
        typedef UIntType result_type;

        // parameter values
        static const UIntType multiplier = a;
        static const UIntType increment = c;
        static const UIntType modulus = m;

        // constructors and member function
        explicit linear_congruential(unsigned long x0 = 1);
        template<class Gen> linear_congruential(Gen& g);
        void seed(unsigned long x0 = 1);
        template<class Gen> void seed(Gen& g);
    }
The template parameter UIntType shall denote an unsigned integral type large enough to store values up to \((m-1)\). If the template parameter \(m\) is 0, the modulus \(m\) used throughout this section is \(\text{std::numeric_limits<UIntType>::max()} + 1\). [Note: The result is not representable as a value of type UIntType. — end note] Otherwise, the template parameters \(a\) and \(c\) shall be less than \(m\).

The size of the state \(x(i)\) is 1. The textual representation is the value of \(x(i)\).

### 26.4.4.2 Class template mersenne_twister

A mersenne_twister engine produces random numbers \(o(x(i))\) using the following computation, performed modulo \(2^w\). \(um\) is a value with only the upper \(w-r\) bits set in its binary representation. \(lm\) is a value with only its lower \(r\) bits set in its binary representation. \(rshift\) is a bitwise right shift with zero-valued bits appearing in the high bits of the result. \(lshift\) is a bitwise left shift with zero-valued bits appearing in the low bits of the result.

\[
\begin{align*}
y(i) &= (x(i-n) \text{ bitand } um) \text{ l (x(i-(n-1)) \text{ bitand } lm)} \\
\text{If the lowest bit of the binary representation of } y(i) \text{ is set, } x(i) &= x(i-(n-m)) \text{ xor (y(i) rshift 1) xor a; otherwise } x(i) = x(i-(n-m)) \text{ xor (y(i) rshift 1).} \\
z1(i) &= x(i) \text{ xor (x(i) rshift u)} \\
z2(i) &= z1(i) \text{ xor ((z1(i) lshift s) bitand b)} \\
z3(i) &= z2(i) \text{ xor ((z2(i) lshift t) bitand c)} \\
o(x(i)) &= z3(i) \text{ xor (z3(i) rshift 1)}
\end{align*}
\]

### Template Code

```cpp
template<class UIntType, int w, int n, int m, int r, 
        UIntType a, int u, int s, UIntType b, int t, UIntType c, int l>
class mersenne_twister
{
    // Template code
}
```

Draft
26.4 TR1: Random number generation

public:
// types
typedef UIntType result_type;

// parameter values
static const int word_size = w;
static const int state_size = n;
static const int shift_size = m;
static const int mask_bits = r;
static const UIntType parameter_a = a;
static const int output_u = u;
static const int output_s = s;
static const UIntType output_b = b;
static const int output_t = t;
static const UIntType output_c = c;
static const int output_l = l;

// constructors and member function
merсенne_twister();
explicit mersenne_twister(unsigned long value);
template<class Gen> mersenne_twister(Gen& g);
void seed();
void seed(unsigned long value);
template<class Gen> void seed(Gen& g);
result_type min() const;
result_type max() const;
result_type operator();
};

The template parameter UIntType shall denote an unsigned integral type large enough to store values up to \(2^w - 1\).

Also, the following relations shall hold: \(1 \leq m \leq n\). \(0 \leq r, u, s, t, l \leq w\). \(0 \leq a, b, c \leq 2^w - 1\).

The size of the state \(x(i)\) is \(n\). The textual representation is the values of \(x(i-n), \ldots, x(i-1)\), in that order.

\textbf{mersenne_twister()}

\textbf{Effects:} Constructs a mersenne_twister engine and invokes seed().

\textbf{explicit mersenne_twister(unsigned long value)}

\textbf{Effects:} Constructs a mersenne_twister engine and invokes seed(value).

template<class Gen> mersenne_twister(Gen& g)

\textbf{Effects:} Given the values \(2^0 \ldots 2^{n-1}\) obtained by successive invocations of \(g\), sets \(x(-n) \ldots x(-1)\) to \(z_0 \mod 2^w \ldots z_{n-1} \mod 2^w\).

\textbf{Complexity:} Exactly \(n\) invocations of \(g\).

\textbf{void seed()}

\textbf{Effects:} Invokes seed(5489UL).
void seed(unsigned long v)

Effects: Sets $x(-n)$ to $v \mod 2^w$. Then, iteratively, sets

$$x(-n+i) = [(i+1)\times1812433253(x(-n+i-1) \xor (x(-n+i-1) \mathrm{rshift} (w-2)))] \mod 2^w$$

for $i = 1 \ldots n-1$.

Complexity: $O(n)$

template<class UIntType, int w, int n, int m, int r,
UIntType a, int u, int s, UIntType b, int t, UIntType c, int l>
bool operator==(const mersenne_twister<UIntType, w,n,m,r,a,u,s,b,t,c,l>& y,
        const mersenne_twister<UIntType, w,n,m,r,a,u,s,b,t,c,l>& x)

Returns: $x(i-n) == y(j-n)$ and ... and $x(i-1) == y(j-1)$

Remarks: Assumes the next output of $x$ is $o(x(i))$ and the next output of $y$ is $o(y(j))$.

Complexity: $O(n)$

26.4.4.3 Class template subtract_with_carry

A `subtract_with_carry` engine produces integer random numbers using the computation $x(i) = (x(i-s) - x(i-r) - carry(i-1)) \mod m$ and setting $carry(i) = 1$ if $x(i-s) - x(i-r) - carry(i-1) < 0$, else $carry(i) = 0$.

template<class IntType, IntType m, int s, int r>
class subtract_with_carry
{
    public:
        // types
        typedef IntType result_type;

        // parameter values
        static const IntType modulus = m;
        static const int long_lag = r;
        static const int short_lag = s;

        // constructors and member function
        subtract_with_carry();
        explicit subtract_with_carry(unsigned long value);
        template<class Gen> subtract_with_carry(Gen& g);
        void seed(unsigned long value = 19780503ul);
        template<class Gen> void seed(Gen& g);
        result_type min() const;
        result_type max() const;
        result_type operator()();
};

The template parameter `IntType` shall denote a signed integral type large enough to store values up to $m$. The following relation shall hold: $0 < s < r$. Let $w$ be the number of bits in the binary representation of $m$. Draft
The size of the state is \( r \). The textual representation is the values of \( x(i-r), \ldots, x(i-1), \text{carry}(i-1) \), in that order.

```c
subtract_with_carry()
```

**Effects:** Constructs a `subtract_with_carry` engine and invokes `seed()`.

```c
explicit subtract_with_carry(unsigned long value)
```

**Effects:** Constructs a `subtract_with_carry` engine and invokes `seed(value)`.

```c
template<class Gen> subtract_with_carry(Gen& g)
```

**Effects:** With \( n = (m+31)/32 \) (rounded downward) and given the values \( z_0 \ldots z_{n+r-1} \) obtained by successive invocations of \( g \), sets \( x(-r) \ldots x(-1) \) to \( (z_0 \cdot 2^{32} + \cdots + z_n \cdot 2^{32(n-1)}) \mod m \ldots (z_{n+r-n} \cdot 2^{32} + \cdots + z_{n+r-1} \cdot 2^{32(n-1)}) \mod m \).

If \( x(-1) == 0 \), sets \( \text{carry}(-1) = 1 \), else sets \( \text{carry}(-1) = 0 \).

**Complexity:** Exactly \( r \cdot n \) invocations of \( g \).

```c
void seed(unsigned long value = 19780503)
```

**Effects:** If \( value == 0 \), sets \( value \) to 19780503. In any case, with a linear congruential generator \( lcg(i) \) having parameters \( m_{lcg} = 2147483563 \), \( a_{lcg} = 40014 \), \( c_{lcg} = 0 \), and \( lcg(0) = value \), sets \( x(-r) \ldots x(-1) \) to \( lcg(1) \mod m \ldots lcg(r) \mod m \), respectively. If \( x(-1) == 0 \), sets \( \text{carry}(-1) = 1 \), else sets \( \text{carry}(-1) = 0 \).

**Complexity:** \( O(r) \)

```c
template<class IntType, IntType m, int s, int r>
bool operator==(const subtract_with_carry<IntType, m, s, r> & x, const subtract_with_carry<IntType, m, s, r> & y)
```

**Returns:** \( x(i-r) == y(j-r) \) and \( \ldots \) and \( x(i-1) == y(j-1) \).

**Remarks:** Assumes the next output of \( x \) is \( x(i) \) and the next output of \( y \) is \( y(j) \).

**Complexity:** \( O(r) \)

### 26.4.4.4 Class template subtract_with_carry_01

A `subtract_with_carry_01` engine produces floating-point random numbers using \( x(i) = (x(i-s) - x(i-r) - \text{carry}(i-1)) \mod 1 \); and setting \( \text{carry}(i) = 2^{-w} \) if \( x(i-s) - x(i-r) - \text{carry}(i-1) < 0 \), else \( \text{carry}(i) = 0 \).

```c
template<class RealType, int w, int s, int r>
class subtract_with_carry_01
{
public:
    // types
    typedef RealType result_type;

    // parameter values
    static const int word_size = w;
    static const int long_lag = r;
    static const int short_lag = s;
}
```
// constructors and member function
subtract_with_carry_01();
explicit subtract_with_carry_01(unsigned long value);
template<class Gen> subtract_with_carry_01(Gen& g);
void seed(unsigned long value = 19780503);
template<class Gen> void seed(Gen& g);
result_type min() const;
result_type max() const;
result_type operator()();
};

The following relation shall hold: \( 0 < s < r \).

The size of the state is \( r \). With \( n = (w + 31)/32 \) (rounded downward) and integer numbers \( z[k, j] \) such that \( x(i−k) \cdot 2^w = z[k, 0] + z[k, 1] \cdot 2^{32} + z[k, n−1] \cdot 2^{32(n−1)} \), the textual representation is the values of \( z[r, 0], \ldots, z[r, n−1], \ldots, z[1, 0], \ldots, z[1, n−1], \) \( \text{carry}(i−1) \cdot 2^w \), in that order. [Note: The algorithm ensures that only integer numbers representable in 32 bits are written. — end note]

\( \text{subtract_with_carry_01()} \)

Effects: Constructs a \( \text{subtract_with_carry_01} \) engine and invokes \( \text{seed()} \).

explicit \( \text{subtract_with_carry_01}(\text{unsigned long value}) \)

Effects: Constructs a \( \text{subtract_with_carry_01} \) engine and invokes \( \text{seed(value)} \).

template<class Gen> \( \text{subtract_with_carry_01}(\text{Gen } g) \)

Effects: With \( n = (w + 31)/32 \) (rounded downward) and given the values \( z_0 \ldots z_{n−1} \) obtained by successive invocations of \( g \), sets \( x(-r) \ldots x(-1) \) to \( (z_0 \cdot 2^{32} + \ldots + z_{n−1} \cdot 2^{32(n−1)}) \cdot 2^w \text{mod} 1 \ldots (z_{r−1}n \cdot 2^{32} + \ldots + z_{r−1} \cdot 2^{32(n−1)}) \cdot 2^w \text{mod} 1 \). If \( x(-1) == 0 \), sets \( \text{carry}(-1) = 2^w \), else sets \( \text{carry}(-1) = 0 \).

Complexity: Exactly \( r \cdot n \) invocations of \( g \).

void seed(\text{unsigned long value} = 19780503)

Effects: If \( \text{value} == 0 \), sets value to 19780503. In any case, with a linear congruential generator \( \text{lcg}(i) \) having parameters \( \text{m}_{\text{lcg}} = 2147483563, \ a_{\text{lcg}} = 40014, \ c_{\text{lcg}} = 0, \) and \( \text{lcg}(0) = \text{value} \), sets \( x(-r) \ldots x(-1) \) to \( (\text{lcg}(1) \cdot 2^w \text{mod} 1 \ldots (\text{lcg}(r) \cdot 2^w \text{mod} 1 \), respectively. If \( x(-1) == 0 \), sets \( \text{carry}(-1) = 2^w \), else sets \( \text{carry}(-1) = 0 \).

Complexity: \( \Theta(n \cdot r) \).

template<class RealType, int w, int s, int r>
bool operator==(const \( \text{subtract_with_carry<RealType, w, s, r>} x, \)
const \( \text{subtract_with_carry<RealType, w, s, r> y} \);

Returns: true, if and only if \( x(i−r) == y(j−r) \) and \( \ldots \) and \( x(i−1) == y(j−1) \).

Complexity: \( \Theta(r) \)
26.4.4.5 Class template discard_block

A discard_block engine produces random numbers from some base engine by discarding blocks of data.

```cpp
template<class UniformRandomNumberGenerator, int p, int r>
class discard_block
{
public:
    // types
    typedef UniformRandomNumberGenerator base_type;
    typedef typename base_type::result_type result_type;

    // parameter values
    static const int block_size = p;
    static const int used_block = r;

    // constructors and member function
    discard_block();
    explicit discard_block(const base_type& rng);
    explicit discard_block(unsigned long s);
    template<class Gen> discard_block(Gen& g);
    void seed();
    template<class Gen> void seed(Gen& g);
    const base_type& base() const;
    result_type min() const;
    result_type max() const;
    result_type operator()();
private:
    base_type b; // exposition only
    int n; // exposition only
};
```

2 The template parameter UniformRandomNumberGenerator shall denote a class that satisfies all the requirements of a uniform random number generator, given in table 97 in clause 26.4.1. $0 \leq r \leq p$. The size of the state is the size of $b$ plus 1. The textual representation is the textual representation of $b$ followed by the value of $n$.

discard_block()

Effects: Constructs a discard_block engine. To construct the subobject $b$, invokes its default constructor. Sets $n = 0$.

explicit discard_block(const base_type& rng)

Effects: Constructs a discard_block engine. Initializes $b$ with a copy of $rng$. Sets $n = 0$.

explicit discard_block(unsigned long s)

Effects: Constructs a discard_block engine. To construct the subobject $b$, invokes the $b(s)$ constructor. Sets $n = 0$.

template<class Gen> discard_block(Gen)
Effects: Constructs a discard_block engine. To construct the subobject b, invokes the b(g) constructor. Sets \( n = 0 \).

```cpp
void seed()
```

Effects: Invokes b.seed() and sets \( n = 0 \).

```cpp
const base_type& base() const
```

Returns: b

```cpp
result_type operator()()
```

Effects: If \( n \geq r \), invokes b \((p-r)\) times, discards the values returned, and sets \( n = 0 \). In any case, then increments \( n \) and returns b().

### 26.4.4.6 Class template xor_combine

An xor_combine engine produces random numbers from two integer base engines by merging their random values with bitwise exclusive-or.

```cpp
template<class UniformRandomNumberGenerator1, int s1,
  class UniformRandomNumberGenerator2, int s2>
class xor_combine
{
public:
  // types
  typedef UniformRandomNumberGenerator1 base1_type;
  typedef UniformRandomNumberGenerator2 base2_type;
  typedef see below result_type;

  // parameter values
  static const int shift1 = s1;
  static const int shift2 = s2;

  // constructors and member function
  xor_combine();
  xor_combine(const base1_type & rng1, const base2_type & rng2);
  xor_combine(unsigned long s);
  template<class Gen> xor_combine(Gen& g);
  void seed();
  template<class Gen> void seed(Gen& g);
  const base1_type& base1() const;
  const base2_type& base2() const;
  result_type min() const;
  result_type max() const;
  result_type operator()();
private:
  base1_type b1;  // exposition only
  base2_type b2;  // exposition only
};
```

Draft
The template parameters UniformRandomNumberGenerator1 and UniformRandomNumberGenerator2 shall denote classes that satisfy all the requirements of a uniform random number generator, given in table 97 in clause 26.4.1. Both UniformRandomNumberGenerator1::result_type and UniformRandomNumberGenerator2::result_type shall denote (possibly different) unsigned integral types. The following relation shall hold: $0 \leq s_1$ and $0 \leq s_2$. The size of the state is the size of the state of $b_1$ plus the size of the state of $b_2$. The textual representation is the textual representation of $b_1$ followed by the textual representation of $b_2$.

The member result_type is defined to be either the type UniformRandomNumberGenerator1::result_type or the type UniformRandomNumberGenerator2::result_type, whichever one provides the most storage. (As defined in clause [basic.fundamental].)

xor_combine()

Effects: Constructs a xor_combine engine. To construct each of the subobjects $b_1$ and $b_2$, invokes their respective default constructors.

xor_combine(const base1_type & rng1, const base2_type & rng2)

Effects: Constructs a xor_combine engine. Initializes $b_1$ with a copy of rng1 and $b_2$ with a copy of rng2.

xor_combine(unsigned long s)

Effects: Constructs a xor_combine engine. To construct the subobject $b_1$, invokes the $b_1(s)$ constructor. Then, to construct the subobject $b_2$, invokes the $b_2(s+1)$ constructor [Note: If both $b_1$ and $b_2$ are of the same type, both engines should not be initialized with the same seed. — end note]

template<class Gen> xor_combine(Gen& g)

Effects: Constructs a xor_combine engine. To construct the subobject $b_1$, invokes the $b_1(g)$ constructor. Then, to construct the subobject $b_2$, invokes the $b_2(g)$ constructor.

void seed()

Effects: Invokes $b_1.seed()$ and $b_2.seed()$.

const base1_type& base1() const

Returns: $b_1$

const base2_type& base2() const

Returns: $b_2$

result_type operator()()

Returns: $(b_1() \ll s_1) ^ (b_2() \ll s_2)$.

[Note: Two shift values are provided for simplicity of interface. When using this class template, however, it is advisable for at most one of these values to be nonzero. (If both $s_1$ and $s_2$ are nonzero then the low bits will always be zero.) It is also advisable for the unshifted engine to have the property that $\max() = 2^n - 1 - \min()$ for some $n$, and for the shift applied to the other engine to be no greater than $n$.

An xor_combine that does not meet these conditions may have significantly worse uniformity properties than either of the component engines it is based on. — end note]
26.4.5 Engines with predefined parameters  

```cpp
typedef linear_congruential<implementation-defined, 16807, 0, 2147483647> minstd_rand0;
typedef linear_congruential<implementation-defined, 48271, 0, 2147483647> minstd_rand;

typedef mersenne_twister<implementation-defined>,
32, 624, 397, 31, 0x9908b0df, 11, 7, 0x9d2c5680, 15, 0xefc60000, 18> mt19937;

typedef subtract_with_carry<float, 24, 10, 24> ranlux_base_01;
typedef subtract_with_carry<double, 48, 10, 24> ranlux64_base_01;

typedef discard_block<subtract_with_carry<implementation-defined>, (1<<24), 10, 24>, 223, 24> ranlux3;
typedef discard_block<subtract_with_carry<implementation-defined>, (1<<24), 10, 24>, 389, 24> ranlux4;

typedef discard_block<subtract_with_carry<implementation-defined>, (1<<24), 10, 24>, 223, 24> ranlux3_01;
typedef discard_block<subtract_with_carry<implementation-defined>, (1<<24), 10, 24>, 389, 24> ranlux4_01;
```

1. For a default-constructed `minstd_rand0` object, \(x(10000) = 1043618065\). For a default-constructed `minstd_rand` object, \(x(10000) = 399268537\).
2. For a default-constructed `mt19937` object, \(x(10000) = 4123659995\).
3. For a default-constructed `ranlux3` object, \(x(10000) = 5957620\). For a default-constructed `ranlux4` object, \(x(10000) = 8587295\). For a default-constructed `ranlux3_01` object, \(x(10000) = 5957620 \cdot 2^{-24}\). For a default-constructed `ranlux4_01` object, \(x(10000) = 8587295 \cdot 2^{-24}\).

26.4.6 Class random_device  

A `random_device` produces non-deterministic random numbers. It satisfies all the requirements of a uniform random number generator (given in table 97 in clause 26.4.1). Descriptions are provided here only for operations on the engines that are not described in one of these tables or for operations where there is additional semantic information.

If implementation limitations prevent generating non-deterministic random numbers, the implementation may employ a pseudo-random number engine.

```cpp
class random_device
{
public:
  // types
  typedef unsigned int result_type;

  // constructors, destructors and member functions
  explicit random_device(const std::string& token = implementation-defined);
  result_type min() const;
  result_type max() const;
  double entropy() const;
  result_type operator()();

private:
};
```
random_device(const random_device&);
void operator=(const random_device&);
};

explicit random_device(const std::string& token = implementation-defined);

Effects: Constructs a random_device non-deterministic random number engine. The semantics and default value of the token parameter are implementation-defined.\(^{(273)}\)

Throws: A value of some type derived from exception if the random_device could not be initialized.

result_type min() const
Returns: numeric_limits<result_type>::min()

result_type max() const
Returns: numeric_limits<result_type>::max()

double entropy() const
Returns: An entropy estimate for the random numbers returned by operator(), in the range min() to \(\log_2(\max() + 1)\). A deterministic random number generator (e.g. a pseudo-random number engine) has entropy 0.

Throws: Nothing.

result_type operator()()
Returns: A non-deterministic random value, uniformly distributed between min() and max(), inclusive. It is implementation-defined how these values are generated.

Throws: A value of some type derived from exception if a random number could not be obtained.

### 26.4.7 Random distribution class templates

The class templates specified in this section satisfy all the requirements of a random distribution (given in tables in clause 26.4.1). Descriptions are provided here only for operations on the distributions that are not described in one of these tables or for operations where there is additional semantic information.

Given an object whose type is specified in this subclause, if the lifetime of the uniform random number generator referred to in the constructor invocation for that object has ended, any use of that object is undefined.

The algorithms for producing each of the specified distributions are implementation-defined.

#### 26.4.7.1 Class template uniform_int

A uniform_int random distribution produces integer random numbers \(x\) in the range \(\min \leq x \leq \max\), with equal probability. \(\min\) and \(\max\) are the parameters of the distribution.

A uniform_int random distribution satisfies all the requirements of a uniform random number generator (given in table 97 in clause 26.4.1).

\(^{(273)}\) The parameter is intended to allow an implementation to differentiate between different sources of randomness.
template<class IntType = int>
class uniform_int
{
public:
    // types
    typedef IntType input_type;
    typedef IntType result_type;

    // constructors and member function
    explicit uniform_int(IntType min = 0, IntType max = 9);
    result_type min() const;
    result_type max() const;
    void reset();

    template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
    template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng, result_type n);
};

uniform_int(IntType min = 0, IntType max = 9)

Requires: min \leq max

Effects: Constructs a uniform_int object. min and max are the parameters of the distribution.

result_type min() const

Returns: The “min” parameter of the distribution.

result_type max() const

Returns: The “max” parameter of the distribution.

result_type operator()(UniformRandomNumberGenerator& urng, result_type n)

Returns: A uniform random number x in the range 0 \leq x < n. [Note: This allows a variate_generator object with a uniform_int distribution to be used with std::random_shuffle, see [lib.alg.random.shuffle]. — end note]

26.4.7.2 Class bernoulli_distribution

A bernoulli_distribution random distribution produces bool values distributed with probabilities p(true) = p and p(false) = 1-p. p is the parameter of the distribution.

class bernoulli_distribution
{
public:
    // types
    typedef int input_type;
    typedef bool result_type;

26.4 TR1: Random number generation
Numerics library 764

// constructors and member function
explicit bernoulli_distribution(double p = 0.5);
double p() const;
void reset();
template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
};

bernoulli_distribution(double p = 0.5)

2 Requires: 0 ≤ p ≤ 1
3 Effects: Constructs a bernoulli_distribution object. p is the parameter of the distribution.

double p() const
4 Returns: The “p” parameter of the distribution.

26.4.7.3 Class template geometric_distribution [lib.rand.dist.geom]

A geometric_distribution random distribution produces integer values i ≥ 1 with
p(i) = (1 − p) · p^{i−1}. p is the parameter of the distribution.

template<class IntType = int, class RealType = double>
    class geometric_distribution
    {
        public:
            // types
            typedef RealType input_type;
            typedef IntType result_type;

            // constructors and member function
            explicit geometric_distribution(const RealType& p = RealType(0.5));
            RealType p() const;
            void reset();
            template<class UniformRandomNumberGenerator>
                result_type operator()(UniformRandomNumberGenerator& urng);
    };

geometric_distribution(const RealType& p = RealType(0.5))

2 Requires: 0 < p < 1
3 Effects: Constructs a geometric_distribution object; p is the parameter of the distribution.

RealType p() const
4 Returns: The “p” parameter of the distribution.
26.4.7.4  Class template `poisson_distribution`  

A `poisson_distribution` random distribution produces integer values $i > 0$ with probability distribution

$$p(i) = \frac{\text{mean}^i}{i!} e^{-\text{mean}},$$

where `mean` is the parameter of the distribution.

```cpp
template<class IntType = int, class RealType = double>
class poisson_distribution
{
public:
    // types
    typedef RealType input_type;
    typedef IntType result_type;

    // constructors and member function
    explicit poisson_distribution(const RealType& mean = RealType(1));
    RealType mean() const;
    void reset();
    template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
};

poisson_distribution(const RealType& mean = RealType(1))

Requires: `mean` > 0

Effects: Constructs a `poisson_distribution` object; `mean` is the parameter of the distribution.

RealType mean() const

Returns: The `mean` parameter of the distribution.
```

26.4.7.5  Class template `binomial_distribution`  

A `binomial_distribution` random distribution produces integer values $i > 0$ with

$$p(i) = \binom{n}{i} \cdot p^i \cdot (1 - p)^{n - i},$$

where $n$ and $p$ are the parameters of the distribution.

```cpp
template<class IntType = int, class RealType = double>
class binomial_distribution
{
public:
    // types
    typedef implementation-defined input_type;
    typedef IntType result_type;

    // constructors and member function
    explicit binomial_distribution(const RealType& n, const RealType& p);
    RealType n() const;
    RealType p() const;
    void reset();
    template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
};

binomial_distribution(const RealType& n, const RealType& p)

Requires: $n > 0, 0 < p < 1$

Effects: Constructs a `binomial_distribution` object; $n$ and $p$ are the parameters of the distribution.

RealType n() const

Returns: The `n` parameter of the distribution.
```
26.4 TR1: Random number generation

// constructors and member function
explicit binomial_distribution(IntType t = 1, const RealType& p = RealType(0.5));
IntType t() const;
RealType p() const;
void reset();
template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
};

binomial_distribution(IntType t = 1, const RealType& p = RealType(0.5))

Requires: 0 ≤ p ≤ 1 and t ≥ 0.
Effects: Constructs a binomial_distribution object; t and p are the parameters of the distribution.

IntType t() const
Returns: The “t” parameter of the distribution.

RealType p() const
Returns: The “p” parameter of the distribution.

26.4.7.6 Class template uniform_real [lib.rand.dist.runif]

A uniform_real random distribution produces floating-point random numbers x in the range \( \min \leq x < \max \), with equal probability. \( \min \) and \( \max \) are the parameters of the distribution.

A uniform_real random distribution satisfies all the requirements of a uniform random number generator (given in table 97 in clause 26.4.1).

template<class RealType = double>
class uniform_real
{
    public:
        // types
        typedef RealType input_type;
        typedef RealType result_type;

        // constructors and member function
        explicit uniform_real(RealType min = RealType(0), RealType max = RealType(1));
        result_type min() const;
        result_type max() const;
        void reset();
        template<class UniformRandomNumberGenerator>
            result_type operator()(UniformRandomNumberGenerator& urng);
    };

uniform_real(RealType min = RealType(0), RealType max = RealType(1))

Requires: \( \min \leq \max \).

Draft
Effects: Constructs a uniform_real object; min and max are the parameters of the distribution.

result_type min() const

Returns: The “min” parameter of the distribution.

result_type max() const

Returns: The “max” parameter of the distribution.

26.4.7.7 Class template exponential_distribution

An exponential_distribution random distribution produces random numbers \( x > 0 \) distributed with probability density function

\[
p(x) = \lambda e^{-\lambda x},
\]

where \( \lambda \) is the parameter of the distribution.

```
template<class RealType = double>
class exponential_distribution
{
public:
    // types
    typedef RealType input_type;
    typedef RealType result_type;

    // constructors and member function
    explicit exponential_distribution(const result_type& lambda = result_type(1));
    RealType lambda() const;
    void reset();
    template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
};
```

exponential_distribution(const result_type& lambda = result_type(1))

Requires: \( \lambda > 0. \)

Effects: Constructs an exponential_distribution object with \( \text{rng} \) as the reference to the underlying source of random numbers. \( \lambda \) is the parameter for the distribution.

RealType lambda() const

Returns: The “\( \lambda \)” parameter of the distribution.

26.4.7.8 Class template normal_distribution

A normal_distribution random distribution produces random numbers \( x \) distributed with probability density function

\[
p(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-(x-\text{mean})^2/(2\sigma^2)},
\]

Draft
where \( \text{mean} \) and \( \sigma \) are the parameters of the distribution.

```cpp
template<class RealType = double>
class normal_distribution
{
public:
  // types
  typedef RealType input_type;
  typedef RealType result_type;

  // constructors and member function
  explicit normal_distribution(const result_type& mean = 0, const result_type& sigma = 1);
  RealType mean() const;
  RealType sigma() const;
  void reset();
  template<class UniformRandomNumberGenerator>
  result_type operator()(UniformRandomNumberGenerator& urng);
};

explicit normal_distribution(const result_type& mean = 0, const result_type& sigma = 1);
```

2 Requires: \( \sigma > 0 \).

3 Effects: Constructs a `normal_distribution` object; \( \text{mean} \) and \( \sigma \) are the parameters for the distribution.

\[
\text{RealType mean() const}
\]

Returns: The “\( \text{mean} \)” parameter of the distribution.

\[
\text{RealType sigma() const}
\]

Returns: The “\( \sigma \)” parameter of the distribution.

### 26.4.7.9 Class template `gamma_distribution`

A `gamma_distribution` random distribution produces random numbers \( x \) distributed with probability density function

\[
p(x) = \frac{1}{\Gamma(\alpha)} \alpha^{\alpha^{-1}} e^{-x},
\]

where \( \alpha \) is the parameter of the distribution.

```cpp
template<class RealType = double>
class gamma_distribution
{
public:
  // types
  typedef RealType input_type;
  typedef RealType result_type;

  // constructors and member function
  explicit gamma_distribution(const result_type& alpha = result_type(1));
```
RealType alpha() const;
void reset();
template<class UniformRandomNumberGenerator>
    result_type operator()(UniformRandomNumberGenerator& urng);
};

explicit gamma_distribution(const result_type& alpha = result_type(1));

Requires: alpha > 0.
Effects: Constructs a gamma_distribution object; alpha is the parameter for the distribution.

RealType alpha() const

Returns: The “α” parameter of the distribution.

26.5 Numeric arrays

26.5.1 Header <valarray> synopsis

namespace std {

    template<class T> class valarray; // An array of type T
    class slice; // a BLAS-like slice out of an array
    template<class T> class slice_array;
    class gslice; // a generalized slice out of an array
    template<class T> class gslice_array;
    template<class T> class mask_array; // a masked array
    template<class T> class indirect_array; // an indirected array

    template<class T> valarray<T> operator* (const valarray<T>&, const valarray<T>&);
    template<class T> valarray<T> operator* (const valarray<T>&, const T&);
    template<class T> valarray<T> operator* (const T&, const valarray<T>&);

    template<class T> valarray<T> operator/ (const valarray<T>&, const valarray<T>&);
    template<class T> valarray<T> operator/ (const valarray<T>&, const T&);
    template<class T> valarray<T> operator/ (const T&, const valarray<T>&);

    template<class T> valarray<T> operator% (const valarray<T>&, const valarray<T>&);
    template<class T> valarray<T> operator% (const valarray<T>&, const T&);
    template<class T> valarray<T> operator% (const T&, const valarray<T>&);

    template<class T> valarray<T> operator+ (const valarray<T>&, const valarray<T>&);
    template<class T> valarray<T> operator+ (const valarray<T>&, const T&);
    template<class T> valarray<T> operator+ (const T&, const valarray<T>&);

    template<class T> valarray<T> operator- (const valarray<T>&, const valarray<T>&);
}
template<class T> valarray<T> operator- (const valarray<T>&, const T&);

template<class T> valarray<T> operator- (const T&, const valarray<T>&);

template<class T> valarray<T> operator+(const valarray<T>&, const valarray<T>&);

template<class T> valarray<T> operator+(const valarray<T>&, const T&);

template<class T> valarray<T> operator+(const T&, const valarray<T>&);

template<class T> valarray<T> operator&(const valarray<T>&, const valarray<T>&);

template<class T> valarray<T> operator&(const valarray<T>&, const T&);

template<class T> valarray<T> operator&(const T&, const valarray<T>&);

template<class T> valarray<T> operator|(const valarray<T>&, const valarray<T>&);

template<class T> valarray<T> operator|(const valarray<T>&, const T&);

template<class T> valarray<T> operator|(const T&, const valarray<T>&);

template<class T> valarray<T> operator<<(const valarray<T>&, const T&);

template<class T> valarray<T> operator<<(const T&, const valarray<T>&);

template<class T> valarray<T> operator>>(const valarray<T>&, const T&);

template<class T> valarray<T> operator>>(const T&, const valarray<T>&);

template<class T> valarray<bool> operator&&(const valarray<T>&, const valarray<T>&);

template<class T> valarray<bool> operator&&(const valarray<T>&, const T&);

template<class T> valarray<bool> operator&&(const T&, const valarray<T>&);

template<class T> valarray<bool> operator||(const valarray<T>&, const valarray<T>&);

template<class T> valarray<bool> operator||(const valarray<T>&, const T&);

template<class T> valarray<bool> operator||(const T&, const valarray<T>&);

Draft
template<
class T>
valarray<bool>
operator<
(const T&, const valarray<T>&);

template<class T>
valarray<T>
abs
(const valarray<T>&);

The header <valarray> defines five class templates (valarray, slice_array, gslice_array, mask_array, and indirect_array), two classes (slice and gslice), and a series of related function templates for representing and manipulating arrays of values.

The valarray array classes are defined to be free of certain forms of aliasing, thus allowing operations on these classes to be optimized.

Any function returning a valarray<T> is permitted to return an object of another type, provided all the const member functions of valarray<T> are also applicable to this type. This return type shall not add more than two levels of
template nesting over the most deeply nested argument type.\footnote{Clause B recommends a minimum number of recursively nested template instantiations. This requirement thus indirectly suggests a minimum allowable complexity for valarray expressions.}

4 Implementations introducing such replacement types shall provide additional functions and operators as follows:

   — for every function taking a `\texttt{const valarray<T>&}`, identical functions taking the replacement types shall be added;

   — for every function taking two \texttt{const valarray<T>&} arguments, identical functions taking every combination of \texttt{const valarray<T>&} and replacement types shall be added.

5 In particular, an implementation shall allow a \texttt{valarray<T>} to be constructed from such replacement types and shall allow assignments and computed assignments of such types to \texttt{valarray<T>, slice_array<T>, gslice_array<T>, mask_array<T> and indirect_array<T>} objects.

6 These library functions are permitted to throw a `\texttt{bad_alloc}` (\ref{18.5.2.1}) exception if there are not sufficient resources available to carry out the operation. Note that the exception is not mandated.

26.5.2 Class template \texttt{valarray} [\libfile{template.valarray}]

```cpp
namespace std {
    template<class T> class valarray {
        public:
            typedef T value_type;

            // 26.5.2.1 construct/destroy:
            valarray();
            explicit valarray(size_t);
            valarray(const T&, size_t);
            valarray(const T*, size_t);
            valarray(const valarray&);
            valarray(const slice_array<T>&);
            valarray(const gslice_array<T>&);
            valarray(const mask_array<T>&);
            valarray(const indirect_array<T>&);

            ~valarray();

            // 26.5.2.2 assignment:
            valarray<T>& operator=(const valarray<T>&);
            valarray<T>& operator=(const T&);
            valarray<T>& operator=(const slice_array<T>&);
            valarray<T>& operator=(const gslice_array<T>&);
            valarray<T>& operator=(const mask_array<T>&);
            valarray<T>& operator=(const indirect_array<T>&);

            // 26.5.2.3 element access:
            const T& operator[](size_t) const;
            T& operator[](size_t);
```

Draft
// 26.5.2.4 subset operations:
valarray<T> operator[](slice) const;
slice_array<T> operator[](slice);
valarray<T> operator[](const gslice&) const;
gslice_array<T> operator[](const gslice&);
valarray<T> operator[](const valarray<bool>&) const;
mask_array<T> operator[](const valarray<bool>&);
valarray<T> operator[](const valarray<size_t>&) const;
indirect_array<T> operator[](const valarray<size_t>&);

// 26.5.2.5 unary operators:
valarray<T> operator+() const;
valarray<T> operator-() const;
valarray<T> operator~() const;
valarray<bool> operator!() const;

// 26.5.2.6 computed assignment:
valarray<T>& operator*= (const T&);
valarray<T>& operator/= (const T&);
valarray<T>& operator%= (const T&);
valarray<T>& operator+= (const T&);
valarray<T>& operator-= (const T&);
valarray<T>& operator^= (const T&);
valarray<T>& operator|= (const T&);
valarray<T>& operator&= (const T&);
valarray<T>& operator<<=(const T&);
valarray<T>& operator>>=(const T&);
valarray<T>& operator*= (const valarray<T>&);
valarray<T>& operator/= (const valarray<T>&);
valarray<T>& operator%= (const valarray<T>&);
valarray<T>& operator+= (const valarray<T>&);
valarray<T>& operator-= (const valarray<T>&);
valarray<T>& operator^= (const valarray<T>&);
valarray<T>& operator|= (const valarray<T>&);
valarray<T>& operator&= (const valarray<T>&);
valarray<T>& operator<<=(const valarray<T>&);
valarray<T>& operator>>=(const valarray<T>&);

// 26.5.2.7 member functions:
size_t size() const;
T sum() const;
T min() const;
T max() const;

valarray<T> shift (int) const;
valarray<T> cshift(int) const;
valarray<T> apply(T func(T)) const;
valarray<T> apply(T func(const T&)) const;

Draft
The class template `valarray<T>` is a one-dimensional smart array, with elements numbered sequentially from zero. It is a representation of the mathematical concept of an ordered set of values. The illusion of higher dimensionality may be produced by the familiar idiom of computed indices, together with the powerful subsetting capabilities provided by the generalized subscript operators.\(^\text{275}\)

An implementation is permitted to qualify any of the functions declared in `<valarray>` as `inline`.

### 26.5.2.1 valarray constructors

#### `valarray();`

*Effects:* Constructs an object of class `valarray<T>`,\(^\text{276}\) which has zero length until it is passed into a library function as a modifiable lvalue or through a non-constant `this` pointer.\(^\text{277}\)

#### `explicit valarray(size_t);`

The array created by this constructor has a length equal to the value of the argument. The elements of the array are constructed using the default constructor for the instantiating type `T`.

#### `valarray(const T&, size_t);`

The array created by this constructor has a length equal to the second argument. The elements of the array are initialized with the value of the first argument.

#### `valarray(const T*, size_t);`

The array created by this constructor has a length equal to the second argument `n`. The values of the elements of the array are initialized with the first `n` values pointed to by the first argument.\(^\text{278}\) If the value of the second argument is greater than the number of values pointed to by the first argument, the behavior is undefined.

#### `valarray(const valarray<T> &);`

The array created by this constructor has the same length as the argument array. The elements are initialized with the values of the corresponding elements of the argument array.\(^\text{279}\)

#### `valarray(const slice_array<T>&);`<br>`valarray(const gslice_array<T>&);`<br>`valarray(const mask_array<T>&);`<br>`valarray(const indirect_array<T>&);`
These conversion constructors convert one of the four reference templates to a valarray.

```
~valarray();
```

The destructor is applied to every element of \*this; an implementation may return all allocated memory.

### 26.5.2.2 valarray assignment

```
valarray<T>& operator=(const valarray<T>&);
```

Each element of the \*this array is assigned the value of the corresponding element of the argument array. The resulting behavior is undefined if the length of the argument array is not equal to the length of the \*this array.

```
valarray<T>& operator=(const T&);
```

The scalar assignment operator causes each element of the \*this array to be assigned the value of the argument.

```
valarray<T>& operator=(const slice_array<T>&);
valarray<T>& operator=(const gslice_array<T>&);
valarray<T>& operator=(const mask_array<T>&);
valarray<T>& operator=(const indirect_array<T>&);
```

These operators allow the results of a generalized subscripting operation to be assigned directly to a valarray.

If the value of an element in the left-hand side of a valarray assignment operator depends on the value of another element in that left-hand side, the resulting behavior is undefined.

### 26.5.2.3 valarray element access

```
const T& operator[](size_t) const;
T& operator[](size_t);
```

When applied to a constant array, the subscript operator returns the value of the corresponding element of the array. When applied to a non-constant array, the subscript operator returns a reference to the corresponding element of the array.

Thus, the expression \( a[i] = q, \ a[i] == q \) evaluates as true for any non-constant \( \text{valarray}<T> \ a, \) any \( T \) \( q, \) and for any \( \text{size} \_t \ i \) such that the value of \( i \) is less than the length of \( a \).

The expression \&a[i+j] == \&a[i] + j \) evaluates as true for all \( \text{size} \_t \ i \) and \( \text{size} \_t \ j \) such that \( i+j \) is less than the length of the non-constant array \( a \).

Likewise, the expression \&a[i] != \&b[j] \) evaluates as true for any two non-constant arrays \( a \) and \( b \) and for any \( \text{size} \_t \ i \) and \( \text{size} \_t \ j \) such that \( i \) is less than the length of \( a \) and \( j \) is less than the length of \( b \). This property indicates an absence of aliasing and may be used to advantage by optimizing compilers.

The reference returned by the subscript operator for a non-constant array is guaranteed to be valid until the member function \( \text{resize(size}_t, \ T) \) (26.5.2.7) is called for that array or until the lifetime of that array ends, whichever happens first.

---

280) Compilers may take advantage of inlining, constant propagation, loop fusion, tracking of pointers obtained from \text{operator new}, and other techniques to generate efficient valarrays.
6 If the subscript operator is invoked with a size_t argument whose value is not less than the length of the array, the behavior is undefined.

26.5.2.4 valarray subset operations

valarray<T> operator[](slice) const;
slice_array<T> operator[](slice);
valarray<T> operator[](const gslice&) const;
gslice_array<T> operator[](const gslice&);
valarray<T> operator[](const valarray<bool>&) const;
mask_array<T> operator[](const valarray<bool>&);
valarray<T> operator[](const valarray<size_t>&) const;
indirect_array<T> operator[](const valarray<size_t>&);

1 Each of these operations returns a subset of the array. The const-qualified versions return this subset as a new valarray. The non-const versions return a class template object which has reference semantics to the original array.

26.5.2.5 valarray unary operators

valarray<T> operator+(() const;
valarray<T> operator-() const;
valarray<T> operator~() const;
valarray<bool> operator!() const;

1 Each of these operators may only be instantiated for a type T to which the indicated operator can be applied and for which the indicated operator returns a value which is of type T (bool for operator!) or which may be unambiguously converted to type T (bool for operator!).

2 Each of these operators returns an array whose length is equal to the length of the array. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding element of the array.

26.5.2.6 valarray computed assignment

valarray<T>& operator*=(const valarray<T>&);
valarray<T>& operator/=(const valarray<T>&);
valarray<T>& operator%=(const valarray<T>&);
valarray<T>& operator+=(const valarray<T>&);
valarray<T>& operator-=(const valarray<T>&);
valarray<T>& operator^=(const valarray<T>&);
valarray<T>& operator&=(const valarray<T>&);
valarray<T>& operator|=(const valarray<T>&);
valarray<T>& operator<<=(const valarray<T>&);
valarray<T>& operator>>=(const valarray<T>&);
Each of these operators may only be instantiated for a type \( T \) to which the indicated operator can be applied. Each of these operators performs the indicated operation on each of its elements and the corresponding element of the argument array.

The array is then returned by reference.

If the array and the argument array do not have the same length, the behavior is undefined. The appearance of an array on the left-hand side of a computed assignment does not invalidate references or pointers.

If the value of an element in the left-hand side of a valarray computed assignment operator depends on the value of another element in that left hand side, the resulting behavior is undefined.

```cpp
valarray<T>& operator**= (const T&);
valarray<T>& operator/=(const T&);
valarray<T>& operator%=(const T&);
valarray<T>& operator+= (const T&);
valarray<T>& operator-= (const T&);
valarray<T>& operator^= (const T&);
valarray<T>& operator&= (const T&);
valarray<T>& operator|= (const T&);
valarray<T>& operator<<=(const T&);
valarray<T>& operator>>=(const T&);
```

Each of these operators may only be instantiated for a type \( T \) to which the indicated operator can be applied. Each of these operators applies the indicated operation to each element of the array and the non-array argument. The array is then returned by reference. The appearance of an array on the left-hand side of a computed assignment does not invalidate references or pointers to the elements of the array.

### 26.5.2.7 valarray member functions

**size_t size() const;**

This function returns the number of elements in the array.

T sum() const;

This function may only be instantiated for a type \( T \) to which \( \text{operator}+\) can be applied. This function returns the sum of all the elements of the array.

If the array has length 0, the behavior is undefined. If the array has length 1, \( \text{sum()} \) returns the value of element 0. Otherwise, the returned value is calculated by applying \( \text{operator}+\) to a copy of an element of the array and all other elements of the array in an unspecified order.

T min() const;

This function returns the minimum value contained in \(*\text{this}\). The value returned for an array of length 0 is undefined. For an array of length 1, the value of element 0 is returned. For all other array lengths, the determination is made using \( \text{operator<}\).
T max() const;

This function returns the maximum value contained in *this. The value returned for an array of length 0 is undefined. For an array of length 1, the value of element 0 is returned. For all other array lengths, the determination is made using operator<.

valarray<T> shift(int n) const;

This function returns an object of class valarray<T> of length size(), each of whose elements I is (*this)[I + n] if I + n is non-negative and less than size(), otherwise T(). Thus if element zero is taken as the leftmost element, a positive value of n shifts the elements left n places, with zero fill.

[Example: If the argument has the value -2, the first two elements of the result will be constructed using the default constructor; the third element of the result will be assigned the value of the first element of the argument; etc. — end example]

valarray<T> cshift(int n) const;

This function returns an object of class valarray<T>, of length size(), each of whose elements I is (*this)[(I + n) % size()]. Thus, if element zero is taken as the leftmost element, a positive value of n shifts the elements circularly left n places.

valarray<T> apply(T func(T)) const;
valarray<T> apply(T func(const T&)) const;

These functions return an array whose length is equal to the array. Each element of the returned array is assigned the value returned by applying the argument function to the corresponding element of the array.

void resize(size_t sz, T c = T());

This member function changes the length of the *this array to sz and then assigns to each element the value of the second argument. Resizing invalidates all pointers and references to elements in the array.

26.5.3 valarray non-member operations [lib.valarray.nonmembers]

26.5.3.1 valarray binary operators [lib.valarray.binary]

template<class T> valarray<T> operator* (const valarray<T>&, const valarray<T>&);
template<class T> valarray<T> operator/ (const valarray<T>&, const valarray<T>&);
template<class T> valarray<T> operator% (const valarray<T>&, const valarray<T>&);
template<class T> valarray<T> operator+ (const valarray<T>&, const valarray<T>&);
template<class T> valarray<T> operator- (const valarray<T>&, const valarray<T>&);
template<class T> valarray<T> operator^ (const valarray<T>&, const valarray<T>&);
template<class T> valarray<T> operator& (const valarray<T>&, const valarray<T>&);
Each of these operators may only be instantiated for a type T to which the indicated operator can be applied and for which the indicated operator returns a value which is of type T or which can be unambiguously converted to type T.

Each of these operators returns an array whose length is equal to the lengths of the argument arrays. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding elements of the argument arrays.

If the argument arrays do not have the same length, the behavior is undefined.

Each of these operators returns an array whose length is equal to the length of the array argument. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding element of the array argument and the non-array argument.

26.5.3.2 valarray logical operators

```cpp
template<class T> valarray<T> operator| (const valarray<T>&, const valarray<T>&);
```

```
template<class T> valarray<T> operator<< (const valarray<T>&, const valarray<T>&);
```

```
template<class T> valarray<T> operator>> (const valarray<T>&, const valarray<T>&);
```

```
template<class T> valarray<T> operator* (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator*/ (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator/ (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator/ (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator% (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator% (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator+ (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator+ (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator- (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator- (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator^ (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator^ (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator& (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator& (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator| (const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator| (const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator<<(const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator<<(const T&, const valarray<T>&);
```

```
template<class T> valarray<T> operator>>(const valarray<T>&, const T&);
```

```
template<class T> valarray<T> operator>>(const T&, const valarray<T>&);
```

Each of these operators may only be instantiated for a type T to which the indicated operator can be applied and for which the indicated operator returns a value which is of type T or which can be unambiguously converted to type T.

Each of these operators returns an array whose length is equal to the lengths of the argument arrays. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding elements of the argument arrays.

If the argument arrays do not have the same length, the behavior is undefined.

Each of these operators returns an array whose length is equal to the length of the array argument. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding element of the array argument and the non-array argument.
Each of these operators may only be instantiated for a type \( T \) to which the indicated operator can be applied and for which the indicated operator returns a value which is of type \( \text{bool} \) or which can be unambiguously converted to type \( \text{bool} \).

Each of these operators returns a \( \text{bool} \) array whose length is equal to the length of the array arguments. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding elements of the argument arrays.

If the two array arguments do not have the same length, the behavior is undefined.

Each of these operators may only be instantiated for a type \( T \) to which the indicated operator can be applied and for which the indicated operator returns a value which is of type \( \text{bool} \) or which can be unambiguously converted to type \( \text{bool} \).

Each of these operators returns a \( \text{bool} \) array whose length is equal to the length of the array argument. Each element of the returned array is initialized with the result of applying the indicated operator to the corresponding element of the array and the non-array argument.
26.5.3.3 valarray transcendental functions

template<class T> valarray<T> abs (const valarray<T>&);
template<class T> valarray<T> acos (const valarray<T>&);
template<class T> valarray<T> asin (const valarray<T>&);
template<class T> valarray<T> atan (const valarray<T>&);
template<class T> valarray<T> atan2 (const valarray<T>&, const T&);
template<class T> valarray<T> atan2 (const T&, const valarray<T>&);
template<class T> valarray<T> cos (const valarray<T>&);
template<class T> valarray<T> cosh (const valarray<T>&);
template<class T> valarray<T> exp (const valarray<T>&);
template<class T> valarray<T> log (const valarray<T>&);
template<class T> valarray<T> log10 (const valarray<T>&);
template<class T> valarray<T> pow (const valarray<T>&, const T&);
template<class T> valarray<T> pow (const T&, const valarray<T>&);
template<class T> valarray<T> sin (const valarray<T>&);
template<class T> valarray<T> sinh (const valarray<T>&);
template<class T> valarray<T> sqrt (const valarray<T>&);
template<class T> valarray<T> tan (const valarray<T>&);
template<class T> valarray<T> tanh (const valarray<T>&);

Each of these functions may only be instantiated for a type T to which a unique function with the indicated name can be applied (unqualified). This function shall return a value which is of type T or which can be unambiguously converted to type T.

26.5.4 Class slice

namespace std {
    class slice {
    public:
        slice();
        slice(size_t, size_t, size_t);
        size_t start() const;
        size_t size() const;
        size_t stride() const;
    }
}

The slice class represents a BLAS-like slice from an array. Such a slice is specified by a starting index, a length, and
a stride.\(^{281}\)

### 26.5.4.1 slice constructors

```
slice();
slice(size_t start, size_t length, size_t stride);
slice(const slice&);
```

1. The default constructor for `slice` creates a slice which specifies no elements. A default constructor is provided only to permit the declaration of arrays of slices. The constructor with arguments for a slice takes a start, length, and stride parameter.

2. `[Example: slice(3, 8, 2) constructs a slice which selects elements 3, 5, 7, ... 17 from an array. — end example]`

### 26.5.4.2 slice access functions

```
slice_t start() const;
slice_t size() const;
slice_t stride() const;
```

1. These functions return the start, length, or stride specified by a `slice` object.

### 26.5.5 Class template slice_array

```
namespace std {
  template <class T> class slice_array {
  public:
    typedef T value_type;

    void operator=(const valarray<T>&) const;
    void operator*=(const valarray<T>&) const;
    void operator/=(const valarray<T>&) const;
    void operator/=(const valarray<T>&) const;
    void operator^=(const valarray<T>&) const;
    void operator&= (const valarray<T>&) const;
    void operator|= (const valarray<T>&) const;
    void operator<<=(const valarray<T>&) const;
    void operator>>=(const valarray<T>&) const;
    void operator=(const T&) const;
  
    slice_array(const slice_array&);
~slice_array();
slice_array& operator=(const slice_array&);
  void operator=(const T&) const;
  
  slice_array(const slice_array&);
  
  slice_array& operator=(const slice_array&);
  void operator=(const T&) const;
}
```

---

\(^{281}\) BLAS stands for Basic Linear Algebra Subprograms. C++ programs may instantiate this class. See, for example, Dongarra, Du Croz, Duff, and Hammerling: *A set of Level 3 Basic Linear Algebra Subprograms*; Technical Report MCS-P1-0888, Argonne National Laboratory (USA), Mathematics and Computer Science Division, August, 1988.
The `slice_array` template is a helper template used by the `slice` subscript operator

```
slice_array<T> valarray<T>::operator[](slice);
```

It has reference semantics to a subset of an array specified by a `slice` object.

**Example:** The expression `a[slice(1, 5, 3)] = b;` has the effect of assigning the elements of `b` to a slice of the elements in `a`. For the slice shown, the elements selected from `a` are 1, 4, ..., 13. — end example

26.5.5.1 slice_array constructors

```
slice_array();
```

This constructor is declared to be private. This constructor need not be defined.

26.5.5.2 slice_array assignment

```
void operator=(const valarray<T>&) const;
slice_array& operator=(const slice_array&);
```

These assignment operators have reference semantics, assigning the values of the argument array elements to selected elements of the `valarray<T>` object to which the `slice_array` object refers.

26.5.5.3 slice_array computed assignment

```
void operator*= (const valarray<T>&) const;
void operator/= (const valarray<T>&) const;
void operator%= (const valarray<T>&) const;
void operator+= (const valarray<T>&) const;
void operator-= (const valarray<T>&) const;
void operator^= (const valarray<T>&) const;
void operator&= (const valarray<T>&) const;
void operator|= (const valarray<T>&) const;
void operator<<=(const valarray<T>&) const;
void operator>>=(const valarray<T>&) const;
```

These computed assignments have reference semantics, applying the indicated operation to the elements of the argument array and selected elements of the `valarray<T>` object to which the `slice_array` object refers.

26.5.5.4 slice_array fill function

```
void operator=(const T&) const;
```
26.5 Numeric arrays

This function has reference semantics, assigning the value of its argument to the elements of the valarray<T> object to which the slice_array object refers.

26.5.6 The gslice class

namespace std {
  class gslice {
    public:
    gslice();
    gslice(size_t s, const valarray<size_t>& l, const valarray<size_t>& d);
    
    size_t start() const;
    valarray<size_t> size() const;
    valarray<size_t> stride() const;
  };
};

This class represents a generalized slice out of an array. A gslice is defined by a starting offset (s), a set of lengths (l), and a set of strides (d). The number of lengths shall equal the number of strides.

A gslice represents a mapping from a set of indices (i), equal in number to the number of strides, to a single index k. It is useful for building multidimensional array classes using the valarray template, which is one-dimensional. The set of one-dimensional index values specified by a gslice are

\[ k = s + \sum_{j} i_j d_j \]

where the multidimensional indices \( i_j \) range in value from 0 to \( l_j - 1 \).

[Example: The gslice specification]

\[
\begin{align*}
\text{start} & = 3 \\
\text{length} & = \{2, 4, 3\} \\
\text{stride} & = \{19, 4, 1\}
\end{align*}
\]

yields the sequence of one-dimensional indices

\[
 k = 3 + (0, 1) \times 19 + (0, 1, 2, 3) \times 4 + (0, 1, 2) \times 1
\]

which are ordered as shown in the following table:

\[
\begin{align*}
(i_0, & \quad i_1, \quad i_2, \quad k) \\
(0, 0, 0, 3), & \\
(0, 0, 1, 4), & \\
(0, 0, 2, 5), & \\
(0, 1, 0, 7), & \\
(0, 1, 1, 8), & \\
(0, 1, 2, 9), & \\
(0, 2, 0, 11), & 
\end{align*}
\]
(0, 2, 1, 12),
(0, 2, 2, 13),
(0, 3, 0, 15),
(0, 3, 1, 16),
(0, 3, 2, 17),
(1, 0, 0, 22),
(1, 0, 1, 23),
...
(1, 3, 2, 36)

That is, the highest-ordered index turns fastest. — end example ]

It is possible to have degenerate generalized slices in which an address is repeated.

Example: If the stride parameters in the previous example are changed to \{1, 1, 1\}, the first few elements of the resulting sequence of indices will be

(0, 0, 0, 3),
(0, 0, 1, 4),
(0, 0, 2, 5),
(0, 1, 0, 4),
(0, 1, 1, 5),
(0, 1, 2, 6),
...
— end example ]

If a degenerate slice is used as the argument to the non-const version of operator [] (const gslice&), the resulting behavior is undefined.

26.5.6.1 gslice constructors

gslice();
gslice(size_t start, const valarray<size_t>& lengths,
       const valarray<size_t>& strides);
gslice(const gslice&);

The default constructor creates a gslice which specifies no elements. The constructor with arguments builds a gslice based on a specification of start, lengths, and strides, as explained in the previous section.

26.5.6.2 gslice access functions

size_t start() const;
valarray<size_t> size() const;
valarray<size_t> stride() const;

These access functions return the representation of the start, lengths, or strides specified for the gslice.
26.5 Numeric arrays

26.5.7 Class template gslice_array

namespace std {
    template <class T> class gslice_array {
    public:
        typedef T value_type;

        void operator= (const valarray<T>&) const;
        void operator*= (const valarray<T>&) const;
        void operator/= (const valarray<T>&) const;
        void operator%= (const valarray<T>&) const;
        void operator+= (const valarray<T>&) const;
        void operator-= (const valarray<T>&) const;
        void operator^= (const valarray<T>&) const;
        void operator&= (const valarray<T>&) const;
        void operator|= (const valarray<T>&) const;
        void operator<<=(const valarray<T>&) const;
        void operator>>=(const valarray<T>&) const;

        gslice_array(const gslice_array&);
        ~gslice_array();
        gslice_array& operator=(const gslice_array&);
        void operator=(const T&) const;
    private:
        gslice_array();
    };
}

This template is a helper template used by the slice subscript operator

gslice_array<T> valarray<T>::operator[](const gslice&);

It has reference semantics to a subset of an array specified by a gslice object.

Thus, the expression a[gslice(1, length, stride)] = b has the effect of assigning the elements of b to a
generalized slice of the elements in a.

26.5.7.1 gslice_array constructors

gslice_array();

This constructor is declared to be private. This constructor need not be defined.

26.5.7.2 gslice_array assignment

void operator=(const valarray<T>&) const;
    gslice_array& operator=(const gslice_array&);

These assignment operators have reference semantics, assigning the values of the argument array elements to
selected elements of the valarray<T> object to which the gslice_array refers.

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26.5.7.3  

`gslice_array`  

```cpp
void operator*= (const valarray<T>&) const;
void operator/= (const valarray<T>&) const;
void operator%= (const valarray<T>&) const;
void operator+= (const valarray<T>&) const;
void operator-= (const valarray<T>&) const;
void operator^= (const valarray<T>&) const;
void operator&= (const valarray<T>&) const;
void operator|= (const valarray<T>&) const;
void operator<<=(const valarray<T>&) const;
void operator>>=(const valarray<T>&) const;
```

These computed assignments have reference semantics, applying the indicated operation to the elements of the argument array and selected elements of the `valarray<T>` object to which the `gslice_array` object refers.

26.5.7.4  

`gslice_array fill function`  

```cpp
void operator=(const T&) const;
```

This function has reference semantics, assigning the value of its argument to the elements of the `valarray<T>` object to which the `gslice_array` object refers.

26.5.8  

Class template `mask_array`  

```cpp
namespace std {
    template <class T> class mask_array {
        public:
            typedef T value_type;
            void operator= (const valarray<T>&) const;
            void operator*= (const valarray<T>&) const;
            void operator/= (const valarray<T>&) const;
            void operator%= (const valarray<T>&) const;
            void operator+= (const valarray<T>&) const;
            void operator-= (const valarray<T>&) const;
            void operator^= (const valarray<T>&) const;
            void operator&= (const valarray<T>&) const;
            void operator|= (const valarray<T>&) const;
            void operator<<=(const valarray<T>&) const;
            void operator>>=(const valarray<T>&) const;
    };
}
```

`mask_array(const mask_array&);`  

`~mask_array();`  

`mask_array& operator=(const mask_array&);`  

`void operator=(const T&) const;`  

`private:`
    `mask_array();`  
};

Draft
This template is a helper template used by the mask subscript operator:

\[
\text{mask\_array}\langle T\rangle \text{ valarray}\langle T\rangle::\text{operator[]}\text{ }\langle\text{const valarray<}&\text{bool>&}\rangle.
\]

It has reference semantics to a subset of an array specified by a boolean mask. Thus, the expression \( a[\text{mask}] = b \) has the effect of assigning the elements of \( b \) to the masked elements in \( a \) (those for which the corresponding element in \( \text{mask} \) is true.)

### 26.5.8.1 mask\_array constructors

\[
\text{mask\_array}();
\]

This constructor is declared to be private. This constructor need not be defined.

### 26.5.8.2 mask\_array assignment

\[
\text{void operator=}\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{mask\_array& operator=}\langle\text{const mask\_array}&\rangle;
\]

These assignment operators have reference semantics, assigning the values of the argument array elements to selected elements of the \text{valarray}<T> object to which it refers.

### 26.5.8.3 mask\_array computed assignment

\[
\text{void operator}*=(\text{const valarray<}&\text{T>&}) \text{ const;}
\]

\[
\text{void operator}/=(\text{const valarray<}&\text{T>&}) \text{ const;}
\]

\[
\text{void operator}%=\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{void operator}+=\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{void operator}-=\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{void operator}^=\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{void operator}&=\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{void operator}|=\langle\text{const valarray<}&\text{T>&}\rangle \text{ const;}
\]

\[
\text{void operator}<<=(\text{const valarray<}&\text{T>&}) \text{ const;}
\]

These computed assignments have reference semantics, applying the indicated operation to the elements of the argument array and selected elements of the \text{valarray}<T> object to which the mask object refers.

### 26.5.8.4 mask\_array fill function

\[
\text{void operator}=(\text{const } &\text{T}) \text{ const;}
\]

This function has reference semantics, assigning the value of its argument to the elements of the \text{valarray}<T> object to which the mask\_array object refers.
26.5.9 Class template indirect_array

namespace std {
    template <class T> class indirect_array {
    public:
        typedef T value_type;
        void operator= (const valarray<T>&) const;
        void operator*= (const valarray<T>&) const;
        void operator/= (const valarray<T>&) const;
        void operator%= (const valarray<T>&) const;
        void operator+= (const valarray<T>&) const;
        void operator-= (const valarray<T>&) const;
        void operator^= (const valarray<T>&) const;
        void operator&= (const valarray<T>&) const;
        void operator|= (const valarray<T>&) const;
        void operator<<=(const valarray<T>&) const;
        void operator>>=(const valarray<T>&) const;
        indirect_array(const indirect_array&);
        ~indirect_array();
        indirect_array& operator=(const indirect_array&);
        void operator=(const T&) const;
    private:
        indirect_array();
    };
}

This template is a helper template used by the indirect subscript operator
indirect_array<T> valarray<T>::operator[] (const valarray< sizes_t>&).

It has reference semantics to a subset of an array specified by an indirect_array. Thus the expression a[ indirect] = b; has the effect of assigning the elements of b to the elements in a whose indices appear in indirect.

26.5.9.1 indirect_array constructors

indirect_array();

This constructor is declared to be private. This constructor need not be defined.

26.5.9.2 indirect_array assignment

void operator=(const valarray<T>&) const;
indirect_array& operator=(const indirect_array&);

These assignment operators have reference semantics, assigning the values of the argument array elements to selected elements of the valarray<T> object to which it refers.
If the indirect_array specifies an element in the valarray<T> object to which it refers more than once, the behavior is undefined.

[Example:

```cpp
int addr[] = {2, 3, 1, 4, 4};
valarray<size_t> indirect(addr, 5);
valarray<double> a(0., 10), b(1., 5);
a[indirect] = b;
```

results in undefined behavior since element 4 is specified twice in the indirection. — end example ]

26.5.9.3 indirect_array computed assignment

```cpp
void operator*= (const valarray<T>&) const;
void operator/= (const valarray<T>&) const;
void operator%= (const valarray<T>&) const;
void operator+= (const valarray<T>&) const;
void operator-= (const valarray<T>&) const;
void operator^= (const valarray<T>&) const;
void operator&= (const valarray<T>&) const;
void operator|= (const valarray<T>&) const;
void operator<<=(const valarray<T>&) const;
void operator>>=(const valarray<T>&) const;
```

These computed assignments have reference semantics, applying the indicated operation to the elements of the argument array and selected elements of the valarray<T> object to which the indirect_array object refers.

If the indirect_array specifies an element in the valarray<T> object to which it refers more than once, the behavior is undefined.

26.5.9.4 indirect_array fill function

```cpp
void operator=(const T&) const;
```

This function has reference semantics, assigning the value of its argument to the elements of the valarray<T> object to which the indirect_array object refers.

26.6 Generalized numeric operations

Header `<numeric>` synopsis

```cpp
namespace std {
    template <class InputIterator, class T>
    T accumulate(InputIterator first, InputIterator last, T init);
    template <class InputIterator, class T, class BinaryOperation>
    T accumulate(InputIterator first, InputIterator last, T init, BinaryOperation binary_op);
```
The requirements on the types of algorithms’ arguments that are described in the introduction to clause 25 also apply to the following algorithms.

### 26.6.1 Accumulate

```cpp
template <class InputIterator, class T>
T accumulate(InputIterator first, InputIterator last, T init);
```

```cpp
template <class InputIterator, class T, class BinaryOperation>
T accumulate(InputIterator first, InputIterator last, T init, BinaryOperation binary_op);
```

**Effects:** Computes its result by initializing the accumulator acc with the initial value init and then modifies it with acc = acc + *i or acc = binary_op(acc, *i) for every iterator i in the range [first,last) in order.\(^{282}\)

\(^{282}\) accumulate is similar to the APL reduction operator and Common Lisp reduce function, but it avoids the difficulty of defining the result of reduction on an empty sequence by always requiring an initial value.
26.6 Generalized numeric operations

2 Requires: T shall meet the requirements of CopyConstructible (20.1.3) and Assignable (23.1) types. In the range [first, last], binary_op shall neither modify elements nor invalidate iterators or subranges.\(^{283}\)

### 26.6.2 Inner product

```
template <class InputIterator1, class InputIterator2, class T>
T inner_product(InputIterator1 first1, InputIterator1 last1,
                InputIterator2 first2, T init);
template <class InputIterator1, class InputIterator2, class T,
          class BinaryOperation1, class BinaryOperation2>
T inner_product(InputIterator1 first1, InputIterator1 last1,
                InputIterator2 first2, T init,
                BinaryOperation1 binary_op1,
                BinaryOperation2 binary_op2);
```

1 Effects: Computes its result by initializing the accumulator acc with the initial value init and then modifying it with acc = acc + (*i1) * (*i2) or acc = binary_op1(acc, binary_op2(*i1, *i2)) for every iterator i1 in the range [first, last) and iterator i2 in the range [first2, first2 + (last - first)) in order.

2 Requires: T shall meet the requirements of CopyConstructible (20.1.3) and Assignable (23.1) types. In the ranges [first, last] and [first2, first2 + (last - first)] binary_op1 and binary_op2 shall neither modify elements nor invalidate iterators or subranges.\(^{284}\)

### 26.6.3 Partial sum

```
template <class InputIterator, class OutputIterator>
OutputIterator
    partial_sum(InputIterator first, InputIterator last,
                OutputIterator result);
```

```
template <class InputIterator, class OutputIterator, class BinaryOperation>
OutputIterator
    partial_sum(InputIterator first, InputIterator last,
                OutputIterator result, BinaryOperation binary_op);
```

1 Effects: Assigns to every element referred to by iterator i in the range [result, result + (last - first)) a value correspondingly equal to

\[
((...(*first + *(first + 1)) + ...) + *(first + (i - result)))
\]

or

\[
binary_op(binary_op(...,
                     binary_op(*first, *(first + 1)),...), *(first + (i - result)))
\]

\(^{283}\)The use of fully closed ranges is intentional

\(^{284}\)The use of fully closed ranges is intentional
Returns: result + (last - first).

Complexity: Exactly (last - first) - 1 applications of binary_op.

Requires: In the ranges [first, last] and [result, result + (last - first)] binary_op shall neither modify elements nor invalidate iterators or subranges.\(^\text{285}\)

Remarks: result may be equal to first.

### 26.6.4 Adjacent difference

\[
\text{template } \langle \text{class InputIterator, class OutputIterator} \rangle \\
\text{OutputIterator} \\
\quad \text{adjacent_difference(InputIterator } \text{first, InputIterator last,} \\
\quad \text{OutputIterator result);} \\
\text{template} \\
\langle \text{class InputIterator, class OutputIterator, class BinaryOperation} \rangle \\
\text{OutputIterator} \\
\quad \text{adjacent_difference(InputIterator } \text{first, InputIterator last,} \\
\quad \text{OutputIterator result,} \\
\quad \text{BinaryOperation binary_op);} \\
\]

Effects: Assigns to every element referred to by iterator \(i\) in the range \([\text{result + 1}, \text{result + (last - first)})\) a value correspondingly equal to

\[
*(\text{first + (i - result)}) - *(\text{first + (i - result) - 1})
\]

or

\[
\text{binary_op}(*(\text{first + (i - result)}), *(\text{first + (i - result) - 1})).
\]

result gets the value of \(*\text{first}\).

Requires: In the ranges \([\text{first, last}]\) and \([\text{result, result + (last - first]}\), binary_op shall neither modify elements nor invalidate iterators or subranges.\(^\text{286}\)

Remarks: result may be equal to first.

Returns: result + (last - first).

Complexity: Exactly (last - first) - 1 applications of binary_op.

### 26.7 C Library

TR1 The header <tgmath.h> effectively includes the headers <complex.h> and <math.h>.

TR2 [ \text{Note: The overloads provided in C99 by magic macros are already provided in <complex.h> and <math.h> by "sufficient" additional overloads. — end note} \]

TR3 The header <tgmath.h> effectively includes the headers <complex.h> and <math.h>.

\(^\text{285}\) The use of fully closed ranges is intentional.

\(^\text{286}\) The use of fully closed ranges is intentional.
Tables 100 and 101 describe headers `<cmath>` and `<cstdlib>`, respectively.

![Table 100: Header `<cmath>` synopsis](attachment:image.png)

The contents of these headers are the same as the Standard C library headers `<math.h>` and `<stdlib.h>` respectively, with the following changes:

6 The `rand` function has the semantics specified in the C standard, except that the implementation may specify that particular library functions may call `rand`.

7 In addition to the int versions of certain math functions in `<cstdlib>`, C++ adds long and long long overloaded versions of these functions, with the same semantics.

8 The added signatures are:

```c
long abs(long); //labs()
long abs(long long); //llabs()
ldiv_t div(long, long); //ldiv()
ldiv_t div(long long, long long); //lldiv()
```

9 In addition to the double versions of the math functions in `<cmath>`, C++ adds float and long double overloaded versions of these functions, with the same semantics.

---

287) all macros except HUGE_VAL, both types, many functions, and all templates added by TR1.
The added signatures are:

```c
float abs(float);
float acos(float);
float acosh(float);
float asin(float);
float asinh(float);
float atan(float);
float atan2(float, float);
float atanh(float);
float cbrt(float);
float ceil(float);
float copysign(float, float);
float cos(float);
float cosh(float);
float erf(float);
float erfc(float);
float exp(float);
float exp2(float);
float expm1(float);
float fabs(float);
float fdim(float, float);
float floor(float);
float fma(float, float, float);
float fmax(float, float);
float fmin(float, float);
float fmod(float, float);
float frexp(float, int*);
float hypot(float, float);
float ilogb(float);
float ldexp(float, int);
float lgamma(float);
float llrint(float);
float llround(float);
float log(float);
float log10(float);
float log1p(float);
```

Table 101: Header `<cstdlib>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro:</td>
<td>RAND_MAX</td>
</tr>
<tr>
<td>Types:</td>
<td>div_t</td>
</tr>
<tr>
<td>Functions:</td>
<td>abs</td>
</tr>
<tr>
<td></td>
<td>div</td>
</tr>
<tr>
<td></td>
<td>labs</td>
</tr>
</tbody>
</table>
float log2(float);
float logb(float);
float lrint(float);
float lround(float);
float modf(float, float*);
float nearbyint(float);
float nextafter(float, float);
float nexttoward(float, long double);
float pow(float, float);
float pow(float, int);
float remainder(float, float);
float remquo(float, float, int *);
float rint(float);
float round(float);
float roundf(float);
float scalbn(float, long);
float scalbnf(float, int);
float sin(float);
float sinh(float);
float sqrt(float);
float tan(float);
float tanh(float);
float tgamma(float);
float trunc(float);

// fabs()
double abs(double);

long double abs(long double);
long double acos(long double);
long double acosh(long double);
long double asin(long double);
long double asinh(long double);
long double atan(long double);
long double atan2(long double, long double);
long double atanh(long double);
long double cbrt(long double);
long double ceil(long double);
long double copysign(long double, long double);
long double cos(long double);
long double cosh(long double);
long double erf(long double);
long double erfc(long double);
long double exp(long double);
long double exp2(long double);
long double expm1(long double);
long double fabs(long double);
long double fdim(long double, long double);
long double floor(long double);
long double fma(long double, long double, long double);
long double fmax(long double, long double);
long double fmin(long double, long double);
long double fmod(long double, long double);
long double frexpf(long double, int*);
long double frexpl(long double, int*);
long double ftopn(long double, long double);
long double fmin(long double, long double);
long double fmod(long double, long double);
long double frexp(long double, int*);
long double hypot(long double, long double);
long double ilogb(long double);
long double ldexp(long double, int);
long double lgamma(long double);
long double llrint(long double);
long double llround(long double);
long double log(long double);
long double log10(long double);
long double log1p(long double);
long double log2(long double);
long double logb(long double);
long double lrint(long double);
long double lround(long double);
long double modf(long double, long double*);
long double nearbyint(long double);
long double nextafter(long double, long double);
long double nexttoward(long double, long double);
long double pow(long double, long double);
long double pow(long double, int);
long double remainder(long double, long double);
long double remquo(long double, long double, int *);
long double rint(long double);
long double round(long double);
long double scalbln(long double, long);
long double scalbn(long double, int);
long double sin(long double);
long double sinh(long double);
long double sqrt(long double);
long double tan(long double);
long double tanh(long double);
long double tgamma(long double);
long double trunc(long double);

Moreover, there shall be additional overloads sufficient to ensure:

1. If any argument corresponding to a `double` parameter has type `long double`, then all arguments corresponding to `double` parameters are effectively cast to `long double`.

2. Otherwise, if any argument corresponding to a `double` parameter has type `double` or an integer type, then all arguments corresponding to `double` parameters are effectively cast to `double`.

3. Otherwise, all arguments corresponding to `double` parameters are effectively cast to `float`.

The templates defined in `<cmath>` replace the C99 macros with the same names. The templates have the following declarations:

```c
namespace std {
    template <class T> bool signbit(T x);
} // namespace std
```
template <class T> int fpclassify(T x);

template <class T> bool isfinite(T x);
template <class T> bool isinf(T x);
template <class T> bool isnan(T x);
template <class T> bool isnormal(T x);

template <class T> bool isgreater(T x);
template <class T> bool isgreaterequal(T x);
template <class T> bool isless(T x);
template <class T> bool islessequal(T x);
template <class T> bool islessgreater(T x);
template <class T> bool isunordered(T x);
} // namespace std

The templates behave the same as the C99 macros with corresponding names defined in C99 subclause 7.12.3, Classification macros, and C99 subclause 7.12.14, Comparison macros.

SEE ALSO: ISO C subclauses 7.5, 7.10.2, 7.10.6.
Chapter 27 Input/output library [lib.input.output]

1 This clause describes components that C++ programs may use to perform input/output operations.

2 The following subclauses describe requirements for stream parameters, and components for forward declarations of iostreams, predefined iostreams objects, base iostreams classes, stream buffering, stream formatting and manipulators, string streams, and file streams, as summarized in Table 102.

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.1 Requirements</td>
<td></td>
</tr>
<tr>
<td>27.2 Forward declarations</td>
<td><code>&lt;iosfwd&gt;</code></td>
</tr>
<tr>
<td>27.3 Standard iostream objects</td>
<td><code>&lt;iostream&gt;</code></td>
</tr>
<tr>
<td>27.4 Iostreams base classes</td>
<td><code>&lt;ios&gt;</code></td>
</tr>
<tr>
<td>27.5 Stream buffers</td>
<td><code>&lt;streambuf&gt;</code></td>
</tr>
<tr>
<td>27.6 Formatting and manipulators</td>
<td><code>&lt;istream&gt;</code>, <code>&lt;ostream&gt;</code>, <code>&lt;iomanip&gt;</code></td>
</tr>
<tr>
<td>27.7 String streams</td>
<td><code>&lt;sstream&gt;</code></td>
</tr>
<tr>
<td>27.8 File streams</td>
<td><code>&lt;fstream&gt;</code>, <code>&lt;cstdio&gt;</code></td>
</tr>
</tbody>
</table>

27.1 Iostreams requirements [lib.iostreams.requirements]

27.1.1 Imbue Limitations [lib.iostream.limits.imbue]

1 No function described in clause 27 except for `ios_base::imbue` causes any instance of `basic_ios::imbue` or `basic_streambuf::imbue` to be called. If any user function called from a function declared in clause 27 or as an overriding virtual function of any class declared in clause 27 calls `imbue`, the behavior is undefined.

27.1.2 Positioning Type Limitations [lib.iostreams.limits.pos]

1 The classes of clause 27 with template arguments `charT` and `traits` behave as described if `traits::pos_type` and `traits::off_type` are `streampos` and `streamoff` respectively. Except as noted explicitly below, their behavior when `traits::pos_type` and `traits::off_type` are other types is implementation-defined.

27.2 Forward declarations [lib.iostream.forward]

Header `<iosfwd>` synopsis
namespace std {
    template<class charT> class char_traits;
    template<> class char_traits<char>;
    template<> class char_traits<wchar_t>;

    template<class T> class allocator;

    template <class charT, class traits = char_traits<charT> >
    class basic_ios;

    template <class charT, class traits = char_traits<charT> >
    class basic_streambuf;

    template <class charT, class traits = char_traits<charT> >
    class basic_istream;

    template <class charT, class traits = char_traits<charT> >
    class basic_ostream;

    template <class charT, class traits = char_traits<charT> >
    class basic_iostream;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_stringbuf;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_istringstream;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_ostringstream;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_stringstream;

    template <class charT, class traits = char_traits<charT> >
    class basic_filebuf;

    template <class charT, class traits = char_traits<charT> >
    class basic_ifstream;

    template <class charT, class traits = char_traits<charT> >
    class basic_ofstream;

    template <class charT, class traits = char_traits<charT> >
    class basic_fstream;

Draft
template <class charT, class traits = char_traits<charT> >
   class istreambuf_iterator;

template <class charT, class traits = char_traits<charT> >
   class ostreambuf_iterator;

typedef basic_ios<char>     ios;
typedef basic_ios<wchar_t> wios;

typedef basic_streambuf<char> streambuf;
typedef basic_istream<char>  istream;
typedef basic_ostream<char>  ostream;
typedef basic_iostream<char> iostream;

typedef basic_stringbuf<char>  stringbuf;
typedef basic_istream<wchar_t>  wistream;
typedef basic_ostream<wchar_t>  wostream;
typedef basic_iostream<wchar_t> wiostream;

typedef basic_stringbuf<wchar_t> wstringbuf;
typedef basic_istream<wchar_t> wistream;
typedef basic_ostream<wchar_t> wostream;
typedef basic_iostream<wchar_t> wiostream;

typedef basic_stringbuf<wchar_t> wstringbuf;
typedef basic_istream<wchar_t> wistream;
typedef basic_ostream<wchar_t> wostream;
typedef basic_iostream<wchar_t> wiostream;

typedef basic_filebuf<char>  filebuf;
typedef basic_ifstream<char>  ifstream;
typedef basic_ofstream<char>  ofstream;
typedef basic_fstream<char>  fstream;

typedef basic_filebuf<wchar_t> wfilebuf;
typedef basic_ifstream<wchar_t> wifstream;
typedef basic_ofstream<wchar_t> wofstream;
typedef basic_fstream<wchar_t> wfstream;

template <class state> class fpos;
typedef fpos<char_traits<char>::state_type>  streampos;
typedef fpos<char_traits<wchar_t>::state_type> wstreampos;

1 Default template arguments are described as appearing both in <iosfwd> and in the synopsis of other headers but it is well-formed to include both <iosfwd> and one or more of the other headers.288)

288 It is the implementation’s responsibility to implement headers so that including <iosfwd> and other headers does not violate the rules about multiple occurrences of default arguments.

Draft
27.3 Standard iostream objects  

[Note: The class template specialization basic_ios<\texttt{charT,traits}> serves as a virtual base class for the class templates basic_istream, basic_ostream, and class templates derived from them. basic_iostream is a class template derived from both basic_istream<\texttt{charT,traits}> and basic_ostream<\texttt{charT,traits}>.]

The class template specialization basic_streambuf<\texttt{charT,traits}> serves as a base class for template classes basic_stringbuf and basic_filebuf.

The class template specialization basic_istream<\texttt{charT,traits}> serves as a base class for template classes basic_stringstream and basic_ifstream.

The class template specialization basic_ostream<\texttt{charT,traits}> serves as a base class for template classes basic_ostringstream and basic_ofstream.

The class template specialization basic_iostream<\texttt{charT,traits}> serves as a base class for template classes basic_stringstream and basic_fstream.

Other typedefs define instances of class templates specialized for \texttt{char} or \texttt{wchar_t} types.

Specializations of the class template \texttt{fpos} are used for specifying file position information.

The types \texttt{streampos} and \texttt{wstreampos} are used for positioning streams specialized on \texttt{char} and \texttt{wchar_t} respectively.

This synopsis suggests a circularity between \texttt{streampos} and \texttt{char_traits<\texttt{char}>}. An implementation can avoid this circularity by substituting equivalent types. One way to do this might be

```cpp
template<class stateT> class fpos { ... };  // depends on nothing
typedef ... _STATE; // implementation private declaration of stateT
typedef fpos<_STATE> streampos;

template<> struct char_traits<char> {
    typedef streampos
    pos_type;
    // ...
}
```

— end note ]

27.3 Standard iostream objects  

[lib.iostream.objects]

Header <iostream> synopsis

```cpp
namespace std {
    extern istream cin;
    extern ostream cout;
    extern ostream cerr;
    extern ostream clog;

    extern wistream wcin;
    extern wostream wcout;
    extern wostream wcerr;
    extern wostream wclog;
}
```

Draft
The header `<iostream>` declares objects that associate objects with the standard C streams provided for by the functions declared in `<cstdio>` (27.8.2).

The objects are constructed and the associations are established at some time prior to or during the first time an object of class `ios_base::Init` is constructed, and in any case before the body of `main` begins execution. The objects are not destroyed during program execution. If a translation unit includes `<iostream>` or explicitly constructs an `ios_base::Init` object, these stream objects shall be constructed before dynamic initialization of non-local objects defined later in that translation unit, and these stream objects shall be destroyed after the destruction of dynamically initialized non-local objects defined later in that translation unit.

Mixing operations on corresponding wide- and narrow-character streams follows the same semantics as mixing such operations on FILEs, as specified in Amendment 1 of the ISO C standard.

### 27.3.1 Narrow stream objects

`istream cin;`

The object `cin` controls input from a stream buffer associated with the object `stdin`, declared in `<cstdio>`.

After the object `cin` is initialized, `cin.tie()` returns `&cout`. Its state is otherwise the same as required for `basic_ios<char>::init` (27.4.4.1).

`ostream cout;`

The object `cout` controls output to a stream buffer associated with the object `stdout`, declared in `<cstdio>` (27.8.2).

`ostream cerr;`

The object `cerr` controls output to a stream buffer associated with the object `stderr`, declared in `<cstdio>` (27.8.2).

After the object `cerr` is initialized, `cerr.flags() & unitbuf` is nonzero and `cerr.tie()` returns `&cout`. Its state is otherwise the same as required for `basic_ios<char>::init` (27.4.4.1).

`ostream clog;`

The object `clog` controls output to a stream buffer associated with the object `stderr`, declared in `<cstdio>` (27.8.2).

### 27.3.2 Wide stream objects

`wistream wcin;`

The object `wcin` controls input from a stream buffer associated with the object `stdin`, declared in `<cstdio>`.

After the object `wcin` is initialized, `wcin.tie()` returns `&wcout`. Its state is otherwise the same as required for `basic_ios<wchar_t>::init` (27.4.4.1).

`wostream wcout;`
The object \texttt{wcout} controls output to a stream buffer associated with the object \texttt{stdout}, declared in \texttt{<cstdio>} (27.8.2).

\begin{verbatim}
ostream wcerr;
\end{verbatim}

The object \texttt{wcerr} controls output to a stream buffer associated with the object \texttt{stderr}, declared in \texttt{<cstdio>} (27.8.2).

After the object \texttt{wcerr} is initialized, \texttt{wcerr.flags() \& unitbuf} is nonzero and \texttt{wcerr.tie()} returns \texttt{\&wcout}. Its state is otherwise the same as required for \texttt{basic_ios\_wchar\_t::init} (27.4.4.1).

\begin{verbatim}
ostream wclog;
\end{verbatim}

The object \texttt{wclog} controls output to a stream buffer associated with the object \texttt{stderr}, declared in \texttt{<cstdio>} (27.8.2).

### 27.4 Iostreams base classes

**Header <ios> synopsis**

```cpp
#include <iosfwd>

namespace std {
    typedef OFF_T streamoff;
    typedef SZ_T streamsize;
    template <class stateT> class fpos;

    class ios_base;
    template <class charT, class traits = char_traits<charT> >
        class basic_ios;

    // 27.4.5, manipulators:
    ios_base& boolalpha (ios_base& str);
    ios_base& noboolalpha(ios_base& str);
    ios_base& showbase (ios_base& str);
    ios_base& noshowbase (ios_base& str);
    ios_base& showpoint (ios_base& str);
    ios_base& noshowpoint(ios_base& str);
    ios_base& showpos (ios_base& str);
    ios_base& noshowpos (ios_base& str);
    ios_base& skipws (ios_base& str);
    ios_base& noskipws (ios_base& str);
    ios_base& uppercase (ios_base& str);
    ios_base& nouppercase(ios_base& str);
    ios_base& unitbuf (ios_base& str);
```
27.4.1 Types

The type `streamoff` is an implementation-defined type that satisfies the requirements of 27.4.3.2.

The type `streamsize` is a synonym for one of the signed basic integral types. It is used to represent the number of characters transferred in an I/O operation, or the size of I/O buffers.\(^{201}\)

27.4.2 Class `ios_base`

```cpp
namespace std {
    class ios_base {
        public:
            class failure;

            typedef T1 fmtflags;
            static const fmtflags boolalpha;
            static const fmtflags dec;
            static const fmtflags fixed;
            static const fmtflags hex;
            static const fmtflags internal;
            static const fmtflags left;
            static const fmtflags oct;
```

\(^{201}\) `streamsize` is used in most places where ISO C would use `size_t`. Most of the uses of `streamsize` could use `size_t`, except for the `strstreambuf` constructors, which require negative values. It should probably be the signed type corresponding to `size_t` (which is what Posix.2 calls `ssize_t`).

Draft
static const fmtflags right;
static const fmtflags scientific;
static const fmtflags showbase;
static const fmtflags showpoint;
static const fmtflags showpos;
static const fmtflags skipws;
static const fmtflags unitbuf;
static const fmtflags uppercase;
static const fmtflags adjustfield;
static const fmtflags basefield;
static const fmtflags floatfield;

typedef T2 iostate;
static const iostate badbit;
static const iostate eofbit;
static const iostate failbit;
static const iostate goodbit;

typedef T3 openmode;
static const openmode app;
static const openmode ate;
static const openmode binary;
static const openmode in;
static const openmode out;
static const openmode trunc;

typedef T4 seekdir;
static const seekdir beg;
static const seekdir cur;
static const seekdir end;

class Init;

// 27.4.2.2 fmtflags state:
fmtflags flags() const;
fmtflags flags(fmtflags fmtfl);
fmtflags setf(fmtflags fmtfl);
fmtflags setf(fmtflags fmtfl, fmtflags mask);
void unsetf(fmtflags mask);

streamsize precision() const;
streamsize precision(streamsize prec);
streamsize width() const;
streamsize width(streamsize wide);

// 27.4.2.3 locales:
locale imbue(const locale& loc);
locale getloc() const;

// 27.4.2.5 storage:
Draft
static int xalloc();
long& iword(int index);
void*& pword(int index);

// destructor
virtual ~ios_base();

// 27.4.2.6 callbacks;
enum event { erase_event, imbue_event, copyfmt_event };
typedef void (*event_callback)(event, ios_base&, int index);
void register_callback(event_callback fn, int index);

static bool sync_with_stdio(bool sync = true);

protected:
ios_base();

private:
// static int index;
// long* iarray;
// void** parray;
private:
ios_base(const ios_base&);
ios_base& operator=(const ios_base&);
};

ios_base defines several member types:
— a class failure derived from exception;
— a class Init;
— three bitmask types, fmtflags, iostate, and openmode;
— an enumerated type, seekdir.

It maintains several kinds of data:
— state information that reflects the integrity of the stream buffer;
— control information that influences how to interpret (format) input sequences and how to generate (format) output sequences;
— additional information that is stored by the program for its private use.

[Note: For the sake of exposition, the maintained data is presented here as:
— static int index, specifies the next available unique index for the integer or pointer arrays maintained for the private use of the program, initialized to an unspecified value;
— long* tarray, points to the first element of an arbitrary-length long array maintained for the private use of the program;]
27.4 Iostreams base classes

<table>
<thead>
<tr>
<th>27.4.2.1 Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.4.2.1.1 Class ios_base::failure</td>
</tr>
</tbody>
</table>

```cpp
namespace std {
    class ios_base::failure : public exception {
        public:
            explicit failure(const string& msg);
            virtual const char* what() const throw();
    };
}
```

The class `failure` defines the base class for the types of all objects thrown as exceptions, by functions in the iostreams library, to report errors detected during stream buffer operations.

```cpp
explicit failure(const string& msg);
```

**Effects:** Constructs an object of class `failure`.

```cpp
Postcondition: strcmp(what(), msg.c_str()) == 0
```

**Returns:** The message `msg` with which the exception was created.

27.4.2.1.2 Type ios_base::fmtflags

typedef T1 fmtflags;

The type `fmtflags` is a bitmask type (17.3.2.1.2). Setting its elements has the effects indicated in Table 103.

Type `fmtflags` also defines the constants indicated in Table 104.

27.4.2.1.3 Type ios_base::iostate

typedef T2 iostate;

The type `iostate` is a bitmask type (17.3.2.1.2) that contains the elements indicated in Table 105.

Type `iostate` also defines the constant:

- `goodbit`, the value zero.
### Table 103: `fmtflags` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Effect(s) if set</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolalpha</td>
<td>insert and extract bool type in alphabetic format</td>
</tr>
<tr>
<td>dec</td>
<td>converts integer input or generates integer output in decimal base</td>
</tr>
<tr>
<td>fixed</td>
<td>generate floating-point output in fixed-point notation</td>
</tr>
<tr>
<td>hex</td>
<td>converts integer input or generates integer output in hexadecimal base</td>
</tr>
<tr>
<td>internal</td>
<td>adds fill characters at a designated internal point in certain generated output, or identical to right if no such point is designated</td>
</tr>
<tr>
<td>left</td>
<td>adds fill characters on the right (final positions) of certain generated output</td>
</tr>
<tr>
<td>oct</td>
<td>converts integer input or generates integer output in octal base</td>
</tr>
<tr>
<td>right</td>
<td>adds fill characters on the left (initial positions) of certain generated output</td>
</tr>
<tr>
<td>scientific</td>
<td>generates floating-point output in scientific notation</td>
</tr>
<tr>
<td>showbase</td>
<td>generates a prefix indicating the numeric base of generated integer output</td>
</tr>
<tr>
<td>showpoint</td>
<td>generates a decimal-point character unconditionally in generated floating-point output</td>
</tr>
<tr>
<td>showpos</td>
<td>generates a + sign in non-negative generated numeric output</td>
</tr>
<tr>
<td>skipws</td>
<td>skips leading whitespace before certain input operations</td>
</tr>
<tr>
<td>unitbuf</td>
<td>flushes output after each output operation</td>
</tr>
<tr>
<td>uppercase</td>
<td>replaces certain lowercase letters with their uppercase equivalents in generated output</td>
</tr>
</tbody>
</table>

### Table 104: `fmtflags` constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Allowable values</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjustfield</td>
<td>left</td>
</tr>
<tr>
<td>basefield</td>
<td>dec</td>
</tr>
<tr>
<td>floatfield</td>
<td>scientific</td>
</tr>
</tbody>
</table>

### Table 105: `iostate` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Effect(s) if set</th>
</tr>
</thead>
<tbody>
<tr>
<td>badbit</td>
<td>indicates a loss of integrity in an input or output sequence (such as an irrecoverable read error from a file);</td>
</tr>
<tr>
<td>eofbit</td>
<td>indicates that an input operation reached the end of an input sequence;</td>
</tr>
<tr>
<td>failbit</td>
<td>indicates that an input operation failed to read the expected characters, or that an output operation failed to generate the desired characters.</td>
</tr>
</tbody>
</table>

Draft
27.4 Iostreams base classes

27.4.2.1.4 Type `ios_base::openmode` [lib.ios::openmode]

typedef T3 openmode;

The type `openmode` is a bitmask type (17.3.2.1.2). It contains the elements indicated in Table 106.

<table>
<thead>
<tr>
<th>Element</th>
<th>Effect(s) if set</th>
</tr>
</thead>
<tbody>
<tr>
<td>app</td>
<td>seek to end before each write</td>
</tr>
<tr>
<td>ate</td>
<td>open and seek to end immediately after opening</td>
</tr>
<tr>
<td>binary</td>
<td>perform input and output in binary mode (as opposed to text mode)</td>
</tr>
<tr>
<td>in</td>
<td>open for input</td>
</tr>
<tr>
<td>out</td>
<td>open for output</td>
</tr>
<tr>
<td>trunc</td>
<td>truncate an existing stream when opening</td>
</tr>
</tbody>
</table>

27.4.2.1.5 Type `ios_base::seekdir` [lib.ios::seekdir]

typedef T4 seekdir;

The type `seekdir` is an enumerated type (17.3.2.1.1) that contains the elements indicated in Table 107.

<table>
<thead>
<tr>
<th>Element</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>beg</td>
<td>request a seek (for subsequent input or output) relative to the beginning of the stream</td>
</tr>
<tr>
<td>cur</td>
<td>request a seek relative to the current position within the sequence</td>
</tr>
<tr>
<td>end</td>
<td>request a seek relative to the current end of the sequence</td>
</tr>
</tbody>
</table>

27.4.2.1.6 Class `ios_base::Init` [lib.ios::Init]

namespace std {
    class ios_base::Init {
        public:
            Init();
            ~Init();
        private:
            // static int init_cnt; exposition only
    };

The class `Init` describes an object whose construction ensures the construction of the eight objects declared in `<iostream>` (27.3) that associate file stream buffers with the standard C streams provided for by the functions declared in `<cstdio>` (27.8.2).

For the sake of exposition, the maintained data is presented here as:

Draft
—— static int init_cnt, counts the number of constructor and destructor calls for class Init, initialized to zero.

Init();

Effects: Constructs an object of class Init. If init_cnt is zero, the function stores the value one in init_cnt, then constructs and initializes the objects cin, cout, cerr, clog (27.3.1), wcin, wcout, wcerr, and wclog (27.3.2). In any case, the function then adds one to the value stored in init_cnt.

~Init();

Effects: Destroys an object of class Init. The function subtracts one from the value stored in init_cnt and, if the resulting stored value is one, calls cout.flush(), cerr.flush(), clog.flush(), wcout.flush(), wcerr.flush(), wclog.flush().

### 27.4.2.2 ios_base state functions

fmtflags flags() const;

Returns: The format control information for both input and output.

fmtflags flags(fmtflags fmtfl);

Postcondition: fmtfl == flags().

Returns: The previous value of flags().

fmtflags setf(fmtflags fmtfl);

Effects: Sets fmtfl in flags().

Returns: The previous value of flags().

fmtflags setf(fmtflags fmtfl, fmtflags mask);

Effects: Clears mask in flags(), sets fmtfl & mask in flags().

Returns: The previous value of flags().

void unsetf(fmtflags mask);

Effects: Clears mask in flags().

streamsize precision() const;

Returns: The precision to generate on certain output conversions.

streamsize precision(streamsize prec);

Postcondition: prec == precision().

Returns: The previous value of precision().

streamsize width() const;

Returns: The minimum field width (number of characters) to generate on certain output conversions.
streamsize width(streamsize wide);

Postcondition: wide == width().

Returns: The previous value of width().

### 27.4.2.3 ios_base functions

locale imbue(const locale& loc);

Effects: Calls each registered callback pair (fn, index) (27.4.2.6) as (*fn)(imbue_event, *this, index) at such a time that a call to ios_base::getloc() from within fn returns the new locale value loc.

Returns: The previous value of getloc().

Postcondition: loc == getloc().

locale getloc() const;

Returns: If no locale has been imbued, a copy of the global C++ locale, locale(), in effect at the time of construction. Otherwise, returns the imbued locale, to be used to perform locale-dependent input and output operations.

### 27.4.2.4 ios_base static members

bool sync_with_stdio(bool sync = true);

Returns: true if the previous state of the standard iostream objects (27.3) was synchronized and otherwise returns false. The first time it is called, the function returns true.

Effects: If any input or output operation has occurred using the standard streams prior to the call, the effect is implementation-defined. Otherwise, called with a false argument, it allows the standard streams to operate independently of the standard C streams.

When a standard iostream object `str` is synchronized with a standard stdio stream `f`, the effect of inserting a character `c` by

```
fputc(f, c);
```

is the same as the effect of

```
str.rdbuf()->sputc(c);
```

for any sequences of characters; the effect of extracting a character `c` by

```
c = fgetc(f);
```

is the same as the effect of

```
c = str.rdbuf()->sbumpc(c);
```

for any sequences of characters; and the effect of pushing back a character `c` by
is the same as the effect of
    str.rdbuf()->sputbackc(c);

for any sequence of characters.\footnote{This implies that operations on a standard iostream object can be mixed arbitrarily with operations on the corresponding stdio stream. In practical terms, synchronization usually means that a standard iostream object and a standard stio object share a buffer.}

\subsection*{27.4.2.5 \texttt{ios\_base} storage functions \footnote{An implementation is free to implement both the integer array pointed at by \texttt{iarray} and the pointer array pointed at by \texttt{parray} as sparse data structures, possibly with a one-element cache for each.}}

\begin{verbatim}
static int xalloc();

    \textit{Returns: index ++.}

long& iword(int \texttt{idx});

    \textit{Effects: If \texttt{iarray} is a null pointer, allocates an array of long of unspecified size and stores a pointer to its first element in \texttt{iarray}. The function then extends the array pointed at by \texttt{iarray} as necessary to include the element \texttt{iarray[\texttt{idx}]]. Each newly allocated element of the array is initialized to zero. The reference returned is invalid after any other operations on the object. However, the value of the storage referred to is retained, so that until the next call to \texttt{copyfmt}, calling \texttt{iword} with the same index yields another reference to the same value. If the function fails and \texttt{*this} is a base subobject of a basic\_ios object or subobject, the effect is equivalent to calling basic\_ios::setstate(badbit) on the derived object (which may throw failure).}

    \textit{Returns: On success \texttt{iarray[\texttt{idx}]. On failure, a valid long& initialized to 0.}

void* & pword(int \texttt{idx});

    \textit{Effects: If \texttt{parray} is a null pointer, allocates an array of pointers to void of unspecified size and stores a pointer to its first element in \texttt{parray}. The function then extends the array pointed at by \texttt{parray} as necessary to include the element \texttt{parray[\texttt{idx}]. Each newly allocated element of the array is initialized to a null pointer. The reference returned is invalid after any other operations on the object. However, the value of the storage referred to is retained, so that until the next call to \texttt{copyfmt}, calling \texttt{pword} with the same index yields another reference to the same value. If the function fails and \texttt{*this} is a base subobject of a basic\_ios object or subobject, the effect is equivalent to calling basic\_ios::setstate(badbit) on the derived object (which may throw failure).}

    \textit{Returns: On success \texttt{parray[\texttt{idx}. On failure a valid void*& initialized to 0.}

Remarks: After a subsequent call to \texttt{pword(int)} for the same object, the earlier return value may no longer be valid.\footnote{for example, because it cannot allocate space.}
\end{verbatim}
27.4 Iostreams base classes

27.4.2.6 ios_base callbacks

```cpp
void register_callback(event_callback fn, int index);
```

**Effects:** Registers the pair \((fn, index)\) such that during calls to `imbue()` (27.4.2.3), `copyfmt()`, or `~ios_base()` (27.4.2.7), the function \(fn\) is called with argument \(index\). Functions registered are called when an event occurs, in opposite order of registration. Functions registered while a callback function is active are not called until the next event.

**Requires:** The function \(fn\) shall not throw exceptions.

**Remarks:** Identical pairs are not merged. A function registered twice will be called twice.

27.4.2.7 ios_base constructors/destructors

```cpp
ios_base();
```

**Effects:** Each `ios_base` member has an indeterminate value after construction. These members shall be initialized by calling `basic_ios::init`. If an `ios_base` object is destroyed before these initializations have taken place, the behavior is undefined.

```cpp
~ios_base()
```

**Effects:** Destroys an object of class `ios_base`. Calls each registered callback pair \((fn, index)\) (27.4.2.6) as \((*fn)(\text{erase\_event}, *this, index)\) at such time that any `ios_base` member function called from within `fn` has well defined results.

27.4.3 Class template fpos

```cpp
namespace std {
    template <class stateT> class fpos {
        public:
            // 27.4.3.1 Members
            stateT state() const;
            void state(stateT);
        private:
            // stateT st;
            };
    }
```

27.4.3.1 fpos Members

```cpp
void state(stateT s);
```

**Effects:** Assign \(s\) to \(st\).

```cpp
stateT state() const;
```

**Returns:** Current value of \(st\).
27.4.3.2 fpos requirements

Operations specified in Table 108 are permitted. In that table,

— P refers to an instance of fpos,
— p and q refer to values of type P,
— O refers to type streamoff,
— o refers to a value of type streamoff,
— sz refers to a value of type streamsize and
— i refers to a value of type int.

Table 108: Position type requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>return type</th>
<th>operational semantics</th>
<th>assertion/note</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(i)</td>
<td>p</td>
<td>p == P(i)</td>
<td>note: a destructor is assumed.</td>
</tr>
<tr>
<td>P p(i);</td>
<td>P p = i;</td>
<td></td>
<td>post: p == P(i).</td>
</tr>
<tr>
<td>P(o)</td>
<td>fpos</td>
<td>converts from offset</td>
<td></td>
</tr>
<tr>
<td>OFF_T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0(p)</td>
<td>OFF_T</td>
<td>converts to offset</td>
<td>P(O(p)) == p</td>
</tr>
<tr>
<td>p == q</td>
<td>convertible to bool</td>
<td></td>
<td>== is an equivalence relation</td>
</tr>
<tr>
<td>p != q</td>
<td>convertible to bool</td>
<td></td>
<td>!(p == q)</td>
</tr>
<tr>
<td>q = p + o</td>
<td>fpos</td>
<td>+ offset</td>
<td>q - o == p</td>
</tr>
<tr>
<td>p += o</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q = p - o</td>
<td>fpos</td>
<td>- offset</td>
<td>q + o == p</td>
</tr>
<tr>
<td>p -= o</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o = p - q</td>
<td>OFF_T</td>
<td>distance</td>
<td>q + o == p</td>
</tr>
<tr>
<td>streamsize(o)</td>
<td>streamsize</td>
<td>converts</td>
<td>streamsize(O(sz)) == sz</td>
</tr>
<tr>
<td>O(sz)</td>
<td>OFF_T</td>
<td>converts</td>
<td>streamsize(O(sz)) == sz</td>
</tr>
</tbody>
</table>

[Note: Every implementation is required to supply overloaded operators on fpos objects to satisfy the requirements of 27.4.3.2. It is unspecified whether these operators are members of fpos, global operators, or provided in some other way. — end note]

Stream operations that return a value of type traits::pos_type return P(O(-1)) as an invalid value to signal an error. If this value is used as an argument to any istream, ostream, or streambuf member that accepts a value of type traits::pos_type then the behavior of that function is undefined.

27.4 Class template basic_ios

namespace std {
    template <class charT, class traits = char_traits<charT> >
class basic_ios : public ios_base {

public:

    // Types:
    typedef charT char_type;
    typedef typename traits::int_type int_type;
    typedef typename traits::pos_type pos_type;
    typedef typename traits::off_type off_type;
    typedef traits traits_type;

    operator unspecified-bool-type() const;
    bool operator!() const;
    iostate rdstate() const;
    void clear(iostate state = goodbit);
    void setstate(iostate state);
    bool good() const;
    bool eof() const;
    bool fail() const;
    bool bad() const;

    iostate exceptions() const;
    void exceptions(iostate except);

    // 27.4.4.1 Constructor/destructor:
    explicit basic_ios(basic_streambuf<charT,traits>** sb);
    virtual ~basic_ios();

    // 27.4.4.2 Members:
    basic_ostream<charT,traits>* tie() const;
    basic_ostream<charT,traits>* tie(basic_ostream<charT,traits>* tiestr);

    basic_streambuf<charT,traits>* rdbuf() const;
    basic_streambuf<charT,traits>* rdbuf(basic_streambuf<charT,traits>* sb);

    basic_ios& copyfmt(const basic_ios& rhs);

    char_type fill() const;
    char_type fill(char_type ch);

    // 27.4.2.3 Locales:
    locale imbue(const locale& loc);

    char narrow(char_type c, char default) const;
    char_type widen(char c) const;

protected:
    basic_ios();
    void init(basic_streambuf<charT,traits>* sb);

private:

    Draft
27.4.4.1 basic_ios constructors

explicit basic_ios(basic_streambuf<charT,traits>* sb);

Effects: Constructs an object of class basic_ios, assigning initial values to its member objects by calling init(sb).

basic_ios();

Effects: Constructs an object of class basic_ios (27.4.2.7) leaving its member objects uninitialized. The object shall be initialized by calling its init member function. If it is destroyed before it has been initialized the behavior is undefined.

~basic_ios();

Remarks: The destructor does not destroy rdbuf().

void init(basic_streambuf<charT,traits>* sb);

Postconditions: The postconditions of this function are indicated in Table 109.

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>rdbuf()</td>
<td>sb</td>
</tr>
<tr>
<td>tie()</td>
<td>0</td>
</tr>
<tr>
<td>rdstate()</td>
<td>goodbit if sb is not a null pointer, otherwise badbit.</td>
</tr>
<tr>
<td>exceptions()</td>
<td>goodbit</td>
</tr>
<tr>
<td>flags()</td>
<td>skipws</td>
</tr>
<tr>
<td>width()</td>
<td>0</td>
</tr>
<tr>
<td>precision()</td>
<td>6</td>
</tr>
<tr>
<td>fill()</td>
<td>widen(' ')</td>
</tr>
<tr>
<td>getloc()</td>
<td>a copy of the value returned by locale()</td>
</tr>
<tr>
<td>iarray</td>
<td>a null pointer</td>
</tr>
<tr>
<td>parray</td>
<td>a null pointer</td>
</tr>
</tbody>
</table>

27.4.4.2 Member functions

basic_ostream<charT,traits>* tie() const;

Returns: An output sequence that is tied to (synchronized with) the sequence controlled by the stream buffer.

basic_ostream<charT,traits>* tie(basic_ostream<charT,traits>* tiestr);
Postcondition: tiestr == tie().

Returns: The previous value of tie().

basic_streambuf<charT, traits>* rdbuf() const;

Returns: A pointer to the streambuf associated with the stream.

basic_streambuf<charT, traits>* rdbuf(basic_streambuf<charT, traits>* sb);

Postcondition: sb == rdbuf().

Effects: Calls clear().

Returns: The previous value of rdbuf().

// 27.4.2.3 locales:
locale imbue(const locale& loc);

Effects: Calls ios_base::imbue(loc) (27.4.2.3) and if rdbuf()! = 0 then rdbuf()->pubimbue(loc) (27.5.2.2.1).

Returns: The prior value of ios_base::imbue().

char narrow(char_type c, char default) const;

Returns: use_facet<ctype<char_type>>(getloc()).narrow(c, default)

char_type widen(char c) const;

Returns: use_facet<ctype<char_type>>(getloc()).widen(c)

char_type fill() const;

Returns: The character used to pad (fill) an output conversion to the specified field width.

char_type fill(char_type fillch);

Postcondition: traits::eq(fillch, fill())

Returns: The previous value of fill().

basic_ios& copyfmt(const basic_ios& rhs);

Effects: If (this == &rhs) does nothing. Otherwise assigns to the member objects of *this the corresponding member objects of rhs, except that:

— rdstate() and rdbuf() are left unchanged;
— exceptions() is altered last by calling exceptions(rhs.except).
— The contents of arrays pointed at by pword and iword are copied not the pointers themselves.\(^{296}\)

If any newly stored pointer values in *this point at objects stored outside the object rhs, and those objects are destroyed when rhs is destroyed, the newly stored pointer values are altered to point at newly constructed copies of the objects.

\(^{296}\) This suggests an infinite amount of copying, but the implementation can keep track of the maximum element of the arrays that is non-zero.
Before copying any parts of \( \text{rhs} \), calls each registered callback pair \((\text{fn}, \text{index})\) as \((\text{fn})(\text{erase}-\text{event}, \ast \text{this}, \text{index})\). After all parts but \text{exceptions()}\ have been replaced, calls each callback pair that was copied from \( \text{rhs} \) as \((\text{fn})(\text{copyfmt}-\text{event}, \ast \text{this}, \text{index})\).

Remarks: The second pass permits a copied \text{pword} value to be zeroed, or its referent deep copied or reference counted or have other special action taken.

Returns: \(* \text{this}\).

### 27.4.4.3 basic_ios flags functions

```
operator unspecified-bool-type() const;
1
   Returns: If \text{fail()}\ then a value that will evaluate false in a boolean context; otherwise a value that will evaluate true in a boolean context. The value type returned shall not be convertible to int.

   [ Note: This conversion can be used in contexts where a \text{bool} is expected (e.g., an \text{if} condition); however, implicit conversions (e.g., to \text{int}) that can occur with \text{bool} are not allowed, eliminating some sources of user error. One possible implementation choice for this type is pointer-to-member. — end note ]

bool operator!() const;
2
   Returns: \text{fail()}.

iostate rdstate() const;
3
   Returns: The error state of the stream buffer.

void clear(iostate state = goodbit);
4
   Postcondition: If \text{rdbuf()}!=0 then \text{state} == \text{rdstate()}; otherwise \text{rdstate()}==(\text{state} | \text{ios_base::badbit}).

   Effects: If \((\text{state} | (\text{rdbuf()} ? \text{goodbit} : \text{badbit}) & \text{exceptions()}) == 0\), returns. Otherwise, the function throws an object \text{fail} of class \text{basic_ios::failure} (27.4.2.1.1), constructed with implementation-defined argument values.

void setstate(iostate state);
5
   Effects: Calls \text{clear} (\text{rdstate()} | \text{state})\,(which may throw \text{basic_ios::failure} (27.4.2.1.1)).

bool good() const;
6
   Returns: \text{rdstate()} == 0

bool eof() const;
7
   Returns: true if \text{eofbit} is set in \text{rdstate()}.

bool fail() const;
8
   Returns: true if \text{failbit} or \text{badbit} is set in \text{rdstate()}.
```

297) Checking \text{badbit} also for \text{fail()} is historical practice.
bool bad() const;
  
  Returns: true if badbit is set in rdstate().

iostate exceptions() const;
  
  Returns: A mask that determines what elements set in rdstate() cause exceptions to be thrown.

void exceptions(iostate except);
  
  Postcondition: except == exceptions().
  
  Effects: Calls clear(rdstate()).

### 27.4.5 ios_base manipulators

#### 27.4.5.1 fmtflags manipulators

```cpp
ios_base& boolalpha(ios_base& str);
  
  Effects: Calls str.setf(ios_base::boolalpha).
  
  Returns: str.

ios_base& noboolalpha(ios_base& str);
  
  Effects: Calls str.unsetf(ios_base::boolalpha).
  
  Returns: str.

ios_base& showbase(ios_base& str);
  
  Effects: Calls str.setf(ios_base::showbase).
  
  Returns: str.

ios_base& noshowbase(ios_base& str);
  
  Effects: Calls str.unsetf(ios_base::showbase).
  
  Returns: str.

ios_base& showpoint(ios_base& str);
  
  Effects: Calls str.setf(ios_base::showpoint).
  
  Returns: str.

ios_base& noshowpoint(ios_base& str);
  
  Effects: Calls str.unsetf(ios_base::showpoint).
  
  Returns: str.

ios_base& showpos(ios_base& str);
```
Effects: Calls `str.setf(ios_base::showpos).`

Returns: `str`.

ios_base& noShowpos(ios_base& str);

Effects: Calls `str.unsetf(ios_base::showpos).`

Returns: `str`.

ios_base& skipws(ios_base& str);

Effects: Calls `str.setf(ios_base::skipws).`

Returns: `str`.

ios_base& noskipws(ios_base& str);

Effects: Calls `str.unsetf(ios_base::skipws).`

Returns: `str`.

ios_base& uppercase(ios_base& str);

Effects: Calls `str.setf(ios_base::uppercase).`

Returns: `str`.

ios_base& nounderline(ios_base& str);

Effects: Calls `str.unsetf(ios_base::uppercase).`

Returns: `str`.

ios_base& unitbuf(ios_base& str);

Effects: Calls `str.setf(ios_base::unitbuf).`

Returns: `str`.

ios_base& nounitbuf(ios_base& str);

Effects: Calls `str.unsetf(ios_base::unitbuf).`

Returns: `str`.

27.4.5.2 adjustfield manipulators

ios_base& internal(ios_base& str);

Effects: Calls `str.setf(ios_base::internal, ios_base::adjustfield).`

Returns: `str`.

ios_base& left(ios_base& str);

Draft
Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {left}, \text{ios\_base}\::\text {adjustfield})).

Returns: \( \text{str} \).

ios\_base& \text{right}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {right}, \text{ios\_base}\::\text {adjustfield})).

Returns: \( \text{str} \).

27.4.5.3 basefield manipulators

ios\_base& \text{dec}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {dec}, \text{ios\_base}\::\text {basefield})).

Returns: \( \text{str} \).

ios\_base& \text{hex}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {hex}, \text{ios\_base}\::\text {basefield})).

Returns: \( \text{str} \).

ios\_base& \text{oct}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {oct}, \text{ios\_base}\::\text {basefield})).

Returns: \( \text{str} \).

27.4.5.4 floatfield manipulators

ios\_base& \text{fixed}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {fixed}, \text{ios\_base}\::\text {floatfield})).

Returns: \( \text{str} \).

ios\_base& \text{scientific}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {scientific}, \text{ios\_base}\::\text {floatfield})).

Returns: \( \text{str} \).

TR1: ios\_base& \text{hexfloat}(ios\_base& \text{str});

Effects: Calls \( \text{str} \). \text{setf}(\text{ios\_base}\::\text {fixed} \mid \text{ios\_base}\::\text {scientific}, \text{ios\_base}\::\text {floatfield})).

Returns: \( \text{str} \).

\text{1298) The function signature \text{dec}(ios\_base\&)} can be called by the function signature \text{basic\_ostream\& stream::operator<<(ios\_base\& (\*)(ios\_base\&))} to permit expressions of the form \text{cout \&} \text{dec} to change the format flags stored in \text{cout}.\n
Draft
Note: The more obvious use of \texttt{ios\_base::hex} to specify hexadecimal floating-point format would change the meaning of existing well defined programs. C++2003 gives no meaning to the combination of \texttt{fixed} and \texttt{scientific}. — end note

\begin{verbatim}
ios_base& defaultfloat(ios_base& str);
\end{verbatim}

\textbf{Effects:} Calls \texttt{str.unsetf(ios\_base::floatfield)}.

\textbf{Returns:} \texttt{str}.

\section{Stream buffers} [lib.stream.buffers]

\subsection*{Synopsis}

\begin{verbatim}
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_streambuf;
    typedef basic_streambuf<char> streambuf;
    typedef basic_streambuf<wchar_t> wstreambuf;
}
\end{verbatim}

The header \texttt{<streambuf>} defines types that control input from and output to \textit{character} sequences.

\subsection{Stream buffer requirements} [lib.streambuf.reqs]

Stream buffers can impose various constraints on the sequences they control. Some constraints are:

\begin{itemize}
    \item The controlled input sequence can be not readable.
    \item The controlled output sequence can be not writable.
    \item The controlled sequences can be associated with the contents of other representations for character sequences, such as external files.
    \item The controlled sequences can support operations directly to or from associated sequences.
    \item The controlled sequences can impose limitations on how the program can read characters from a sequence, write characters to a sequence, put characters back into an input sequence, or alter the stream position.
\end{itemize}

Each sequence is characterized by three pointers which, if non-null, all point into the same \texttt{charT} array object. The array object represents, at any moment, a (sub)sequence of characters from the sequence. Operations performed on a sequence alter the values stored in these pointers, perform reads and writes directly to or from associated sequences, and alter “the stream position” and conversion state as needed to maintain this subsequence relationship. The three pointers are:

\begin{itemize}
    \item the \textit{beginning pointer}, or lowest element address in the array (called \texttt{xbeg} here);
    \item the \textit{next pointer}, or next element address that is a current candidate for reading or writing (called \texttt{xnext} here);
    \item the \textit{end pointer}, or first element address beyond the end of the array (called \texttt{xend} here).
\end{itemize}

The following semantic constraints shall always apply for any set of three pointers for a sequence, using the pointer names given immediately above:
— If \texttt{xnext} is not a null pointer, then \texttt{xbeg} and \texttt{xend} shall also be non-null pointers into the same charT array, as described above; otherwise, \texttt{xbeg} and \texttt{xend} shall also be null.

— If \texttt{xnext} is not a null pointer and \texttt{xnext} < \texttt{xend} for an output sequence, then a \textit{write position} is available. In this case, \texttt{*xnext} shall be assignable as the next element to write (to put, or to store a character value, into the sequence).

— If \texttt{xnext} is not a null pointer and \texttt{xbeg} < \texttt{xnext} for an input sequence, then a \textit{putback position} is available. In this case, \texttt{xnext}[-1] shall have a defined value and is the next (preceding) element to store a character that is put back into the input sequence.

— If \texttt{xnext} is not a null pointer and \texttt{xnext} < \texttt{xend} for an input sequence, then a \textit{read position} is available. In this case, \texttt{*xnext} shall have a defined value and is the next element to read (to get, or to obtain a character value, from the sequence).

### 27.5.2 Class template basic_streambuf<

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_streambuf {
        public:

            // Types:
            typedef charT char_type;
            typedef typename traits::int_type int_type;
            typedef typename traits::pos_type pos_type;
            typedef typename traits::off_type off_type;
            typedef traits traits_type;

            virtual ~basic_streambuf();

            // 27.5.2.2.1 locales:
            locale pubimbue(const locale& loc);
            locale getloc() const;

            // 27.5.2.2.2 buffer and positioning:
            basic_streambuf<char_type,traits>*
            pubsetbuf(char_type* s, streamsize n);
            pos_type pubseekoff(off_type off, ios_base::seekdir way,
                                 ios_base::openmode which =
                                 ios_base::in | ios_base::out);
            pos_type pubseekpos(pos_type sp,
                                ios_base::openmode which =
                                ios_base::in | ios_base::out);
            int pubsync();

            // Get and put areas:
            // 27.5.2.2.3 Get area:
            streamsize in_avail();
            int_type snextc();
```

Draft
int_type sbumpc();
int_type sgetc();
streamsize sgetn(char_type* s, streamsize n);

// 27.5.2.2.4 Putback:
int_type sputbackc(char_type c);
int_type sungetc();

// 27.5.2.2.5 Put area:
int_type sputc(char_type c);
streamsize sputn(const char_type* s, streamsize n);

protected:
    basic_streambuf();

// 27.5.2.3.1 Get area:
    char_type* eback() const;
    char_type* gptr() const;
    char_type* egptr() const;
    void gbump(int n);
    void setg(char_type* gbeg, char_type* gnext, char_type* gend);

// 27.5.2.3.2 Put area:
    char_type* pbase() const;
    char_type* pptr() const;
    char_type* epptr() const;
    void pbump(int n);
    void setp(char_type* pbeg, char_type* pend);

// 27.5.2.4 virtual functions:
// 27.5.2.4.1 Locales:
    virtual void imbue(const locale& loc);

// 27.5.2.4.2 Buffer management and positioning:
    virtual basic_streambuf<char_type,traits>*
        setbuf(char_type* s, streamsize n);
    virtual pos_type seekoff(off_type off, ios_base::seekdir way,
        ios_base::openmode which = ios_base::in | ios_base::out);
    virtual pos_type seekpos(pos_type sp,
        ios_base::openmode which = ios_base::in | ios_base::out);
    virtual int sync();

// 27.5.2.4.3 Get area:
    virtual streamsize showmanyc();
    virtual streamsize xsgetn(char_type* s, streamsize n);
    virtual int_type underflow();
    virtual int_type uflow();

// 27.5.2.4.4 Putback:
    virtual int_type pbackfail(int_type c = traits::eof());
27.5 Stream buffers

The class template `basic_streambuf<charT,traits>` serves as an abstract base class for deriving various stream buffers whose objects each control two character sequences:

- a character input sequence;
- a character output sequence.

[Note: This paragraph is intentionally empty. — end note]

27.5.2.1 basic_streambuf constructors

`basic_streambuf();`

Effects: Constructs an object of class `basic_streambuf<charT,traits>` and initializes:

- all its pointer member objects to null pointers,
- the `getloc()` member to a copy the global locale, `locale()`, at the time of construction.

Remarks: Once the `getloc()` member is initialized, results of calling locale member functions, and of members of facets so obtained, can safely be cached until the next time the member `imbue` is called.

`~basic_streambuf();`

Effects: None.

27.5.2.2 basic_streambuf public member functions

27.5.2.2.1 Locales

`locale pubimbue(const locale& loc);`

Postcondition: `loc == getloc()`.

Effects: Calls `imbue(loc)`.

Returns: Previous value of `getloc()`.

`locale getloc() const;`

299) The default constructor is protected for class `basic_streambuf` to assure that only objects for classes derived from this class may be constructed.
Returns: If `pubimbue()` has ever been called, then the last value of `loc` supplied, otherwise the current global locale, `locale()`, in effect at the time of construction. If called after `pubimbue()` has been called but before `pubimbue` has returned (i.e. from within the call of `imbue()`) then it returns the previous value.

### 27.5.2.2.2 Buffer management and positioning

```cpp
basic_streambuf<char_type,traits>* pubsetbuf(char_type* s, streamsize n);
```

Returns: `setbuf(s, n)`.

```cpp
pos_type pubseekoff(off_type off, ios_base::seekdir way,
                    ios_base::openmode which = ios_base::in | ios_base::out);
```

Returns: `seekoff(off, way, which)`.

```cpp
pos_type pubseekpos(pos_type sp,
                    ios_base::openmode which = ios_base::in | ios_base::out);
```

Returns: `seekpos(sp, which)`.

```cpp
int pubsync();
```

Returns: `sync()`.

### 27.5.2.2.3 Get area

```cpp
streamsize in_avail();
```

Returns: If a read position is available, returns `egptr() - gptr()`. Otherwise returns `showmanyc()` (27.5.2.4.3).

```cpp
int_type snextc();
```

Effects: Calls `sbumpc()`.

Returns: If that function returns `traits::eof()`, returns `traits::eof()`. Otherwise, returns `sgetc()`.

```cpp
int_type sbumpc();
```

Returns: If the input sequence read position is not available, returns `uflow()`. Otherwise, returns `traits::to_int_type(*gptr())` and increments the next pointer for the input sequence.

```cpp
int_type sgetc();
```

Returns: If the input sequence read position is not available, returns `underflow()`. Otherwise, returns `traits::to_int_type(*gptr())`.

```cpp
streamsize sgetn(char_type* s, streamsize n);
```

Returns: `xsgetn(s, n)`.

Draft
27.5 Stream buffers

27.5.2.2.4 Putback

int_type sputbackc(char_type c);

1 Returns: If the input sequence putback position is not available, or if traits::eq(c, gptr()[−1]) is false, returns pbackfail(traits::to_int_type(c)). Otherwise, decrements the next pointer for the input sequence and returns traits::to_int_type(*gptr()).

int_type sungetc();

2 Returns: If the input sequence putback position is not available, returns pbackfail(). Otherwise, decrements the next pointer for the input sequence and returns traits::to_int_type(*gptr()).

27.5.2.2.5 Put area

int_type sputc(char_type c);

1 Returns: If the output sequence write position is not available, returns overflow(traits::to_int_type(c)). Otherwise, stores c at the next pointer for the output sequence, increments the pointer, and returns traits::to_int_type(c).

streamsize sputn(const char_type* s, streamsize n);

2 Returns: xsputn(s, n).

27.5.2.3 basic_streambuf protected member functions

27.5.2.3.1 Get area access

char_type* eback() const;

1 Returns: The beginning pointer for the input sequence.

char_type* gptr() const;

2 Returns: The next pointer for the input sequence.

char_type* egptr() const;

3 Returns: The end pointer for the input sequence.

void gbump(int n);

4 Effects: Adds n to the next pointer for the input sequence.

void setg(char_type* gbeg, char_type* gnext, char_type* gend);

5 Postconditions: gbeg == eback(), gnext == gptr(), and gend == egptr.
### 27.5.2.3.2 Put area access

char_type* pbase() const;

*Returns:* The beginning pointer for the output sequence.

char_type* pptr() const;

*Returns:* The next pointer for the output sequence.

char_type* epptr() const;

*Returns:* The end pointer for the output sequence.

void pbump(int n);

*Effects:* Adds n to the next pointer for the output sequence.

void setp(char_type* pbeg, char_type* pend);

*Postconditions:* pbeg == pbase(), pbeg == pptr(), and pend == epptr().

### 27.5.2.4 basic_streambuf virtual functions

#### 27.5.2.4.1 Locales

void imbue(const locale&);

*Effects:* Change any translations based on locale.

*Remarks:* Allows the derived class to be informed of changes in locale at the time they occur. Between invocations of this function a class derived from streambuf can safely cache results of calls to locale functions and to members of facets so obtained.

*Default behavior:* Does nothing.

#### 27.5.2.4.2 Buffer management and positioning

basic_streambuf* setbuf(char_type* s, streamsize n);

*Effects:* Influences stream buffering in a way that is defined separately for each class derived from basic_streambuf in this clause (27.7.1.3, 27.8.1.4).

*Default behavior:* Does nothing. Returns this.

pos_type seekoff(off_type off, ios_base::seekdir way, ios_base::openmode which = ios_base::in | ios_base::out);

*Effects:* Alters the stream positions within one or more of the controlled sequences in a way that is defined separately for each class derived from basic_streambuf in this clause (27.7.1.3, 27.8.1.4).

*Default behavior:* Returns pos_type(off_type(-1)).
pos_type seekpos(pos_type sp,
    ios_base::openmode which
  = ios_base::in | ios_base::out);

Effects: Alters the stream positions within one or more of the controlled sequences in a way that is defined separately for each class derived from basic_streambuf in this clause (27.7.1, 27.8.1.1).

Default behavior: Returns pos_type(off_type(-1)).

int sync();

Effects: Synchronizes the controlled sequences with the arrays. That is, if pbase() is non-null the characters between pbase() and pptr() are written to the controlled sequence. The pointers may then be reset as appropriate.

Returns: -1 on failure. What constitutes failure is determined by each derived class (27.8.1.4).

Default behavior: Returns zero.

27.5.2.4.3 Get area

streamsize showmanyc();

Returns: an estimate of the number of characters available in the sequence, or -1. If it returns a positive value, then successive calls to underflow() will not return traits::eof() until at least that number of characters have been extracted from the stream. If showmanyc() returns -1, then calls to underflow() or uflow() will fail.

Default behavior: Returns zero.

Remarks: Uses traits::eof().

streamsize xsgetn(char_type* s, streamsize n);

Effects: Assigns up to \( n \) characters to successive elements of the array whose first element is designated by \( s \). The characters assigned are read from the input sequence as if by repeated calls to sbumpc(). Assigning stops when either \( n \) characters have been assigned or a call to sbumpc() would return traits::eof().

Returns: The number of characters assigned.

Remarks: Uses traits::eof().

int_type underflow();

Remarks: The public members of basic_streambuf call this virtual function only if gptr() is null or gptr() \( \geq \) egptr().
8 Returns: traits::to_int_type(c), where c is the first character of the pending sequence, without moving the input sequence position past it. If the pending sequence is null then the function returns traits::eof() to indicate failure.

9 The pending sequence of characters is defined as the concatenation of:
   a) If gptr() is non-NULL, then the egptr() - gptr() characters starting at gptr(), otherwise the empty sequence.
   b) Some sequence (possibly empty) of characters read from the input sequence.

10 The result character is
    a) If the pending sequence is non-empty, the first character of the sequence.
    b) If the pending sequence is empty then the next character that would be read from the input sequence.

11 The backup sequence is defined as the concatenation of:
    a) If eback() is null then empty,
    b) Otherwise the gptr() - eback() characters beginning at eback().

12 Effects: The function sets up the gptr() and egptr() satisfying one of:
    a) If the pending sequence is non-empty, egptr() is non-null and egptr() - gptr() characters starting at gptr() are the characters in the pending sequence
    b) If the pending sequence is empty, either gptr() is null or gptr() and egptr() are set to the same non-NULL pointer.

13 If eback() and gptr() are non-null then the function is not constrained as to their contents, but the “usual backup condition” is that either:
    a) If the backup sequence contains at least gptr() - eback() characters, then the gptr() - eback() characters starting at eback() agree with the last gptr() - eback() characters of the backup sequence.
    b) Or the n characters starting at gptr() - n agree with the backup sequence (where n is the length of the backup sequence)

14 Default behavior: Returns traits::eof().

int_type uflow();

15 Requires: The constraints are the same as for underflow(), except that the result character is transferred from the pending sequence to the backup sequence, and the pending sequence may not be empty before the transfer.

16 Default behavior: Calls underflow(). If underflow() returns traits::eof(), returns traits::eof(). Otherwise, returns the value of traits::to_int_type(*gptr()) and increment the value of the next pointer for the input sequence.

17 Returns: traits::eof() to indicate failure.
27.5 Stream buffers

27.5.2.4.4 Putback

’int_type pbackfail(int_type c = traits::eof());

Remarks: The public functions of basic_streambuf call this virtual function only when gptr() is null, gptr() == eback(), or traits::eq(traits::to_char_type(c),gptr()[-1]) returns false. Other calls shall also satisfy that constraint.

The pending sequence is defined as for underflow(), with the modifications that

— If traits::eq_int_type(c,traits::eof()) returns true, then the input sequence is backed up one character before the pending sequence is determined.

— If traits::eq_int_type(c,traits::eof()) return false, then c is prepended. Whether the input sequence is backed up or modified in any other way is unspecified.

Postcondition: On return, the constraints of gptr(), eback(), and pptr() are the same as for underflow().

Returns: traits::eof() to indicate failure. Failure may occur because the input sequence could not be backed up, or if for some other reason the pointers could not be set consistent with the constraints. pbackfail() is called only when put back has really failed.

Returns some value other than traits::eof() to indicate success.

Default behavior: Returns traits::eof().

27.5.2.4.5 Put area

’strreamsize xsputn(const char_type* s, streamsize n);

Effects: Writes up to n characters to the output sequence as if by repeated calls to sputc(c). The characters written are obtained from successive elements of the array whose first element is designated by s. Writing stops when either n characters have been written or a call to sputc(c) would return traits::eof().

Returns: The number of characters written.

’int_type overflow(int_type c = traits::eof());

Effects: Consumes some initial subsequence of the characters of the pending sequence. The pending sequence is defined as the concatenation of

a) if pbase() is NULL then the empty sequence otherwise, pptr() – pbase() characters beginning at pbase().

b) if traits::eq_int_type(c,traits::eof()) returns true, then the empty sequence otherwise, the sequence consisting of c.

Remarks: The member functions sputc() and sputn() call this function in case that no room can be found in the put buffer enough to accomodate the argument character sequence.

Requires: Every overriding definition of this virtual function shall obey the following constraints:
The effect of consuming a character on the associated output sequence is specified.

Let \( r \) be the number of characters in the pending sequence not consumed. If \( r \) is non-zero then \( \text{pbase()} \) and \( \text{pptr()} \) shall be set so that: \( \text{pptr()} - \text{pbase()} = r \) and the \( r \) characters starting at \( \text{pbase()} \) are the associated output stream. In case \( r \) is zero (all characters of the pending sequence have been consumed) then either \( \text{pbase()} \) is set to \( \text{NULL} \), or \( \text{pbase()} \) and \( \text{pptr()} \) are both set to the same \( \text{NULL} \) non-value.

The function may fail if either appending some character to the associated output stream fails or if it is unable to establish \( \text{pbase()} \) and \( \text{pptr()} \) according to the above rules.

Returns: \( \text{traits::eof()} \) or throws an exception if the function fails. Otherwise, returns some value other than \( \text{traits::eof()} \) to indicate success.

Default behavior: Returns \( \text{traits::eof()} \).

### 27.6 Formatting and manipulators

#### Header `<istream>` synopsis

```c
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_istream;
    typedef basic_istream<char> istream;
    typedef basic_istream<wchar_t> wistream;

    template <class charT, class traits = char_traits<charT> >
    class basic_iostream;
    typedef basic_iostream<char> iostream;
    typedef basic_iostream<wchar_t> wiostream;

    template <class charT, class traits>
    basic_istream<charT,traits>& ws(basic_istream<charT,traits>& is);
}
```

#### Header `<ostream>` synopsis

```c
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_ostream;
    typedef basic_ostream<char> ostream;
    typedef basic_ostream<wchar_t> wostream;

    template <class charT, class traits>
    basic_ostream<charT,traits>& endl(basic_ostream<charT,traits>& os);
    template <class charT, class traits>
    basic_ostream<charT,traits>& ends(basic_ostream<charT,traits>& os);
}
```

303) That is, for each class derived from an instance of `basic_streambuf` in this clause (27.7.1, 27.8.1.1), a specification of how consuming a character effects the associated output sequence is given. There is no requirement on a program-defined class.

304) Typically, `overflow` returns \( c \) to indicate success, except when `traits::eq_int_type(c,traits::eof())` returns `true`, in which case it returns `traits::not_eof(c)`.

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template <class charT, class traits>
    basic_ostream<charT,traits>& flush(basic_ostream<charT,traits>& os);
}

Header <iomanip> synopsis

namespace std {
    // Types T1, T2, ... are unspecified implementation types
    T1 resetiosflags(ios_base::fmtflags mask);
    T2 setiosflags (ios_base::fmtflags mask);
    T3 setbase(int base);
    template<charT> T4 setfill(charT c);
    T5 setprecision(int n);
    T6 setw(int n);
}

27.6.1 Input streams [lib.input.streams]

1 The header <istream> defines two types and a function signature that control input from a stream buffer.

27.6.1.1 Class template basic_istream [lib.istream]

namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_istream : virtual public basic_ios<charT,traits> { 

public:
    // Types (inherited from basic_ios (27.4.4)):
    typedef charT char_type;
    typedef typename traits::int_type int_type;
    typedef typename traits::pos_type pos_type;
    typedef typename traits::off_type off_type;
    typedef traits traits_type;

    // 27.6.1.1.1 Constructor/destructor:
    explicit basic_istream(basic_streambuf<charT,traits>* sb);
    virtual ~basic_istream();

    // 27.6.1.1.2 Prefix/suffix:
    class sentry;

    // 27.6.1.2 Formatted input:
    basic_istream<charT,traits>& operator>>(
        (basic_istream<charT,traits>& (*pf)(basic_istream<charT,traits>&&));
    basic_istream<charT,traits>& operator>>(
        (basic_ios<charT,traits>& (*pf)(basic_istream<charT,traits>&&));
    basic_istream<charT,traits>& operator>>(
        (ios_base& (*pf)(ios_base&));

    basic_istream<charT,traits>& operator>>(bool& n);
    basic_istream<charT,traits>& operator>>(short& n);
    basic_istream<charT,traits>& operator>>(unsigned short& n);

Draft
basic_istream<char,traits>& operator>>(int& n);
basic_istream<char,traits>& operator>>(unsigned int& n);
basic_istream<char,traits>& operator>>(long& n);
basic_istream<char,traits>& operator>>(unsigned long& n);
basic_istream<char,traits>& operator>>(float& f);
basic_istream<char,traits>& operator>>(double& f);
basic_istream<char,traits>& operator>>(long double& f);
basic_istream<char,traits>& operator>>(void*& p);
basic_istream<char,traits>& operator>>(basic_streambuf<char_type,traits>* sb);

// 27.6.1.3 Unformatted input:
streamsize gcount() const;
int_type get();
basic_istream<char,traits>& & get(char_type c);
basic_istream<char,traits>& & get(char_type s, streamsize n,
char_type delim);
basic_istream<char,traits>& & get(basic_streambuf<char_type,traits>& sb);
basic_istream<char,traits>& & get(basic_streambuf<char_type,traits>& sb,
char_type delim);

basic_istream<char,traits>& & getline(char_type* s, streamsize n,
char_type delim);
basic_istream<char,traits>& & getline(char_type* s, streamsize n,
char_type delim);

basic_istream<char,traits>& & ignore
(streamsize n = 1, int_type delim = traits::eof());
int_type peek();
basic_istream<char,traits>& & read (char_type* s, streamsize n);
streamsize readsome(char_type* s, streamsize n);

basic_istream<char,traits>& & putback(char_type c);
basic_istream<char,traits>& & unget();
int sync();

pos_type tellg();
basic_istream<char,traits>& & seekg(pos_type);
basic_istream<char,traits>& & seekg(off_type, ios_base::seekdir);
};

// 27.6.1.3.2 character extraction templates:
template<class charT, class traits>
basic_istream<charT,traits>& & operator>>(basic_istream<charT,traits>&, charT&);
template<class traits>
basic_istream<char,traits>& & operator>>(basic_istream<char,traits>&,
unsigned char&);
template<class traits>
The class `basic_istream` defines a number of member function signatures that assist in reading and interpreting input from sequences controlled by a stream buffer.

Two groups of member function signatures share common properties: the formatted input functions (or extractors) and the unformatted input functions. Both groups of input functions are described as if they obtain (or extract) input characters by calling `rdbuf()->sbumpc()` or `rdbuf()->sgetc()`. They may use other public members of `istream`.

If `rdbuf()->sbumpc()` or `rdbuf()->sgetc()` returns `traits::eof()`, then the input function, except as explicitly noted otherwise, completes its actions and sets `setstate(eofbit)`, which may throw `ios_base::failure` (27.4.4.3), before returning.

If one of these called functions throws an exception, then unless explicitly noted otherwise, the input function sets badbit in error state. If badbit is on in `exceptions()`, the input function rethrows the exception without completing its actions, otherwise it does not throw anything and proceeds as if the called function had returned a failure indication.

### 27.6.1.1.1 `basic_istream` constructors

[lib.istream.cons]

```cpp
explicit basic_istream(basic_streambuf<charT,traits>** sb);
```

**Effects:** Constructs an object of class `basic_istream`, assigning initial values to the base class by calling `basic_ios::init(sb)` (27.4.4.1).

**Postcondition:** `gcount() == 0`

```cpp
virtual ~basic_istream();
```

**Effects:** Destroys an object of class `basic_istream`.

**Remarks:** Does not perform any operations of `rdbuf()`.

### 27.6.1.1.2 Class `basic_istream::sentry`

[lib.istream::sentry]

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_istream<charT,traits>::sentry {
        typedef traits traits_type;
        // bool ok_;
    } // exposition only
}
```
The class `sentry` defines a class that is responsible for doing exception safe prefix and suffix operations.

```cpp
explicit sentry(basic_istream<charT,traits>& is, bool noskipws = false);

Effects: If `is.good()` is `true`, prepares for formatted or unformatted input. First, if `is.tie()` is not a null pointer, the function calls `is.tie()->flush()` to synchronize the output sequence with any associated external C stream. Except that this call can be suppressed if the put area of `is.tie()` is empty. Further an implementation is allowed to defer the call to `flush` until a call of `is->rdbuf()->underflow` occurs. If no such call occurs before the `sentry` object is destroyed, the call to `flush` may be eliminated entirely. If `noskipws` is zero and `is.flags() & ios_base::skipws` is nonzero, the function extracts and discards each character as long as the next available input character `c` is a whitespace character. If `is.rdbuf()->sgetc()` returns `traits::eof()`, the function calls `setstate(failbit | eofbit)` (which may throw `ios_base::failure`).

Remarks: The constructor `explicit sentry(basic_istream<charT,traits>& is, bool noskipws = false)` uses the currently imbued locale in `is`, to determine whether the next input character is whitespace or not.

To decide if the character `c` is a whitespace character, the constructor performs “as if” it executes the following code fragment:

```cpp
const ctype<charT>& ctype = use_facet<ctype<charT>>(is.getloc());
if (ctype.is(ctype.space, c)!=0)
    // `c` is a whitespace character.
```

If, after any preparation is completed, `is.good()` is `true`, `ok_` is `false` otherwise, `ok_` is `false`. During preparation, the constructor may call `setstate(failbit)` (which may throw `ios_base::failure(27.4.4.3)`).

[Note: This paragraph is intentionally empty. —end note]

```
sentry();
```

Effects: None.

```cpp
operator bool() const;
```

Effects: Returns `ok_`.  

---

305) This will be possible only in functions that are part of the library. The semantics of the constructor used in user code is as specified.

306) The `sentry` constructor and destructor can also perform additional implementation-dependent operations.
Each formatted input function begins execution by constructing an object of class `sentry` with the `noskipws` (second) argument `false`. If the `sentry` object returns `true`, when converted to a value of type `bool`, the function endeavors to obtain the requested input. If an exception is thrown during input then `ios::badbit` is turned on\(^{307}\) in `*this`'s error state. If \((\text{exceptions() \& \text{badbit}) \neq 0}\) then the exception is rethrown. In any case, the formatted input function destroys the `sentry` object. If no exception has been thrown, it returns `*this`.

As in the case of the inserters, these extractors depend on the locale’s `num_get<>` (22.2.2.1) object to perform parsing the input stream data. These extractors behave as formatted input functions (as described in 27.6.1.2.1). After a `sentry` object is constructed, the conversion occurs as if performed by the following code fragment:

\[
\begin{align*}
\text{typedef num_get< charT,istreambuf_iterator<charT,traits> > numget;}
\text{iostate err = 0;}
\text{use_facet< numget >(loc).get(*this, 0, *this, err, val);}
\text{setstate(err);}
\end{align*}
\]

In the above fragment, `loc` stands for the private member of the `basic_ios` class. [Note: The first argument provides an object of the `istreambuf_iterator` class which is an iterator pointed to an input stream. It bypasses istreams and uses streambufs directly. — end note] Class `locale` relies on this type as its interface to `iostream`, so that it does not need to depend directly on `istream`.

The conversion occurs as if performed by the following code fragment (using the same notation as for the preceding code fragment):

\[
\begin{align*}
\text{typedef num_get< charT,istreambuf_iterator<charT,traits> > numget;}
\text{iostate err = 0;}
\text{long lval;}
\text{use_facet<numget>(loc).get(*this, 0, *this, err, lval);}
\text{if (err == 0)}
\text{  \&\& (lval < numeric_limits<short>::min())}
\text{      \| (numeric_limits<short>::max() < lval))}
\text{  err = ios_base::failbit;}
\text{setstate(err);}
\end{align*}
\]

\(^{307}\) This is done without causing an `ios::failure` to be thrown.
The conversion occurs as if performed by the following code fragment (using the same notation as for the preceding code fragment):

```cpp
typedef num_get<charT, istreambuf_iterator<charT, traits>> numget;
iosstate err = 0;
long lval;
use_facet<numget>(loc).get(*this, 0, *this, err, lval);
if (err == 0)
    && (lval < numeric_limits<int>::min()
        || numeric_limits<int>::max() < lval))
    err = ios_base::failbit;
setstate(err);
```

### 27.6.1.2.3 `basic_istream::operator>>`

`basic_istream<charT, traits>& operator>>(basic_istream<charT, traits>& (*pf)(basic_istream<charT, traits>&&))`

**Effects:** None. This extractor does not behave as a formatted input function (as described in 27.6.1.2.1.)

**Returns:** `pf(*this).` \(^{308}\)

`basic_istream<charT, traits>& operator>>(basic_istream<charT, traits>& (*pf)(basic_istream<charT, traits>&&));`

**Effects:** Calls `pf(*this).` This extractor does not behave as a formatted input function (as described in 27.6.1.2.1).  

**Returns:** `*this.`

`basic_istream<charT, traits>& operator>>(ios_base& (*pf)(ios_base&));`

**Effects:** Calls `pf(*this).` \(^{309}\) This extractor does not behave as a formatted input function (as described in 27.6.1.2.1).  

**Returns:** `*this.`

```cpp
template<class charT, class traits>
    basic_istream<charT, traits>& operator>>(basic_istream<charT, traits>& in, charT* s);
```

```cpp
template<class traits>
    basic_istream<char, traits>& operator>>(basic_istream<char, traits>& in, unsigned char* s);
```

```cpp
template<class traits>
    basic_istream<char, traits>& operator>>(basic_istream<char, traits>& in, signed char* s);
```

\(^{308}\) See, for example, the function signature `ws(basic_istream&)` (27.6.1.4).

\(^{309}\) See, for example, the function signature `dec(ios_base&)` (27.4.5.3).
Effects: Behaves like a formatted input member (as described in 27.6.1.2.1) of \texttt{in}. After a sentry object is constructed, \texttt{operator>>} extracts characters and stores them into successive locations of an array whose first element is designated by \texttt{s}. If width() is greater than zero, \( n \) is width(). Otherwise \( n \) is the number of elements of the largest array of char\_type that can store a terminating char\_T(). \( n \) is the maximum number of characters stored.

Characters are extracted and stored until any of the following occurs:

- \( n-1 \) characters are stored;
- end of file occurs on the input sequence;
- \texttt{ct.is(ct.space,c)} is true for the next available input character \( c \), where \texttt{ct} is \texttt{use_facet<ctype<charT>}>\texttt{(in.getloc())}.

\texttt{operator>>} then stores a null byte (char\_T()) in the next position, which may be the first position if no characters were extracted. \texttt{operator>>} then calls \texttt{width(0)}.

If the function extracted no characters, it calls \texttt{setstate(failbit)}, which may throw \texttt{ios_base::failure} (27.4.4.3).

Returns: \texttt{in}.

\begin{verbatim}
template<class charT, class traits>
basic_istream<charT,traits>& operator>>(basic_istream<charT,traits>& \texttt{in},
char\& \texttt{c});
\end{verbatim}

Effects: Behaves like a formatted input member (as described in 27.6.1.2.1) of \texttt{in}. After a sentry object is constructed a character is extracted from \texttt{in}, if one is available, and stored in \texttt{c}. Otherwise, the function calls \texttt{in.setstate(failbit)}.

Returns: \texttt{in}.

\begin{verbatim}
basic_istream<charT,traits>& operator>>(
(basic_streambuf<charT,traits>* \texttt{sb});
\end{verbatim}

Effects: Behaves as a formatted input function (as described in 27.6.1.2.1). If \texttt{sb} is null, calls \texttt{setstate(failbit)}, which may throw \texttt{ios_base::failure} (27.4.4.3). After a sentry object is constructed, extracts characters from \*\texttt{this} and inserts them in the output sequence controlled by \texttt{sb}. Characters are extracted and inserted until any of the following occurs:

- end-of-file occurs on the input sequence;
- inserting in the output sequence fails (in which case the character to be inserted is not extracted);
- an exception occurs (in which case the exception is caught).
If the function inserts no characters, it calls `setstate(failbit)`, which may throw `ios_base::failure` (27.4.4.3). If it inserted no characters because it caught an exception thrown while extracting characters from `*this` and `failbit` is on in `exceptions()` (27.4.4.3), then the caught exception is rethrown.

**Returns:** `*this`.

### 27.6.1.3 Unformatted input functions

Each unformatted input function begins execution by constructing an object of class `sentry` with the default argument `noskipws` (second) argument `true`. If the `sentry` object returns `true`, when converted to a value of type `bool`, the function endeavors to obtain the requested input. Otherwise, if the `sentry` constructor exits by throwing an exception or if the `sentry` object returns false, when converted to a value of type `bool`, the function returns without attempting to obtain any input. In either case the number of extracted characters is set to 0; unformatted input functions taking a character array of non-zero size as an argument shall also store a null character (using `charT()`) in the first location of the array. If an exception is thrown during input then `ios::badbit` is turned on\(^{310}\) in `*this`'s error state. (Exceptions thrown from `basic_ios<>::clear()` are not caught or rethrown.) If `(exceptions()&badbit) != 0` then the exception is rethrown. It also counts the number of characters extracted. If no exception has been thrown it ends by storing the count in a member object and returning the value specified. In any event the `sentry` object is destroyed before leaving the unformatted input function.

```
streamsize gcount() const;
```

**Effects:** None. This member function does not behave as an unformatted input function (as described in 27.6.1.3, paragraph 1).

**Returns:** The number of characters extracted by the last unformatted input member function called for the object.

```
int_type get();
```

**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a `sentry` object, extracts a character `c`, if one is available. Otherwise, the function calls `setstate(failbit)`, which may throw `ios_base::failure` (27.4.4.3).

**Returns:** `c` if available, otherwise `traits::eof()`.

```
basic_istream<charT,traits>& get(char_type& c);
```

**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a `sentry` object, extracts a character, if one is available, and assigns it to `c`.\(^{311}\) Otherwise, the function calls `setstate(failbit)` (which may throw `ios_base::failure` (27.4.4.3)).

**Returns:** `*this`.

```
basic_istream<charT,traits>& get(char_type* s, streamsize n, char_type delim);
```

**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a `sentry` object, extracts characters and stores them into successive locations of an array whose first element is

---

\(^{310}\) This is done without causing an `ios::failure` to be thrown.

\(^{311}\) Note that this function is not overloaded on types `signed char` and `unsigned char`.  

Draft
27.6 Formatting and manipulators

Input/output library

Designated by s.\textsuperscript{312} Characters are extracted and stored until any of the following occurs:

- \( n - 1 \) characters are stored;
- end-of-file occurs on the input sequence (in which case the function calls \texttt{setstate(eofbit)});
- \texttt{traits::eq(c, delim)} for the next available input character \( c \) (in which case \( c \) is not extracted).

If the function stores no characters, it calls \texttt{setstate(failbit)} (which may throw \texttt{ios_base::failure} (27.4.4.3)). In any case, it then stores a null character into the next successive location of the array.

Returns: \*this.

```
basic_istream<charT,traits>& get(char_type* s, streamsize n)
```

Effects: Calls \texttt{get(s, n, widen(’\n’))}

Returns: Value returned by the call.

```
basic_istream<charT,traits>& get(basic_streambuf<char_type,traits>& sb, char_type delim);
```

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, extracts characters and inserts them in the output sequence controlled by \( sb \). Characters are extracted and inserted until any of the following occurs:

- end-of-file occurs on the input sequence;
- inserting in the output sequence fails (in which case the character to be inserted is not extracted);
- \texttt{traits::eq(c, delim)} for the next available input character \( c \) (in which case \( c \) is not extracted);
- an exception occurs (in which case, the exception is caught but not rethrown).

If the function inserts no characters, it calls \texttt{setstate(failbit)}, which may throw \texttt{ios_base::failure} (27.4.4.3).

Returns: \*this.

```
basic_istream<charT,traits>& get(basic_streambuf<char_type,traits>& sb);
```

Effects: Calls \texttt{get(sb, widen(’\n’))}

Returns: Value returned by the call.

```
basic_istream<charT,traits>& getline(char_type* s, streamsize n, char_type delim);
```

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, extracts characters and stores them into successive locations of an array whose first element is designated by \( s \).\textsuperscript{313} Characters are extracted and stored until one of the following occurs:

1. end-of-file occurs on the input sequence (in which case the function calls \texttt{setstate(eofbit)});

\textsuperscript{312} Note that this function is not overloaded on types \texttt{signed char} and \texttt{unsigned char}.

\textsuperscript{313} Note that this function is not overloaded on types \texttt{signed char} and \texttt{unsigned char}.

Draft
2. \texttt{traits::eq(c, delim)} for the next available input character \(c\) (in which case the input character is extracted but not stored);\(^{314}\)

3. \(n - 1\) characters are stored (in which case the function calls \texttt{setstate(failbit)}).

These conditions are tested in the order shown.\(^{315}\)

If the function extracts no characters, it calls \texttt{setstate(failbit)} (which may throw \texttt{ios\_base::failure (27.4.4.3))}.\(^{316}\)

In any case, it then stores a null character (using \texttt{charT()}) into the next successive location of the array.

\textbf{Returns:} \*this.

\[\text{Example:}\]

\begin{verbatim}
#include <iostream>

int main()
{
    using namespace std;
    const int line_buffer_size = 100;

    char buffer[line_buffer_size];
    int line_number = 0;
    while (cin.getline(buffer, line_buffer_size, '\n') || cin.gcount()) {
        int count = cin.gcount();
        if (cin.eof())
            cout << "Partial final line";  // cin.fail() is false
        else if (cin.fail()) {
            cout << "Partial long line";
            cin.clear(cin.rdstate() & ~ios::failbit);
        } else {
            count--;
            // Don’t include newline in count
            cout << "Line 
" << ++line_number;
        }
        cout << "(" << count << " chars): " << buffer << endl;
    }
}
\end{verbatim}

\[\text{— end example}\]

\texttt{basic\_istream\langle charT, traits\rangle\& getline(char\_type* s, streamsize n);}\(^{24}\)

\textbf{Returns:} getline(s, n, widen(’\n’))

\texttt{basic\_istream\langle charT, traits\rangle\& ignore(streamsize n = 1, int\_type delim = traits::eof());}\(^{24}\)

\(^{314}\) Since the final input character is “extracted,” it is counted in the \texttt{gcount()}, even though it is not stored.

\(^{315}\) This allows an input line which exactly fills the buffer, without setting \texttt{failbit}. This is different behavior than the historical AT&T implementation.

\(^{316}\) This implies an empty input line will not cause \texttt{failbit} to be set.
**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, extracts characters and discards them. Characters are extracted until any of the following occurs:

- if `n != numeric_limits<streamsize>::max()` (18.2.1), `n` characters are extracted
- end-of-file occurs on the input sequence (in which case the function calls `setstate(eofbit)`, which may throw `ios_base::failure` (27.4.4.3));
- `traits::eq_int_type(traits::to_int_type(c), delim)` for the next available input character `c` (in which case `c` is extracted).

**Remarks:** The last condition will never occur if `traits::eq_int_type(delim, traits::eof())`.

**Returns:** *this.

```cpp
int_type peek();
```

**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, reads but does not extract the current input character.

**Returns:** `traits::eof()` if `good()` is false. Otherwise, returns `rdbuf()->sgetc()`.

```cpp
basic_istream<charT,traits>& read(char_type* s, streamsize n);
```

**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, if `!good()` calls `setstate(failbit)` which may throw an exception, and return. Otherwise extracts characters and stores them into successive locations of an array whose first element is designated by `s`. Characters are extracted and stored until either of the following occurs:

- `n` characters are stored;
- end-of-file occurs on the input sequence (in which case the function calls `setstate(failbit|eofbit)`, which may throw `ios_base::failure` (27.4.4.3)).

**Returns:** *this.

```cpp
streamsize readsome(char_type* s, streamsize n);
```

**Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, if `!good()` calls `setstate(failbit)` which may throw an exception, and return. Otherwise extracts characters and stores them into successive locations of an array whose first element is designated by `s`. If `rdbuf()->in_avail() == -1`, calls `setstate(eofbit)` (which may throw `ios_base::failure` (27.4.4.3)), and extracts no characters;

- If `rdbuf()->in_avail() == 0`, extracts no characters
- If `rdbuf()->in_avail() > 0`, extracts `min(rdbuf()->in_avail(), n)`.

**Returns:** The number of characters extracted.

```cpp
basic_istream<charT,traits>& putback(char_type c);
```

\[^{17}]\text{Note that this function is not overloaded on types \texttt{signed char} and \texttt{unsigned char}.\]
Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, if !good() calls setstate(failbit) which may throw an exception, and return. If rdbuf() is not null, calls rdbuf->sputbackc(). If rdbuf() is null, or if sputbackc() returns traits::eof(), calls setstate(badbit) (which may throw ios_base::failure (27.4.4.3)). [Note: this function extracts no characters, so the value returned by the next call to gcount() is 0. — end note]

Returns: *this.

basic_istream<charT,traits>& unget();

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1). After constructing a sentry object, if !good() calls setstate(failbit) which may throw an exception, and return. If rdbuf() is not null, calls rdbuf()->sungetc(). If rdbuf() is null, or if sungetc() returns traits::eof(), calls setstate(badbit) (which may throw ios_base::failure (27.4.4.3)). [Note: this function extracts no characters, so the value returned by the next call to gcount() is 0. — end note]

Returns: *this.

int sync();

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1), except that it does not count the number of characters extracted and does not affect the value returned by subsequent calls to gcount(). After constructing a sentry object, if rdbuf() is a null pointer, returns -1. Otherwise, calls rdbuf()->pubsync() and, if that function returns -1 calls setstate(badbit) (which may throw ios_base::failure (27.4.4.3), and returns -1. Otherwise, returns zero.

pos_type tellg();

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1), except that it does not count the number of characters extracted and does not affect the value returned by subsequent calls to gcount(). After constructing a sentry object, if fail() != false, returns pos_type(-1) to indicate failure. Otherwise, returns rdbuf()->pubseekoff(0, cur, in).

basic_istream<charT,traits>& seekg(pos_type pos);

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1), except that it does not count the number of characters extracted and does not affect the value returned by subsequent calls to gcount(). After constructing a sentry object, if fail() != true, executes rdbuf()->pubseekpos(pos, ios_base::in). In case of failure, the function calls setstate(failbit) (which may throw ios_base::failure).

Returns: *this.

basic_istream<charT,traits>& seekg(off_type& off, ios_base::seekdir dir);

Effects: Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1), except that it does not count the number of characters extracted and does not affect the value returned by subsequent calls to gcount(). After constructing a sentry object, if fail() != true, executes rdbuf()->pubseekoff(off, dir, ios_base::in).

Returns: *this.
27.6 Formatting and manipulators

27.6.1.4 Standard `basic_istream` manipulators

```cpp
namespace std {
    template <class charT, class traits>
    basic_istream<charT,traits>& ws(basic_istream<charT,traits>& is);
}
```

1. **Effects:** Behaves as an unformatted input function (as described in 27.6.1.3, paragraph 1), except that it does not count the number of characters extracted and does not affect the value returned by subsequent calls to is.gcount(). After constructing a sentry object extracts characters as long as the next available character `c` is whitespace or until there are no more characters in the sequence. Whitespace characters are distinguished with the same criterion as used by `sentry::sentry` (27.6.1.1.2). If `ws` stops extracting characters because there are no more available it sets eofbit, but not failbit.

2. **Returns:** `is`.

27.6.1.5 Class template `basic_iostream`

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_iostream :
    public basic_istream<charT,traits>,
    public basic_ostream<charT,traits> {
    public:
        // types:
        typedef charT char_type;
        typedef typename traits::int_type int_type;
        typedef typename traits::pos_type pos_type;
        typedef typename traits::off_type off_type;
        typedef traits traits_type;

        // constructor/destructor
        explicit basic_iostream(basic_streambuf<charT,traits>* sb);
        virtual ~basic_iostream();
    }
}
```

1. The class `basic_iostream` inherits a number of functions that allow reading input and writing output to sequences controlled by a stream buffer.

27.6.1.5.1 `basic_iostream` constructors

```cpp
explicit basic_iostream(basic_streambuf<charT,traits>* sb);
```

1. **Effects:** Constructs an object of class `basic_iostream`, assigning initial values to the base classes by calling `basic_istream<charT,traits>(sb)` (27.6.1.1) and `basic_ostream<charT,traits>(sb)` (27.6.2.1)

2. **Postcondition:** rdbuf()==sb and gcount()==0.
27.6.1.5.2 basic_iostream destructor

virtual ~basic_iostream();

Effects: Destroys an object of class basic_iostream.
Remarks: Does not perform any operations on rdbuf().

27.6.2 Output streams

The header <ostream> defines a type and several function signatures that control output to a stream buffer.

27.6.2.1 Class template basic_ostream

namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_ostream : virtual public basic_ios<charT,traits> {
        public:
            // Types (inherited from basic_ios (27.4.4)):
            typedef charT char_type;
            typedef typename traits::int_type int_type;
            typedef typename traits::pos_type pos_type;
            typedef typename traits::off_type off_type;
            typedef traits traits_type;

            // 27.6.2.2 Constructor/destructor:
            explicit basic_ostream(basic_streambuf<char_type,traits>* sb);
            virtual ~basic_ostream();

            // 27.6.2.3 Prefix/suffix:
            class sentry;

            // 27.6.2.5 Formatted output:
            basic_ostream<charT,traits>& & operator<<
                (basic_ostream<charT,traits>& & (*pf)(basic_ostream<charT,traits>& &));
            basic_ostream<charT,traits>& & operator<<
                (basic_ios<charT,traits>& (*pf)(basic_ios<charT,traits>& &));
            basic_ostream<charT,traits>& & operator<<
                (ios_base& (*pf)(ios_base& &));

            basic_ostream<charT,traits>& & operator<<(bool n);
            basic_ostream<charT,traits>& & operator<<(short n);
            basic_ostream<charT,traits>& & operator<<(unsigned short n);
            basic_ostream<charT,traits>& & operator<<(int n);
            basic_ostream<charT,traits>& & operator<<(unsigned int n);
            basic_ostream<charT,traits>& & operator<<(long n);
            basic_ostream<charT,traits>& & operator<<(unsigned long n);
            basic_ostream<charT,traits>& & operator<<(float f);
            basic_ostream<charT,traits>& & operator<<(double f);
            basic_ostream<charT,traits>& & operator<<(long double f);

    } // end class basic_ostream
} // end namespace std
basic_ostream<charT,traits>& operator<<(const void* p);
basic_ostream<charT,traits>& operator<<
(basic_streambuf<char_type,traits>* sb);

// 27.6.2.6 Unformatted output:
basic_ostream<charT,traits>& put(char_type c);
basic_ostream<charT,traits>& write(const char_type* s, streamsize n);
basic_ostream<charT,traits>& flush();

// 27.6.2.4 seeks:
pos_type tellp();
basic_ostream<charT,traits>& seekp(pos_type);
basic_ostream<charT,traits>& seekp(off_type, ios_base::seekdir);

// 27.6.2.5.4 character inserters
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>&, charT);
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>&, char);
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>&, char);

// signed and unsigned
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>&, signed char);
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>&, unsigned char)
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>&, const charT*);
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>&, const char*);
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>&, const char*);

// signed and unsigned
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>&, const signed char*);
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>&, const unsigned char*)

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The class `basic_ostream` defines a number of member function signatures that assist in formatting and writing output to output sequences controlled by a stream buffer.

Two groups of member function signatures share common properties: the formatted output functions (or `inserters`) and the unformatted output functions. Both groups of output functions generate (or `insert`) output characters equivalent to calling `rdbuf()->sputc(int_type)`. They may use other public members of `basic_ostream` except that they shall not invoke any virtual members of `rdbuf()` except `overflow()`, `xsputn()`, and `sync()`.

If one of these called functions throws an exception, then unless explicitly noted otherwise the output function sets `badbit` in error state. If `badbit` is on in `exceptions()`, the output function rethrows the exception without completing its actions, otherwise it does not throw anything and treat as an error.

### 27.6.2.2 `basic_ostream` Constructors

```cpp
explicit basic_ostream(basic_streambuf<charT, traits>* sb);
```

**Effects:** Constructs an object of class `basic_ostream`, assigning initial values to the base class by calling `basic_ios<charT, traits>::init(sb)` (27.4.4.1).

**Postcondition:** `rdbuf() == sb`.

**Effects:** Destroys an object of class `basic_ostream`.

**Remarks:** Does not perform any operations on `rdbuf()`.

### 27.6.2.3 Class `basic_ostream::sentry`

The class `sentry` defines a class that is responsible for doing exception safe prefix and suffix operations.

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_ostream<charT, traits>::sentry {
    // bool ok_;
    public:
        explicit sentry(basic_ostream<charT, traits>& os);
        ~sentry();
        operator bool() const { return ok_; } 
    private:
        sentry(const sentry&); // not defined
        sentry& operator=(const sentry&); // not defined
    };
}
```

The class `sentry` defines a class that is responsible for doing exception safe prefix and suffix operations.

```cpp
explicit sentry(basic_ostream<charT, traits>& os);
```
If `os.good()` is nonzero, prepares for formatted or unformatted output. If `os.tie()` is not a null pointer, calls `os.tie()->flush();`.

If, after any preparation is completed, `os.good()` is true, `ok_` is true otherwise, `ok_` is false. During preparation, the constructor may call `setstate(failbit)` (which may throw `ios_base::failure`) if the function can determine that no synchronization is necessary.

The `sentry` constructor and destructor can also perform additional implementation-dependent operations.

The call `os.tie()->flush()` does not necessarily occur if the function can determine that no synchronization is necessary.

The `sentry` constructor and destructor can also perform additional implementation-dependent operations.

Draft
2 The descriptions of the individual formatted output operations describe how they perform output and do not mention the sentry object.

27.6.2.5.2 Arithmetic Inserters

operator<<(bool ival);
operator<<(short ival);
operator<<(unsigned short ival);
operator<<(int ival);
operator<<(unsigned int ival);
operator<<(long ival);
operator<<(unsigned long ival);
operator<<(float ival);
operator<<(double ival);
operator<<(long double ival);
operator<<(const void* val);

Effects: The classes num_get<> and num_put<> handle locale-dependent numeric formatting and parsing. These inserter functions use the imbued locale value to perform numeric formatting. When val is of type bool, long, unsigned long, double, long double, or const void*, the formatting conversion occurs as if it performed the following code fragment:

```cpp
bool failed = use_facet<
    num_put<charT,ostreambuf_iterator<charT,traits> >
    >(getloc()).put(*this, *this, fill(), val).failed();
```

When val is of type short the formatting conversion occurs as if it performed the following code fragment:

```cpp
ios_base::fmtflags baseflags = ios_base::flags() & ios_base::basefield;
bool failed = use_facet<
    num_put<charT,ostreambuf_iterator<charT,traits> >
    >(getloc()).put(*this, *this, fill(),
    baseflags == ios_base::oct || baseflag == ios_base::hex
    ? static_cast<long>(static_cast<unsigned short>(val))
    : static_cast<long>(val)).failed();
```

When val is of type int the formatting conversion occurs as if it performed the following code fragment:

```cpp
ios_base::fmtflags baseflags = ios_base::flags() & ios_base::basefield;
bool failed = use_facet<
    num_put<charT,ostreambuf_iterator<charT,traits> >
    >(getloc()).put(*this, *this, fill(),
    baseflags == ios_base::oct || baseflags == ios_base::hex
    ? static_cast<long>(static_cast<unsigned int>(val))
    : static_cast<long>(val)).failed();
```

When val is of type unsigned short or unsigned int the formatting conversion occurs as if it performed the following code fragment:

```cpp
bool failed = use_facet<
    num_put<charT,ostreambuf_iterator<charT,traits> >
    >(getloc()).put(*this, *this, fill(),
```
When \texttt{val} is of type \texttt{float} the formatting conversion occurs as if it performed the following code fragment:

```cpp
bool failed = use_facet<
    num_put<charT,ostreambuf_iterator<charT,traits> >
>(getloc()).put(*this, *this, fill(),
    static_cast<double>(val)).failed();
```

The first argument provides an object of the \texttt{ostreambuf\_iterator<>} class which is an iterator for class \texttt{basic\_ostream<>}. It bypasses \texttt{ostreams} and uses \texttt{streambufs} directly. Class \texttt{locale} relies on these types as its interface to \texttt{iostreams}, since for flexibility it has been abstracted away from direct dependence on \texttt{ostream}. The second parameter is a reference to the base subobject of type \texttt{ios\_base}. It provides formatting specifications such as field width, and a \texttt{locale} from which to obtain other facets. If \texttt{failed} is \texttt{true} then does \texttt{setstate(badbit)}, which may throw an exception, and returns.

Returns: *this.

\subsection*{27.6.2.5.3 \texttt{basic\_ostream::operator<<}}

\begin{verbatim}
basic_ostream\langle charT,traits\rangle& operator<<(basic_ostream\langle charT,traits\rangle& (*pf)(basic_ostream\langle charT,traits\rangle&))

Effects: None. Does not behave as a formatted output function (as described in 27.6.2.5.1).

Returns: \texttt{pf(*this).}\footnote{See, for example, the function signature \texttt{endl(basic\_ostream\&)} (27.6.2.7).}
\end{verbatim}

\begin{verbatim}
basic_ostream\langle charT,traits\rangle& operator<<(basic_ios\langle charT,traits\rangle& (*pf)(basic_ios\langle charT,traits\rangle&))

Effects: Calls \texttt{pf(*this)}. This inserter does not behave as a formatted output function (as described in 27.6.2.5.1).

Returns: *this.\footnote{See, for example, the function signature \texttt{dec(ios\_base\&)} (27.4.5.3).}
\end{verbatim}

\begin{verbatim}
basic_ostream\langle charT,traits\rangle& operator<<(ios_base& (*pf)(ios_base&))

Effects: Calls \texttt{pf(*this)}. This inserter does not behave as a formatted output function (as described in 27.6.2.5.1).

Returns: *this.
\end{verbatim}

\begin{verbatim}
basic_ostream\langle charT,traits\rangle& operator<<(basic_streambuf\langle charT,traits\rangle* sb);

Effects: Behaves as a formatted output function (as described in 27.6.2.5.1). After the sentry object is constructed, if \texttt{sb} is null calls \texttt{setstate(badbit)} (which may throw \texttt{ios\_base::failure}).

Gets characters from \texttt{sb} and inserts them in *this. Characters are read from \texttt{sb} and inserted until any of the following occurs:
\end{verbatim}

\footnote{See, for example, the function signature \texttt{endl(basic\_ostream\&)} (27.6.2.7).}

\footnote{See, for example, the function signature \texttt{dec(ios\_base\&)} (27.4.5.3).}

Draft
— end-of-file occurs on the input sequence;
— inserting in the output sequence fails (in which case the character to be inserted is not extracted);
— an exception occurs while getting a character from \( s b \).

If the function inserts no characters, it calls `setstate(failbit)` (which may throw `ios_base::failure` (27.4.4.3)). If an exception was thrown while extracting a character, the function sets `failbit` in error state, and if `failbit` is on in `exceptions()` the caught exception is rethrown.

**Returns:** `*this`.

### 27.6.2.5.4 Character inserter function templates
[lib.ostream.inserters.character]

```cpp
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>& out, charT c);

// specialization
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>& out, char c);
// signed and unsigned
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>& out, signed char c);
template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>& out, unsigned char c);
```

**Effects:** Behaves like a formatted inserter (as described in 27.6.2.5.1) of `out`. After a `sentry` object is constructed it inserts characters. In case `c` has type `char` and the character type of the stream is not `char`, then the character to be inserted is `out.widen(c)`; otherwise the character is `c`. Padding is determined as described in 22.2.2.2.2. `width(0)` is called. The insertion character and any required padding are inserted into `out`.

**Returns:** `out`.

```cpp
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>& out, const charT* s);
template<class charT, class traits>
basic_ostream<charT,traits>& operator<<(basic_ostream<charT,traits>& out, const char* s);
```

323)
27.6 Formatting and manipulators

```
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>& out,  
                        const signed char* s);

template<class traits>
basic_ostream<char,traits>& operator<<(basic_ostream<char,traits>& out,  
                        const unsigned char* s);
```

``` requires: s is non-null.

effects: Behaves like a formatted inserter (as described in 27.6.2.5.1) of out. After a sentry object is constructed it inserts n characters starting at s, where n is the number that would be computed as if by:

- traits::length(s) for the overload where the first argument is of type basic_ostream<charT, traits>& and the second is of type const charT*, and also for the overload where the first argument is of type basic_ostream<char, traits>& and the second is of type const char*,
- std::char_traits<char>::length(s) for the overload where the first argument is of type basic_ostream<charT, traits>& and the second is of type const char*,
- traits::length(reinterpret_cast<const char*>(s)) for the other two overloads.
```

Padding is determined as described in 22.2.2.2.2. The n characters starting at s are widened using out.widen (27.4.4.2). The widened characters and any required padding are inserted into out. Calls width(0).

Returns: out.

27.6.2.6 Unformatted output functions

```
basic_ostream<charT,traits>& put(char_type c);
```

```
effects: Behaves as an unformatted output function (as described in 27.6.2.6, paragraph 1). After constructing a sentry object, inserts the character c, if possible.
```

```
otherwise, calls setstate(badbit) (which may throw ios_base::failure (27.4.4.3)).
```

Returns: *this.

```
basic_ostream& write(const char_type* s, streamsize n);
```

```
effects: Behaves as an unformatted output function (as described in 27.6.2.6, paragraph 1). After constructing a sentry object, obtains characters to insert from successive locations of an array whose first element is designated by s. Characters are inserted until either of the following occurs:
```

```
- n characters are inserted;
```

324) without causing an ios::failure to be thrown.

325) Note that this function is not overloaded on types signed char and unsigned char.

326) Note that this function is not overloaded on types signed char and unsigned char.
— inserting in the output sequence fails (in which case the function calls setstate(badbit), which may throw ios_base::failure (27.4.4.3)).

Returns: \*this.

\begin{verbatim}
basic_ostream& flush();
\end{verbatim}

If rdbuf() is not a null pointer, calls rdbuf() \texttt{->pubsync()}. If that function returns -1 calls setstate(badbit) (which may throw ios_base::failure (27.4.4.3)). Does not behave as an unformatted output function (as described in 27.6.2.6, paragraph 1).

Returns: \*this.

\subsection{Standard basic_ostream manipulators} \hfill \texttt{[lib.ostream.manip]}

\begin{verbatim}
namespace std {
  template <class charT, class traits>
  basic_ostream<charT,traits>& endl(basic_ostream<charT,traits>& os);
}
\end{verbatim}

Effects: Calls \texttt{os.put(os.widen(\textquoteright\textbackslash n\textquoteright))}, then \texttt{os.flush()}.

Returns: \texttt{os}.

\begin{verbatim}
namespace std {
  template <class charT, class traits>
  basic_ostream<charT,traits>& ends(basic_ostream<charT,traits>& os);
}
\end{verbatim}

Effects: Inserts a null character into the output sequence: calls \texttt{os.put(charT())}.

Returns: \texttt{os}.

\begin{verbatim}
namespace std {
  template <class charT, class traits>
  basic_ostream<charT,traits>& flush(basic_ostream<charT,traits>& os);
}
\end{verbatim}

Effects: Calls \texttt{os.flush()}.

Returns: \texttt{os}.

\subsection{Standard manipulators} \hfill \texttt{[lib.std.manip]}

The header \texttt{iomanip} defines a type and several related functions that use this type to provide extractors and inserters that alter information maintained by class ios_base and its derived classes.

The type designated \texttt{smanip} in each of the following function descriptions is implementation-defined and may be different for each function.

\begin{verbatim}
smanip resetiosflags(ios_base::fmtflags mask);
\end{verbatim}
Returns: An object \( s \) of unspecified type such that if \( \text{out} \) is an instance of `basic_ostream<charT, traits>` then the expression `\text{out} \ll s` behaves as if \( f(s, \ \text{mask}) \) were called, or if \( \text{in} \) is an instance of `basic_istream<charT, traits>` then the expression `\text{in} \gg s` behaves as if \( f(s, \ \text{mask}) \) were called. The function \( f \) can be defined as:

```cpp
ios_base& f(ios_base& str, ios_base::fmtflags mask)
{
    // reset specified flags
    str.setf(ios_base::fmtflags(0), mask);
    return str;
}
```

The expression `\text{out} \ll s` has type `basic_ostream<charT, traits>&` and value `\text{out}`. The expression `\text{in} \gg s` has type `basic_istream<charT, traits>&` and value `\text{in}`.

```cpp
smanip setiosflags(ios_base::fmtflags mask);
```

Returns: An object \( s \) of unspecified type such that if \( \text{out} \) is an instance of `basic_ostream<charT, traits>` then the expression `\text{out} \ll s` behaves as if \( f(s, \ \text{mask}) \) were called, or if \( \text{in} \) is an instance of `basic_istream<charT, traits>` then the expression `\text{in} \gg s` behaves as if \( f(s, \ \text{mask}) \) were called. The function \( f \) can be defined as:

```cpp
ios_base& f(ios_base& str, ios_base::fmtflags mask)
{
    // set specified flags
    str.setf(mask);
    return str;
}
```

The expression `\text{out} \ll s` has type `basic_ostream<charT, traits>&` and value `\text{out}`. The expression `\text{in} \gg s` has type `basic_istream<charT, traits>&` and value `\text{in}`.

```cpp
smanip setbase(int base);
```

Returns: An object \( s \) of unspecified type such that if \( \text{out} \) is an instance of `basic_ostream<charT, traits>` then the expression `\text{out} \ll s` behaves as if \( f(s) \) were called, or if \( \text{in} \) is an instance of `basic_istream<charT, traits>` then the expression `\text{in} \gg s` behaves as if \( f(s, \ \text{base}) \) were called. The function \( f \) can be defined as:

```cpp
ios_base& f(ios_base& str, int base)
{
    // set basefield
    str.setf(base == 8 ? ios_base::oct :
             base == 10 ? ios_base::dec :
             base == 16 ? ios_base::hex :
                ios_base::fmtflags(0), ios_base::basefield);
    return str;
}
```

\(^{327}\) The expression `\text{cin} \gg \text{resetiosflags(ios_base::skipws)}` clears `ios_base::skipws` in the format flags stored in the `basic_istream<charT, traits>` object `\text{cin}` (the same as `\text{cin} \gg \text{noskipws}`), and the expression `\text{cout} \ll \text{resetiosflags(ios_base::showbase)}` clears `ios_base::showbase` in the format flags stored in the `basic_ostream<charT, traits>` object `\text{cout}` (the same as `\text{cout} \ll \text{noshowbase}`).
The expression `out<<s` has type `basic_ostream<charT, traits>&` and value `out`. The expression `in>>s` has type `basic_istream<charT, traits>&` and value `in`.

```cpp
smanip setfill(char_type c);
```

**Returns:** An object `s` of unspecified type such that if `out` is (or is derived from) `basic_ostream<charT, traits>` and `c` has type `charT` then the expression `out<<s` behaves as if `f(s, c)` were called. The function `f` can be defined as:

```cpp
template<class charT, class traits>
basic_ostream<charT, traits>& f(basic_ostream<charT, traits>& str, charT c)
{
    // set fill character
    str.fill(c);
    return str;
}
```

The expression `out<<s` has type `basic_ostream<charT, traits>&` and value `out`.

```cpp
smanip setprecision(int n);
```

**Returns:** An object `s` of unspecified type such that if `out` is an instance of `basic_ostream<charT, traits>` then the expression `out<<s` behaves as if `f(s, n)` were called, or if `in` is an instance of `basic_istream<charT, traits>` then the expression `in>>s` behaves as if `f(s, n)` were called. The function `f` can be defined as:

```cpp
ios_base& f(ios_base& str, int n)
{
    // set precision
    str.precision(n);
    return str;
}
```

The expression `out<<s` has type `basic_ostream<charT, traits>&` and value `out`. The expression `in>>s` has type `basic_istream<charT, traits>&` and value `in`.

```cpp
smanip setw(int n);
```

**Returns:** An object `s` of unspecified type such that if `out` is an (instance of) `basic_ostream<charT, traits>` then the expression `out<<s` behaves as if `f(s, n)` were called, or if `in` is an instance of `basic_istream<charT, traits>` then the expression `in>>s` behaves as if `f(s, n)` were called. The function `f` can be defined as:

```cpp
ios_base& f(ios_base& str, int n)
{
    // set width
    str.width(n);
    return str;
}
```

The expression `out<<s` has type `basic_ostream<charT, traits>&` and value `out`. The expression `in>>s` has type `basic_istream<charT, traits>&` and value `in`. Draft
27.7 String-based streams

The header `<sstream>` defines four class templates and eight types that associate stream buffers with objects of class `basic_string`, as described in 21.2.

**Header `<sstream>` synopsis**

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_stringbuf;

    typedef basic_stringbuf<char> stringbuf;
    typedef basic_stringbuf<wchar_t> wstringbuf;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_istringstream;

    typedef basic_istringstream<char> istringstream;
    typedef basic_istringstream<wchar_t> wistringstream;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_ostringstream;

    typedef basic_ostringstream<char> ostringstream;
    typedef basic_ostringstream<wchar_t> wostringstream;

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_stringstream;

    typedef basic_stringstream<char> stringstream;
    typedef basic_stringstream<wchar_t> wstringstream;
}
```

27.7.1 Class template `basic_stringbuf`

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_stringbuf : public basic_streambuf<charT,traits> {
        public:
            typedef charT char_type;
            typedef typename traits::int_type int_type;
            typedef typename traits::pos_type pos_type;
            typedef typename traits::off_type off_type;
            typedef traits traits_type;
            typedef Allocator allocator_type;

            // 27.7.1.1 Constructors:
            explicit basic_stringbuf(ios_base::openmode which
```
The class basic_stringbuf is derived from basic_streambuf to associate possibly the input sequence and possibly the output sequence with a sequence of arbitrary characters. The sequence can be initialized from, or made available as, an object of class basic_string.

For the sake of exposition, the maintained data is presented here as:

— ios_base::openmode mode, has in set if the input sequence can be read, and out set if the output sequence can be written.

### 27.7.1.1 basic_stringbuf constructors

**explicit basic_stringbuf(ios_base::openmode which =
ios_base::in | ios_base::out);**

1. Effects: Constructs an object of class basic_stringbuf, initializing the base class with basic_streambuf() (27.5.2.1), and initializing mode with which.

2. Postcondition: \( \text{str()} == "". \n
**explicit basic_stringbuf(const basic_string<charT,traits,Allocator>& str,
ios_base::openmode which = ios_base::in | ios_base::out);**

Draft
Effects: Constructs an object of class basic_stringbuf, initializing the base class with basic_streambuf() (27.5.2.1), and initializing mode with which. Then copies the content of str into the basic_stringbuf underlying character sequence. If which & ios_base::out is true, initializes the output sequence such that pbases() points to the first underlying character, eptr() points one past the last underlying character, and pptr() is equal to eptr() if which & ios_base::ate is true, otherwise pptr() is equal to base(). If which & ios_base::in is true, initializes the input sequence such that eback() and gptr() point to the first underlying character and egptr() points one past the last underlying character.

27.7.1.2 Member functions

basic_string<charT,traits,Allocator> str() const;

Returns: A basic_string object whose content is equal to the basic_stringbuf underlying character sequence. If the basic_stringbuf was created only in input mode, the resultant basic_string contains the character sequence in the range [eback(),egptr()). If the basic_stringbuf was created with which & ios_base::out being true then the resultant basic_string contains the character sequence in the range [pbase(),high_mark), where high_mark represents the position one past the highest initialized character in the buffer. Characters can be initialized by writing to the stream, by constructing the basic_stringbuf with a basic_string, or by calling the str(basic_string) member function. In the case of calling the str(basic_string) member function, all characters initialized prior to the call are now considered uninitialized (except for those characters re-initialized by the new basic_string). Otherwise the basic_stringbuf has been created in neither input nor output mode and a zero length basic_string is returned.

void str(const basic_string<charT,traits,Allocator>& s);

Effects: Copies the content of s into the basic_stringbuf underlying character sequence. If mode & ios_base::out is true, initializes the output sequence such that pbases() points to the first underlying character, eptr() points one past the last underlying character, and pptr() is equal to eptr() if mode & ios_base::in is true, otherwise pptr() is equal to base(). If mode & ios_base::in is true, initializes the input sequence such that eback() and gptr() point to the first underlying character and egptr() points one past the last underlying character.

27.7.1.3 Overridden virtual functions

int_type underflow();

Returns: If the input sequence has a read position available, returns traits::to_int_type(*gptr()). Otherwise, returns traits::eof(). Any character in the underlying buffer which has been initialized is considered to be part of the input sequence.

int_type pbackfail(int_type c = traits::eof());

Effects: Puts back the character designated by c to the input sequence, if possible, in one of three ways:

— If traits::eq_int_type(c,traits::eof()) returns false and if the input sequence has a putback position available, and if traits::eq(to_char_type(c),gptr()[~1]) returns true, assigns gptr() = 1 to gptr().

Draft
Returns: \( c \).

- If `traits::eq_int_type(c, traits::eof())` returns false and if the input sequence has a putback position available, and if `mode & ios_base::out` is nonzero, assigns \( c \) to \(*-gptr()\).

Returns: \( c \).

- If `traits::eq_int_type(c, traits::eof())` returns true and if the input sequence has a putback position available, assigns \( gptr() - 1 \) to \( gptr() \).

Returns: `traits::not_eof(c)`.

**Remarks:** If the function can succeed in more than one of these ways, it is unspecified which way is chosen.

```cpp
int_type overflow(int_type c = traits::eof());
```

**Effects:** Appends the character designated by \( c \) to the output sequence, if possible, in one of two ways:

- If `traits::eq_int_type(c, traits::eof())` returns false and if either the output sequence has a write position available or the function makes a write position available (as described below), the function calls `sputc(c)`.

  Signals success by returning \( c \).

- If `traits::eq_int_type(c, traits::eof())` returns true, there is no character to append.

  Signals success by returning a value other than `traits::eof()`.

**Remarks:** The function can alter the number of write positions available as a result of any call.

Returns: `traits::eof()` to indicate failure.

The function can make a write position available only if \((mode & ios_base::out) \neq 0\). To make a write position available, the function reallocates (or initially allocates) an array object with a sufficient number of elements to hold the current array object (if any), plus at least one additional write position. If \((mode & ios_base::in) \neq 0\), the function alters the read end pointer \( egptr() \) to point just past the new write position.

```cpp
pos_type seekoff(off_type off, ios_base::seekdir way,
    ios_base::openmode which = ios_base::in | ios_base::out);
```

**Effects:** Alters the stream position within one of the controlled sequences, if possible, as indicated in Table 110.

For a sequence to be positioned, if its next pointer (either \( gptr() \) or \( pptr() \)) is a null pointer and the new offset `newoff` is nonzero, the positioning operation fails. Otherwise, the function determines `newoff` as indicated in Table 111.

If `newoff + off < 0`, or if `newoff + off` refers to an uninitialized character (as defined in 27.7.1.2 paragraph 1), the positioning operation fails. Otherwise, the function assigns \( \text{xbeg} + \text{newoff} + \text{off} \) to the next pointer \( \text{xnext} \).

Returns: `pos_type(newoff)`, constructed from the resultant offset `newoff` (of type `off_type`), that stores the resultant stream position, if possible. If the positioning operation fails, or if the constructed object cannot represent...
### Table 110: `seekoff` positioning

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(which &amp; ios_base::in) != 0 == ios_base::in</td>
<td>positions the input sequence</td>
</tr>
<tr>
<td>(which &amp; ios_base::out) != 0 == ios_base::out</td>
<td>positions the output sequence</td>
</tr>
<tr>
<td>(which &amp; (ios_base::in</td>
<td>ios_base::out)) == ios_base::beg or ios_base::end</td>
</tr>
<tr>
<td>otherwise</td>
<td>the positioning operation fails.</td>
</tr>
</tbody>
</table>

### Table 111: `newoff` values

<table>
<thead>
<tr>
<th>Condition</th>
<th>newoff Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>way == ios_base::beg</td>
<td>0</td>
</tr>
<tr>
<td>way == ios_base::cur</td>
<td>the next pointer minus the beginning pointer (xnext - xbeg).</td>
</tr>
<tr>
<td>way == ios_base::end</td>
<td>the end pointer minus the beginning pointer (xend - xbeg).</td>
</tr>
</tbody>
</table>
the resultant stream position, the return value is `pos_type(off_type(-1))`.

```cpp
pos_type seekpos(pos_type sp, ios_base::openmode which = ios_base::in | ios_base::out);
```

**Effects:** Alters the stream position within the controlled sequences, if possible, to correspond to the stream position stored in `sp` (as described below).

- If `(which & ios_base::in) != 0`, positions the input sequence.
- If `(which & ios_base::out) != 0`, positions the output sequence.
- If `sp` is an invalid stream position, or if the function positions neither sequence, the positioning operation fails. If `sp` has not been obtained by a previous successful call to one of the positioning functions (`seekoff`, `seekpos`, `tellg`, `tellp`) the effect is undefined.

**Returns:** `sp` to indicate success, or `pos_type(off_type(-1))` to indicate failure.

```cpp
basic_streambuf<charT,traits>* setbuf(charT* s, streamsize n);
```

**Effects:** implementation-defined, except that `setbuf(0,0)` has no effect.

**Returns:** `this`.

### 27.7.2 Class template basic_istringstream

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_istringstream : public basic_istream<charT,traits> {
        public:
            typedef charT char_type;
            typedef typename traits::int_type int_type;
            typedef typename traits::pos_type pos_type;
            typedef typename traits::off_type off_type;
            typedef traits traits_type;
            typedef Allocator allocator_type;

        // 27.7.2.1 Constructors:
            explicit basic_istringstream(ios_base::openmode which = ios_base::in);
            explicit basic_istringstream(
                const basic_string<charT,traits,Allocator>& str,
                ios_base::openmode which = ios_base::in);

        // 27.7.2.2 Members:
            basic_stringbuf<charT,traits,Allocator>* rdbuf() const;
            basic_string<charT,traits,Allocator> str() const;
            void str(const basic_string<charT,traits,Allocator>& s);
        private:
            // basic_stringbuf<charT,traits,Allocator> sb;  /* exposition only */
    }
}
```

Draft
The class `basic_istringstream<charT, traits, Allocator>` supports reading objects of class `basic_string<charT, traits, Allocator>`. It uses a `basic_stringbuf<charT, traits, Allocator>` object to control the associated storage. For the sake of exposition, the maintained data is presented here as:

— `sb`, the stringbuf object.

### 27.7.2.1 basic_istringstream constructors

```cpp
explicit basic_istringstream(ios_base::openmode which = ios_base::in);
```

**Effects:** Constructs an object of class `basic_istringstream<charT, traits>`, initializing the base class with `basic_istream(&sb)` and initializing `sb` with `basic_stringbuf<charT, traits, Allocator>(which | ios_base::in)` (27.7.1.1).

```cpp
explicit basic_istringstream(
    const basic_string<charT,traits,allocator>& str,
    ios_base::openmode which = ios_base::in);
```

**Effects:** Constructs an object of class `basic_istringstream<charT, traits>`, initializing the base class with `basic_istream(&sb)` and initializing `sb` with `basic_stringbuf<charT, traits, Allocator>(str, which | ios_base::in)` (27.7.1.1).

### 27.7.2.2 Member functions

```cpp
basic_stringbuf<charT,traits,Allocator>* rdbuf() const;
```

**Returns:** `const_cast<basic_stringbuf<charT,traits,Allocator>*>(&sb)`.

```cpp
basic_string<charT,traits,Allocator> str() const;
```

**Returns:** `rdbuf()->str()`.

```cpp
void str(const basic_string<charT,traits,Allocator>& s);
```

**Effects:** Calls `rdbuf()->str(s)`.

### 27.7.3 Class basic_ostringstream

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT> >
    class basic_ostringstream : public basic_ostringstream<charT,traits> {
    public:

        // Types:
        typedef charT char_type;
        typedef typename traits::int_type int_type;

    } // basic_ostringstream
}
```

Draft
typedef typename traits::pos_type pos_type;
typedef typename traits::off_type off_type;
typedef traits traits_type;
typedef Allocator allocator_type;

// 27.7.3.1 Constructors/destructor:
explicit basic_ostringstream(ios_base::openmode which = ios_base::out);
explicit basic_ostringstream(
    const basic_string<charT,traits,Allocator>& str,
    ios_base::openmode which = ios_base::out);

// 27.7.3.2 Members:
basic_stringbuf<charT,traits,Allocator>* rdbuf() const;

basic_string<charT,traits,Allocator>* rdbuf() const;

// basic_stringbuf<charT,traits,Allocator> sb; exposition only

private:

The class basic_ostringstream<charT, traits, Allocator> supports writing objects of class basic_string<charT, traits, Allocator>. It uses a basic_stringbuf object to control the associated storage. For the sake of exposition, the maintained data is presented here as:
— sb, the stringbuf object.

27.7.3.1 basic_ostringstream constructors

explicit basic_ostringstream(ios_base::openmode which = ios_base::out);

Effects: Constructs an object of class basic_ostringstream, initializing the base class with basic_ostream(&sb) and initializing sb with basic_stringbuf<charT, traits, Allocator>(which | ios_base::out)) (27.7.1.1).

explicit basic_ostringstream(
    const basic_string<charT,traits,Allocator>& str,
    ios_base::openmode which = ios_base::out);

Effects: Constructs an object of class basic_ostringstream<charT, traits>, initializing the base class with basic_ostream(&sb) and initializing sb with basic_stringbuf<charT, traits, Allocator>(str, which | ios_base::out)) (27.7.1.1).

27.7.3.2 Member functions

basic_stringbuf<charT,traits,Allocator>* rdbuf() const;

Returns: const_cast<basic_stringbuf<charT,traits,Allocator>*>(&sb).
27.7 String-based streams

basic_string<charT, traits, Allocator> str() const;

Returns: rdbuf()->str().

void str(const basic_string<charT, traits, Allocator>& s);

Effects: Calls rdbuf()->str(s).

27.7.4 Class template basic_stringstream

namespace std {

    template <class charT, class traits = char_traits<charT>,
              class Allocator = allocator<charT>>
    class basic_stringstream : public basic_iostream<charT, traits> {

        public:

            // Types
            typedef charT char_type;
            typedef typename traits::int_type int_type;
            typedef typename traits::pos_type pos_type;
            typedef typename traits::off_type off_type;
            typedef traits traits_type;
            typedef Allocator allocator_type;

            // constructors/destructors
            explicit basic_stringstream(
                ios_base::openmode which = ios_base::out|ios_base::in);
            explicit basic_stringstream(
                const basic_string<charT, traits, Allocator>& str,
                ios_base::openmode which = ios_base::out|ios_base::in);

            // Members:
            basic_stringbuf<charT, traits, Allocator>* rdbuf() const;
            basic_string<charT, traits, Allocator> str() const;
            void str(const basic_string<charT, traits, Allocator>& s);

        private:

            // basic_stringbuf<charT, traits> sb;       exposition only

    };

}

The class template basic_stringstream<charT, traits> supports reading and writing from objects of class basic_string<charT, traits, Allocator>. It uses a basic_stringbuf<charT, traits, Allocator> object to control the associated sequence. For the sake of exposition, the maintained data is presented here as — sb, the stringbuf object.

27.7.5 basic_stringstream constructors

Draft
explicit basic_stringstream(
    ios_base::openmode which = ios_base::out|ios_base::in);

    Effects: Constructs an object of class basic_stringstream<charT,traits>, initializing the base class with basic_iostream(&sb) and initializing sb with basic_stringbuf<charT,traits,Allocator>(which).

explicit basic_stringstream(
    const basic_string<charT,traits,Allocator>& str,
    ios_base::openmode which = ios_base::out|ios_base::in);

    Effects: Constructs an object of class basic_stringstream<charT, traits>, initializing the base class with basic_iostream(&sb) and initializing sb with basic_stringbuf<charT, traits, Allocator>(str, which).

27.7.6 Member functions

basic_stringbuf<charT,traits,Allocator>* rdbuf() const;

    Returns: const_cast<basic_stringbuf<charT,traits,Allocator>*>(&sb)

basic_string<charT,traits,Allocator> str() const;

    Returns: rdbuf()->str().

void str(const basic_string<charT,traits,Allocator>& str);

    Effects: Calls rdbuf()->str(str).

27.8 File-based streams

27.8.1 File streams

The header <fstream> defines four class templates and eight types that associate stream buffers with files and assist reading and writing files.

Header <fstream> synopsis

namespace std {
    template <class charT, class traits = char_traits<charT> >
        class basic_filebuf;
    typedef basic_filebuf<char> filebuf;
    typedef basic_filebuf<wchar_t> wfilebuf;

    template <class charT, class traits = char_traits<charT> >
        class basic_ifstream;
    typedef basic_ifstream<char> ifstream;
    typedef basic_ifstream<wchar_t> wifstream;

    template <class charT, class traits = char_traits<charT> >
        class basic_ofstream;
    typedef basic_ofstream<char> ofstream;
    typedef basic_ofstream<wchar_t> wofstream;
}

Draft
27.8 File-based streams

In this subclause, the type name FILE refers to the type FILE declared in <cstdio> (27.8.2).\textsuperscript{328}

File A File provides an external source/sink stream whose \textit{underlaid character type} is char (byte).\textsuperscript{329}

Multibyte character and Files A File provides byte sequences. So the streambuf (or its derived classes) treats a file as the external source/sink byte sequence. In a large character set environment, multibyte character sequences are held in files. In order to provide the contents of a file as wide character sequences, wide-oriented filebuf, namely wfilebuf should convert wide character sequences.

27.8.1.1 Class template basic_filebuf

```cpp
namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_filebuf : public basic_streambuf<charT,traits> {
        public:
            typedef charT char_type;
            typedef typename traits::int_type int_type;
            typedef typename traits::pos_type pos_type;
            typedef typename traits::off_type off_type;
            typedef traits traits_type;

            // 27.8.1.2 Constructors/destructor:
            basic_filebuf();
            virtual ~basic_filebuf();

            // 27.8.1.3 Members:
            bool is_open() const;
            basic_filebuf<charT,traits>*/ open(const char* s,
                ios_base::openmode mode);
            basic_filebuf<charT,traits>*/ open(const string& s,
                ios_base::openmode mode);
            basic_filebuf<charT,traits>*/ close();

            protected:
                // 27.8.1.4 Overridden virtual functions:
                virtual streamsize showmanyc();
                virtual int_type underflow();
                virtual int_type uflow();
                virtual int_type pbackfail(int_type c = traits::eof());
                virtual int_type overflow (int_type c = traits::eof());
}
```

\textsuperscript{328} In C FILE must be a typedef. In C++ it may be a typedef or other type name.

\textsuperscript{329} A File is a sequence of multibyte characters. In order to provide the contents as a wide character sequence, filebuf should convert between wide character sequences and multibyte character sequences.
virtual basic_streambuf<charT,traits>*
    setbuf(char_type* s, streamsize n);
virtual pos_type seekoff(off_type off, ios_base::seekdir way,
    ios_base::openmode which = ios_base::in | ios_base::out);
virtual pos_type seekpos(pos_type sp,
    ios_base::openmode which = ios_base::in | ios_base::out);
virtual int sync();
virtual void imbue(const locale& loc);
);
}

1 The class basic_filebuf<
2 CharT,traits> associates both the input sequence and the output sequence with a file.
3 The restrictions on reading and writing a sequence controlled by an object of class basic_filebuf<
4 CharT,traits> are the same as for reading and writing with the Standard C library FILEs.
5 In particular:
   — If the file is not open for reading the input sequence cannot be read.
   — If the file is not open for writing the output sequence cannot be written.
   — A joint file position is maintained for both the input sequence and the output sequence.
6 An instance of basic_filebuf behaves as described in 27.8.1.1 provided traits::pos_type is fpos<traits::
7 State_type>. Otherwise the behavior is undefined.
8 In order to support file I/O and multibyte/wide character conversion, conversions are performed using members of a
9 facet, referred to as a_codecvt in following sections, obtained “as if” by

   codecvt<CharT,char,typename traits::state_type> a_codecvt =
   use_facet<codecvt<CharT,char,typename traits::state_type> >(getloc());

27.8.1.2 basic_filebuf constructors [lib.filebuf.cons]

basic_filebuf();

1 Effects: Constructs an object of class basic_filebuf<CharT,traits>, initializing the base class with basic-
2 streambuf<CharT,traits>() (27.5.2.1).
3 Postcondition: is_open() == false.

virtual ~basic_filebuf();

1 Effects: Destroys an object of class basic_filebuf<CharT,traits>. Calls close().

27.8.1.3 Member functions [lib.filebuf.members]

bool is_open() const;

Draft
Returns: true if a previous call to open succeeded (returned a non-null value) and there has been no intervening call to close.

basic_filebuf<charT,traits>* open(const char* s,
ios_base::openmode mode);

Effects: If is_open() != false, returns a null pointer. Otherwise, initializes the filebuf as required. It then opens a file, if possible, whose name is the NTBS s (“as if” by calling std::fopen(s,modstr)). The NTBS modstr is determined from mode & ~ios_base::ate as indicated in Table 112. If mode is not some combination of flags shown in the table then the open fails.

Table 112: File open modes

<table>
<thead>
<tr>
<th>ios_base Flag combination</th>
<th>stdio equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>binary in out trunc app</td>
<td>stdio equivalent</td>
</tr>
<tr>
<td>+</td>
<td>&quot;u&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;a&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;w&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;x&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;r+&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;w+&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;wb&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;ab&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;wb&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;rb&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;r+b&quot;</td>
</tr>
<tr>
<td>+</td>
<td>&quot;w+b&quot;</td>
</tr>
</tbody>
</table>

If the open operation succeeds and (mode & ios_base::ate) != 0, positions the file to the end (“as if” by calling std::fseek(file,0,SEEK_END)).

If the repositioning operation fails, calls close() and returns a null pointer to indicate failure.

Returns: this if successful, a null pointer otherwise.

basic_filebuf<charT,traits>* open(const string& s,ios_base::openmode mode);

Returns: open(s.c_str(), mode);

basic_filebuf<charT,traits>* close();

Effects: If is_open() == false, returns a null pointer. If a put area exists, calls overflow(traits::eof()) to flush characters. If the last virtual member function called on *this (between underflow, overflow, seekoff, and seekpos) was overflow then calls a_codecvt.unshift (possibly several times) to determine a termination sequence, inserts those characters and calls overflow(traits::eof()) again. Finally it closes

330 The macro SEEK_END is defined, and the function signatures fopen(const char*, const char*) and fseek(FILE*, long, int) are declared in <cstdio> (27.8.2).
the file ("as if" by calling std::fclose(file)). If any of the calls to overflow or std::fclose fails then close fails.

Returns: this on success, a null pointer otherwise.

Postcondition: is_open() == false.

### 27.8.1.4 Overridden virtual functions

**streamsize showmanyc();**

**Effects:** Behaves the same as basic_streambuf::showmanyc (27.5.2.4).

**Remarks:** An implementation might well provide an overriding definition for this function signature if it can determine that more characters can be read from the input sequence.

**int_type underflow();**

**Effects:** Behaves according to the description of basic_streambuf<charT,traits>::underflow(), with the specialization that a sequence of characters is read from the input sequence “as if” by reading from the associated file into an internal buffer (extern_buf) and then “as if” doing

```c
char extern_buf[XSIZE];
char* extern_end;
charT intern_buf[ISIZE];
charT* intern_end;
codecvt_base::result r =
    a_codecvt.in(state, extern_buf, extern_buf+XSIZE, extern_end,
                 intern_buf, intern_buf+ISIZE, intern_end);
```

This shall be done in such a way that the class can recover the position (fpos_t) corresponding to each character between intern_buf and intern_end. If the value of r indicates that a_codecvt.in() ran out of space in intern_buf, retry with a larger intern_buf.

**int_type uflow();**

**Effects:** Behaves according to the description of basic_streambuf<charT,traits>::uflow(), with the specialization that a sequence of characters is read from the input with the same method as used by underflow.

**int_type pbackfail(int_type c = traits::eof());**

**Effects:** Puts back the character designated by c to the input sequence, if possible, in one of three ways:

- If traits::eq_int_type(c, traits::eof()) returns false and if the function makes a putback position available and if traits::eq(to_char_type(c), gptr()[-1]) returns true, decrements the next pointer for the input sequence, gptr().

Returns: c.

---

331) The function signature fclose(FILE*) is declared in <cstdio> (27.8.2).
— If \( \text{traits::eq_int_type}(c, \text{traits::eof()}) \) returns false and if the function makes a putback position available and if the function is permitted to assign to the putback position, decrements the next pointer for the input sequence, and stores \( c \) there.

Returns: \( c \).

— If \( \text{traits::eq_int_type}(c, \text{traits::eof()}) \) returns true, and if either the input sequence has a putback position available or the function makes a putback position available, decrements the next pointer for the input sequence, \( \text{gptr()} \).

Returns: \( \text{traits::not_eof}(c) \).

\[ 6 \]

Returns: \( \text{traits::eof() \to indicate failure.} \)

\[ 7 \]

Remarks: If \( \text{is_open() == false} \), the function always fails.

The function does not put back a character directly to the input sequence.

If the function can succeed in more than one of these ways, it is unspecified which way is chosen. The function can alter the number of putback positions available as a result of any call.

\[ 8 \]

\[ \text{int_type overflow(int_type c = traits::eof());} \]

\[ 9 \]

Effects: Behaves according to the description of basic_streambuf<charT,traits>::overflow(c), except that the behavior of “consuming characters” is performed by first converting “as if” by:

\[
\begin{align*}
\text{charT* } & b = \text{pbase();} \\
\text{charT* } & p = \text{pptr();} \\
\text{charT* } & \text{end} \\
\text{char } & \text{xbuf[XSIZE];} \\
\text{char* } & \text{xbuf_end;}
\end{align*}
\]

\[ \text{codecvt_base::result } r = 
\begin{align*}
\text{a_codecvt.out(state, } & \text{b, p, end, xbuf, xbuf+XSIZE, xbuf_end);} \\
\end{align*}
\]

and then

— If \( r == \text{codecvt_base::error} \) then fail.

— If \( r == \text{codecvt_base::noconv} \) then output characters from \( b \) up to (and not including) \( p \).

— If \( r == \text{codecvt_base::partial} \) then output to the file characters from \( \text{xbuf} \) up to \( \text{xbuf_end} \), and repeat using characters from \( \text{end} \) to \( p \). If output fails, fail (without repeating).

— Otherwise output from \( \text{xbuf} \) to \( \text{xbuf_end} \), and fail if output fails. At this point if \( b != p \) and \( b == \text{end} \) (\( \text{xbuf} \) isn’t large enough) then increase \( \text{XSIZE} \) and repeat from the beginning.

\[ 10 \]

Returns: \( \text{traits::not_eof}(c) \) to indicate success, and \( \text{traits::eof()} \) to indicate failure. If \( \text{is_open() == false} \), the function always fails.

\[ 11 \]

\[ \text{basic_streambuf* setbuf(char_type* s, streamsize n);} \]

\[ 12 \]

Effects: If \( \text{setbuf(0,0)} \) is called on a stream before any I/O has occurred on that stream, the stream becomes unbuffered. Otherwise the results are implementation-defined. “Unbuffered” means that \( \text{pbase()} \) and \( \text{pptr()} \) always return null and output to the file should appear as soon as possible.

Draft
pos_type seekoff(off_type off, ios_base::seekdir way,  
ios_base::openmode which = ios_base::in | ios_base::out);

Effects: Let width denote a_codecvt.encoding(). If is_open() == false, or off != 0 && width <= 0, then the positioning operation fails. Otherwise, if way != basic_ios::cur or off != 0, and if the last operation was output, then update the output sequence and write any unshift sequence. Next, seek to the new position: if width > 0, call std::fseek(file, width * off, whence), otherwise call std::fseek(file, 0, whence).

Remarks: “The last operation was output” means either the last virtual operation was overflow or the put buffer is non-empty. “Write any unshift sequence” means, if width if less than zero then call a_codecvt.unshift(state, xbuf, xbuf+XSIZE, xbuf_end) and output the resulting unshift sequence. The function determines one of three values for the argument whence, of type int, as indicated in Table 113.

<table>
<thead>
<tr>
<th>way Value</th>
<th>stdio Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>basic_ios::beg SEEK_SET</td>
<td></td>
</tr>
<tr>
<td>basic_ios::cur SEEK_CUR</td>
<td></td>
</tr>
<tr>
<td>basic_ios::end SEEK_END</td>
<td></td>
</tr>
</tbody>
</table>

Returns: a newly constructed pos_type object that stores the resultant stream position, if possible. If the positioning operation fails, or if the object cannot represent the resultant stream position, returns pos_type(off_type(-1)).

pos_type seekpos(pos_type sp,  
ios_base::openmode which = ios_base::in | ios_base::out);

Alters the file position, if possible, to correspond to the position stored in sp (as described below). Altering the file position performs as follows:
1. if (om & ios_base::out) != 0, then update the output sequence and write any unshift sequence;
2. set the file position to sp;
3. if (om & ios_base::in) != 0, then update the input sequence;
where om is the open mode passed to the last call to open(). The operation fails if is_open() returns false.

If sp is an invalid stream position, or if the function positions neither sequence, the positioning operation fails. If sp has not been obtained by a previous successful call to one of the positioning functions (seekoff or seekpos) on the same file the effects are undefined.

Returns: sp on success. Otherwise returns pos_type(off_type(-1)).

int sync();

Effects: If a put area exists, calls filebuf::overflow to write the characters to the file. If a get area exists, the effect is implementation-defined.

void imbue(const locale& loc);

Draft
27.8  File-based streams

Precondition: If the file is not positioned at its beginning and the encoding of the current locale as determined by `a_codevt.encoding()` is state-dependent (22.2.1.4.2) then that facet is the same as the corresponding facet of `loc`.

Effects: Causes characters inserted or extracted after this call to be converted according to `loc` until another call of `imbue`.

Remark: This may require reconversion of previously converted characters. This in turn may require the implementation to be able to reconstruct the original contents of the file.

27.8.1.5 Class template basic_ifstream

```cpp
template <class charT, class traits = char_traits<charT> >
class basic_ifstream : public basic_istream<charT,traits> { public:
    typedef charT char_type;
    typedef typename traits::int_type int_type;
    typedef typename traits::pos_type pos_type;
    typedef typename traits::off_type off_type;
    typedef traits traits_type;

    basic_filebuf<charT,traits>* rdbuf() const; // 27.8.1.6 Constructors:
    explicit basic_ifstream(const char* s,
        ios_base::openmode mode = ios_base::in);
    explicit basic_ifstream(const string& s,
        ios_base::openmode mode = ios_base::in);

    bool is_open() const; // 27.8.1.7 Members:
    void open(const char* s, ios_base::openmode mode = ios_base::in);
    void open(const string& s, ios_base::openmode mode = ios_base::in);
    void close();

private:
    basic_filebuf<charT,traits> sb; // basic_filebuf<charT,traits> sb;
};
```

The class `basic_ifstream<charT, traits>` supports reading from named files. It uses a `basic_filebuf<charT, traits>` object to control the associated sequence. For the sake of exposition, the maintained data is presented here as:

— `sb`, the filebuf object.

27.8.1.6 basic_ifstream constructors

```cpp
basic_ifstream();
```
Effects: Constructs an object of class basic_ifstream<charT,traits>, initializing the base class with basic_istream(&sb) and initializing sb with basic_filebuf<charT,traits>().

explicit basic_ifstream(const char* s, ios_base::openmode mode = ios_base::in);

Effects: Constructs an object of class basic_ifstream, initializing the base class with basic_istream(&sb) and initializing sb with basic_filebuf<charT, traits>(). Then calls rdbuf()->open(s, mode | ios_base::in). If that function returns a null pointer, calls setstate(failbit).

explicit basic_ifstream(const string& s, ios_base::openmode mode = ios_base::in);

Effects: the same as basic_ifstream(s.c_str(), mode).

27.8.1.7 Member functions [lib.ifstream.members]

basic_filebuf<charT,traits>* rdbuf() const;

Returns: const_cast<basic_filebuf<charT,traits>*>(&sb).

bool is_open() const;

Returns: rdbuf()->is_open().

void open(const char* s, ios_base::openmode mode = ios_base::in);

Effects: Calls rdbuf()->open(s, mode | ios_base::in). If that function does not return a null pointer calls clear(), otherwise calls setstate(failbit) (which may throw ios_base::failure(27.4.4.3)).

void open(const string& s, ios_base::openmode mode = ios_base::in);

Effects: calls open(s.c_str(), mode).

void close();

Effects: Calls rdbuf()->close() and, if that function returns false, calls setstate(failbit) (which may throw ios_base::failure(27.4.4.3)).

27.8.1.8 Class template basic_ofstream [lib.ofstream]

namespace std {
    template <class charT, class traits = char_traits<charT> >
    class basic_ofstream : public basic_ostream<charT,traits> {
    public:
        typedef charT char_type;
        typedef typename traits::int_type int_type;
        typedef typename traits::pos_type pos_type;
        typedef typename traits::off_type off_type;
        typedef traits traits_type;
    }
}

332) A successful open does not change the error state.
// 27.8.1.9 Constructors:
basic_ofstream();
explicit basic_ofstream(const char* s,
    ios_base::openmode mode = ios_base::out);
explicit basic_ofstream(const string& s,
    ios_base::openmode mode = ios_base::out);

// 27.8.1.10 Members:
basic_filebuf<charT,traits>* rdbuf() const;
bool is_open() const;
void open(const char* s, ios_base::openmode mode = ios_base::out);
void open(const string& s, ios_base::openmode mode = ios_base::out);
void close();
private:
    // basic_filebuf<charT,traits> sb;
};

The class basic_ofstream<charT, traits> supports writing to named files. It uses a basic_filebuf<charT, traits> object to control the associated sequence. For the sake of exposition, the maintained data is presented here as:

— sb, the filebuf object.

27.8.1.9 basic_ofstream constructors

basic_ofstream();

Effects: Constructs an object of class basic_ofstream<charT, traits>, initializing the base class with basic_ostream(&sb) and initializing sb with basic_filebuf<charT, traits>().

explicit basic_ofstream(const char* s,
    ios_base::openmode mode = ios_base::out);

Effects: Constructs an object of class basic_ofstream<charT, traits>, initializing the base class with basic_ostream(&sb) and initializing sb with basic_filebuf<charT, traits>(). Then calls rdbuf()->open(s, mode|ios_base::out). If that function returns a null pointer, calls setstate(fail-bit).

explicit basic_ofstream(const string& s, ios_base::openmode mode = ios_base::out);

Effects: the same as basic_ofstream(s.c_str(), mode);@

27.8.1.10 Member functions

basic_filebuf<charT,traits>* rdbuf() const;

Returns: const_cast<basic_filebuf<charT,traits>*>(&sb).

bool is_open() const;

Draft
Returns: rdbuf()->is_open().

```cpp
void open(const char* s, ios_base::openmode mode = ios_base::out);
```

Effects: Calls rdbuf()->open(s, mode | ios_base::out). If that function does not return a null pointer calls clear(), otherwise calls setstate(failbit) (which may throw ios_base::failure (27.4.4.3)).

```cpp
void close();
```

Effects: Calls rdbuf()->close() and, if that function fails (returns a null pointer), calls setstate(failbit) (which may throw ios_base::failure (27.4.4.3)).

```cpp
void open(const string& s, ios_base::openmode mode = ios_base::out);
```

Effects: calls open(s.c_str(), mode);

### 27.8.1.11 Class template basic_fstream

```cpp
namespace std {
    template <class charT, class traits=char_traits<charT> >
    class basic_fstream
        : public basic_iostream<charT,traits> {

    public:
        typedef charT char_type;
        typedef typename traits::int_type int_type;
        typedef typename traits::pos_type pos_type;
        typedef typename traits::off_type off_type;
        typedef traits traits_type;

        // constructors/destructor
        basic_fstream();
        explicit basic_fstream(const char* s,
                                 ios_base::openmode mode = ios_base::in|ios_base::out);
        explicit basic_fstream(const string& s,
                                 ios_base::openmode mode = ios_base::in|ios_base::out);

        // Members:
        basic_filebuf<charT,traits>* rdbuf() const;
        bool is_open() const;
        void open(const char* s,
                   ios_base::openmode mode = ios_base::in|ios_base::out);
        void open(const string& s,
                   ios_base::openmode mode = ios_base::in|ios_base::out);
        void close();

    private:
        // basic_filebuf<charT,traits> sb;
    };
```

---

333) A successful open does not change the error state.
The class template basic_fstream<charT, traits> supports reading and writing from named files. It uses a basic_filebuf<charT, traits> object to control the associated sequences. For the sake of exposition, the maintained data is presented here as:

— sb, the basic_filebuf object.

27.8.1.12 basic_fstream constructors

basic_fstream();

Effects: Constructs an object of class basic_fstream<charT, traits>, initializing the base class with basic_istream(&sb) and initializing sb with basic_filebuf<charT, traits>().

explicit basic_fstream(const char* s,
ios_base::openmode mode = ios_base::in|ios_base::out);

Effects: Constructs an object of class basic_fstream<charT, traits>, initializing the base class with basic_istream(&sb) and initializing sb with basic_filebuf<charT, traits>(). Then calls rdbuf()->open(s, mode). If that function returns a null pointer, calls setstate(failbit).

explicit basic_fstream(const string& s, ios_base::openmode mode = ios_base::in|ios_base::out);

Effects: the same as basic_fstream(s.c_str(), mode);

27.8.1.13 Member functions

basic_filebuf<charT, traits>** rdbuf() const;

Returns: const_cast<basic_filebuf<charT, traits>*>(&sb).

bool is_open() const;

Returns: rdbuf()->is_open().

void open(const char* s,
ios_base::openmode mode = ios_base::in|ios_base::out);

Effects: Calls rdbuf()->open(s, mode). If that function does not return a null pointer calls clear(), otherwise calls setstate(failbit), (which may throw ios_base::failure) (27.4.4.3).

void open(const string& s, ios_base::openmode mode = ios_base::in|ios_base::out);

Effects: calls open(s.c_str(), mode);

void close();

Effects: Calls rdbuf()->close() and, if that function returns false, calls setstate(failbit) (27.4.4.3) (which may throw ios_base::failure).
27.8.2 C Library files

Table 114 describes header `<stdio.h>`.

Table 114: Header `<stdio.h>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td></td>
</tr>
<tr>
<td>BUFSIZ</td>
<td>FOPEN_MAX</td>
</tr>
<tr>
<td>EOF</td>
<td>L_tmpnam</td>
</tr>
<tr>
<td>NULL</td>
<td>SEEK_SET</td>
</tr>
<tr>
<td>Types:</td>
<td>FILE</td>
</tr>
<tr>
<td>Functions:</td>
<td></td>
</tr>
<tr>
<td>clearerr</td>
<td>fopen</td>
</tr>
<tr>
<td>fclose</td>
<td>fprintf</td>
</tr>
<tr>
<td>feof</td>
<td>fputc</td>
</tr>
<tr>
<td>ferror</td>
<td>fputs</td>
</tr>
<tr>
<td>fflush</td>
<td>fread</td>
</tr>
<tr>
<td>fgetc</td>
<td>freopen</td>
</tr>
<tr>
<td>fgetpos</td>
<td>fscanf</td>
</tr>
<tr>
<td>fgets</td>
<td>fseek</td>
</tr>
</tbody>
</table>

SEE ALSO: ISO C subclause 7.9, Amendment 1 subclause 4.6.2.

Table 115 describes header `<cinttypes.h>`.

Table 115: Header `<cinttypes.h>` synopsis

<table>
<thead>
<tr>
<th>Type</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros:</td>
<td></td>
</tr>
<tr>
<td>PRI{d i o u x}{FAST LEAST}{8 16 32 64}</td>
<td>imaxdiv_t</td>
</tr>
<tr>
<td>PRI{d i o u x}{MAX PTR}</td>
<td></td>
</tr>
<tr>
<td>SCN{d i o u x}{FAST LEAST}{8 16 32 64}</td>
<td></td>
</tr>
<tr>
<td>SCN{d i o u x}{MAX_PTR}</td>
<td></td>
</tr>
<tr>
<td>Types:</td>
<td>imaxdiv_t</td>
</tr>
<tr>
<td>Functions:</td>
<td></td>
</tr>
<tr>
<td>abs</td>
<td>imaxabs</td>
</tr>
<tr>
<td>div</td>
<td>imaxdiv</td>
</tr>
</tbody>
</table>
Chapter 28  TR1: Regular expressions library[lib.re]

This clause describes components that C++ programs may use to perform operations involving regular expression matching and searching.

28.1 Definitions [lib.re.def]

1 The following definitions shall apply to this clause:

2 **Collating element**: A sequence of one or more characters within the current locale that collate as if they were a single character.

3 **Finite state machine**: An unspecified data structure that is used to represent a regular expression, and which permits efficient matches against the regular expression to be obtained.

4 **Format specifier**: A sequence of one or more characters that is to be replaced with some part of a regular expression match.

5 **Matched**: A sequence of zero or more characters shall be said to be matched by a regular expression when the characters in the sequence correspond to a sequence of characters defined by the pattern.

6 **Primary equivalence class**: A set of one or more characters which share the same primary sort key: that is the sort key weighting that depends only upon character shape, and not accentation, case, or locale specific tailorings.

7 **Regular expression**: A pattern that selects specific strings from a set of character strings.

8 **Sub-expression**: A subset of a regular expression that has been marked by parenthesis.

28.2 Requirements [lib.re.req]

1 This subclause defines requirements on classes representing regular expression traits. [Note: The class template `regex_traits`, defined in clause 28.7, satisfies these requirements. —end note ]

2 The class template `basic_regex`, defined in clause 28.8, needs a set of related types and functions to complete the definition of its semantics. These types and functions are provided as a set of member typedefs and functions in the template parameter `traits` used by the `basic_regex` class template. This subclause defines the semantics guaranteed by these members.

3 To specialize class template `basic_regex` for a character container `CharT` and its related regular expression traits class `Traits`, use `basic_regex<CharT, Traits>`,.

4 In Table 116 `X` denotes a traits class defining types and functions for the character container type `CharT`; `u` is an object of type `X`; `v` is an object of type `const X`; `p` is a value of type `const CharT*`; `I1` and `I2` are Input Iterators; `F1` and `F2` are forward iterators; `c` is a value of type `const CharT`; `s` is an object of type `X::string_type`; `cs` is an
object of type \texttt{const X::string_type}; \(b\) is a value of type \texttt{bool}; \(I\) is a value of type \texttt{int}; \(cl\) is an object of type \texttt{X::char_class_type}, and \(loc\) is an object of type \texttt{X::locale_type}.

### Table 116: regular expression traits class requirements

<table>
<thead>
<tr>
<th>expression</th>
<th>Return Type</th>
<th>Assertion / Note / Pre / Post condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{X::char_type}</td>
<td>\texttt{charT}</td>
<td>The character container type used in the implementation of class template \texttt{basic_regex}.</td>
</tr>
<tr>
<td>\texttt{X::string_type}</td>
<td>\texttt{std::basic_string&lt;charT&gt;}</td>
<td></td>
</tr>
<tr>
<td>\texttt{X::locale_type}</td>
<td>A copy constructible type</td>
<td>A type that represents the locale used by the traits class.</td>
</tr>
<tr>
<td>\texttt{X::char_class_type}</td>
<td>A bitmask type [lib.bitmask.types].</td>
<td>A bitmask type representing a particular character classification.</td>
</tr>
<tr>
<td>\texttt{X::length(p)}</td>
<td>\texttt{std::size_t}</td>
<td>Yields the smallest (i) such that (p[i] == 0). Complexity is linear in (i).</td>
</tr>
<tr>
<td>(v).\texttt{translate(c)}</td>
<td>\texttt{X::char_type}</td>
<td>Returns a character such that for any character (d) that is to be considered equivalent to (c) then (v).\texttt{translate}(c) == v).\texttt{translate}(d).</td>
</tr>
<tr>
<td>(v).\texttt{translate_nocase(c)}</td>
<td>\texttt{X::char_type}</td>
<td>For all characters (C) that are to be considered equivalent to (c) when comparisons are to be performed without regard to case, then (v).\texttt{translate_nocase}(c) == v).\texttt{translate_nocase}(C).</td>
</tr>
<tr>
<td>(v).\texttt{transform(F1, F2)}</td>
<td>\texttt{X::string_type}</td>
<td>Returns a sort key for the character sequence designated by the iterator range ([F1, F2)) such that if the character sequence ([G1, G2)) sorts before the character sequence ([H1, H2)) then (v).\texttt{transform}(G1, G2) &lt; v).\texttt{transform}(H1, H2).</td>
</tr>
<tr>
<td>(v).\texttt{transform_primary(F1, F2)}</td>
<td>\texttt{X::string_type}</td>
<td>Returns a sort key for the character sequence designated by the iterator range ([F1, F2)) such that if the character sequence ([G1, G2)) sorts before the character sequence ([H1, H2)) when character case is not considered then (v).\texttt{transform_primary}(G1, G2) &lt; v).\texttt{transform_primary}(H1, H2).</td>
</tr>
<tr>
<td>(v).\texttt{lookup_collatename(F1, F2)}</td>
<td>\texttt{X::string_type}</td>
<td>Returns a sequence of characters that represents the collating element consisting of the character sequence designated by the iterator range ([F1, F2)). Returns an empty string if the character sequence is not a valid collating element.</td>
</tr>
</tbody>
</table>
883 TR1: Regular expressions library

28.3 Regular expressions summary

<table>
<thead>
<tr>
<th>expression</th>
<th>Return Type</th>
<th>Assertion / Note / Pre / Post condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>v.lookup_classname(F1, F2)</td>
<td>X::char_class_type</td>
<td>Converts the character sequence designated by the iterator range [F1,F2) into a value of a bitmask type that can subsequently be passed to isctype. Values returned from lookup_classname can be bitwise or’ed together; the resulting value represents membership in either of the corresponding character classes. Returns 0 if the character sequence is not the name of a character class recognized by X. The value returned shall be independent of the case of the characters in the sequence.</td>
</tr>
<tr>
<td>v.isctype(c, cl)</td>
<td>bool</td>
<td>Returns true if character c is a member of one of the character classes designated by cl, false otherwise.</td>
</tr>
<tr>
<td>v.value(c, I)</td>
<td>int</td>
<td>Returns the value represented by the digit c in base I if the character c is a valid digit in base I; otherwise returns -1. [Note: the value of I will only be 8, 10, or 16. — end note]</td>
</tr>
<tr>
<td>u.imbue(loc)</td>
<td>X::locale_type</td>
<td>Imbues u with the locale loc and returns the previous locale used by u if any.</td>
</tr>
<tr>
<td>v.getloc()</td>
<td>X::locale_type</td>
<td>Returns the current locale used by v, if any.</td>
</tr>
</tbody>
</table>

[Note: Class template regex_traits satisfies the requirements for a regular expression traits class when it is specialized for char or wchar_t. This Class template is described in the header <regex>, and is described in clause 28.7. — end note]

28.4 Header <regex> synopsis

namespace std {

    // 28.5. regex constants:
    namespace regex_constants { 
        typedef bitmask_type syntax_option_type; 
        typedef bitmask_type match_flag_type; 
        typedef implementation-defined error_type; 

Draft
28.4  Header `<regex>` synopsis

```cpp
} // namespace regex_constants

// 28.6, class regex_error:
class regex_error;

// 28.7, class template regex_traits:
template <class charT> struct regex_traits;

// 28.8, class template basic_regex:
template <class charT, class traits = regex_traits<charT>> class basic_regex;

typedef basic_regex<char>  regex;
typedef basic_regex<wchar_t> wregex;

// 28.8.6, basic_regex swap:
template <class charT, class traits> 
  void swap(basic_regex<charT, traits>& e1, basic_regex<charT, traits>& e2);

// 28.9, class template sub_match:
template <class BidirectionalIterator>
  class sub_match;

typedef sub_match<const char*>  csub_match;
typedef sub_match<const wchar_t*> wcsub_match;
typedef sub_match<string::const_iterator> ssub_match;
typedef sub_match<wstring::const_iterator> wssub_match;

// 28.9.2, sub_match non-member operators:
template <class BiIter>
  bool operator==(const sub_match<BiIter>& lhs, const sub_match<BiIter>& rhs);
template <class BiIter>
  bool operator!=(const sub_match<BiIter>& lhs, const sub_match<BiIter>& rhs);
template <class BiIter>
  bool operator<(const sub_match<BiIter>& lhs, const sub_match<BiIter>& rhs);
template <class BiIter>
  bool operator<=(const sub_match<BiIter>& lhs, const sub_match<BiIter>& rhs);
template <class BiIter>
  bool operator>(const sub_match<BiIter>& lhs, const sub_match<BiIter>& rhs);
template <class BiIter>
  bool operator>=(const sub_match<BiIter>& lhs, const sub_match<BiIter>& rhs);

template <class BiIter, class ST, class SA>
  bool operator==(
    const basic_string<
      typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);
template <class BiIter, class ST, class SA>
  bool operator!=(
    const basic_string<
      typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);
```

Draft
typedef typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

template <class BiIter, class ST, class SA>
bool operator<(
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

template <class BiIter, class ST, class SA>
bool operator>>(
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

template <class BiIter, class ST, class SA>
bool operator<=(
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

template <class BiIter, class ST, class SA>
bool operator>=(
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

template <class BiIter, class ST, class SA>
bool operator==(const sub_match<BiIter>& lhs,
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

template <class BiIter, class ST, class SA>
bool operator!=(const sub_match<BiIter>& lhs,
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

template <class BiIter, class ST, class SA>
bool operator<(const sub_match<BiIter>& lhs,
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

template <class BiIter, class ST, class SA>
bool operator>(const sub_match<BiIter>& lhs,
    const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

Draft
const sub_match<BiIter>& lhs,
const basic_string<typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

template <class BiIter>
bool operator==(typename iterator_traits<BiIter>::value_type const* lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator!=(typename iterator_traits<BiIter>::value_type const* lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator<(typename iterator_traits<BiIter>::value_type const* lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator>(typename iterator_traits<BiIter>::value_type const* lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator>=(typename iterator_traits<BiIter>::value_type const* lhs,
                const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator<=(typename iterator_traits<BiIter>::value_type const* lhs,
                const sub_match<BiIter>& rhs);  

template <class BiIter>
bool operator==(const sub_match<BiIter>& lhs,
               typename iterator_traits<BiIter>::value_type const* rhs);  
template <class BiIter>
bool operator!=(const sub_match<BiIter>& lhs,
               typename iterator_traits<BiIter>::value_type const* rhs);  
template <class BiIter>
bool operator<(const sub_match<BiIter>& lhs,
               typename iterator_traits<BiIter>::value_type const* rhs);  
template <class BiIter>
bool operator>(const sub_match<BiIter>& lhs,
               typename iterator_traits<BiIter>::value_type const* rhs);  
template <class BiIter>
bool operator>=(const sub_match<BiIter>& lhs,
                typename iterator_traits<BiIter>::value_type const* rhs);  
template <class BiIter>
bool operator<=(const sub_match<BiIter>& lhs,
                typename iterator_traits<BiIter>::value_type const* rhs);  

template <class BiIter>
bool operator==(typename iterator_traits<BiIter>::value_type const& lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator!=(typename iterator_traits<BiIter>::value_type const& lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator<(typename iterator_traits<BiIter>::value_type const& lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator>(typename iterator_traits<BiIter>::value_type const& lhs,
               const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator>=(typename iterator_traits<BiIter>::value_type const& lhs,
                const sub_match<BiIter>& rhs);  
template <class BiIter>
bool operator<=(typename iterator_traits<BiIter>::value_type const& lhs,
                const sub_match<BiIter>& rhs);  

Draft
const sub_match<BiIter>& rhs);

template <class BiIter>
  bool operator<(typename iterator_traits<BiIter>::value_type const& lhs,
                const sub_match<BiIter>& rhs);

template <class BiIter>
  bool operator<=(typename iterator_traits<BiIter>::value_type const& lhs,
                 const sub_match<BiIter>& rhs);

template <class BiIter>
  bool operator==(const sub_match<BiIter>& lhs,
                 typename iterator_traits<BiIter>::value_type const& rhs);

template <class BiIter>
  bool operator!=(const sub_match<BiIter>& lhs,
                 typename iterator_traits<BiIter>::value_type const& rhs);

template <class BiIter>
  bool operator>(const sub_match<BiIter>& lhs,
                 typename iterator_traits<BiIter>::value_type const& rhs);

template <class BiIter>
  bool operator>=(const sub_match<BiIter>& lhs,
                  typename iterator_traits<BiIter>::value_type const& rhs);

template <class charT, class ST, class BiIter>
  basic_ostream<charT, ST>&
  operator<<(basic_ostream<charT, ST>& os, const sub_match<BiIter>& m);

// 28.10, class template match_results:

template <class BidirectionalIterator, class Allocator = allocator<sub_match<BidirectionalIterator> > >
class match_results;

typedef match_results<const char*> cmatch;

typedef match_results<const wchar_t*> wcmatch;

typedef match_results<string::const_iterator> smatch;

typedef match_results<wstring::const_iterator> wsmatch;

// match_results comparisons

template <class BidirectionalIterator, class Allocator>
  bool operator==(const match_results<BidirectionalIterator, Allocator>& m1,
                  const match_results<BidirectionalIterator, Allocator>& m2);

template <class BidirectionalIterator, class Allocator>
  bool operator!=(const match_results<BidirectionalIterator, Allocator>& m1,
const match_results<BidirectionalIterator, Allocator>& m2);

// 28.10.6, match_results swap:
template <class BidirectionalIterator, class Allocator>
    void swap(match_results<BidirectionalIterator, Allocator>& m1,
              match_results<BidirectionalIterator, Allocator>& m2);

// 28.11.2, function template regex_match:
template <class BidirectionalIterator, class Allocator, 
          class charT, class traits>
    bool regex_match(BidirectionalIterator first, BidirectionalIterator last, 
                     match_results<BidirectionalIterator, Allocator>& m, 
                     const basic_regex<charT, traits>& e, 
                     regex_constants::match_flag_type flags = 
                     regex_constants::match_default);
template <class BidirectionalIterator, class charT, class traits>
    bool regex_match(BidirectionalIterator first, BidirectionalIterator last, 
                     const basic_regex<charT, traits>& e, 
                     regex_constants::match_flag_type flags = 
                     regex_constants::match_default);
template <class charT, class Allocator, class traits>
    bool regex_match(const charT* str, match_results<const charT*, Allocator>& m, 
                     const basic_regex<charT, traits>& e, 
                     regex_constants::match_flag_type flags = 
                     regex_constants::match_default);
template <class ST, class SA, class Allocator, class charT, class traits>
    bool regex_match(const basic_string<charT, ST, SA>& s, 
                     match_results<
                        typename basic_string<charT, ST, SA>::const_iterator,
                        Allocator>& m, 
                     const basic_regex<charT, traits>& e, 
                     regex_constants::match_flag_type flags = 
                     regex_constants::match_default);
template <class charT, class traits>
    bool regex_match(const charT* str, 
                     const basic_regex<charT, traits>& e, 
                     regex_constants::match_flag_type flags = 
                     regex_constants::match_default);
template <class ST, class SA, class charT, class traits>
    bool regex_match(const basic_string<charT, ST, SA>& s, 
                     const basic_regex<charT, traits>& e, 
                     regex_constants::match_flag_type flags = 
                     regex_constants::match_default);

// 28.11.3, function template regex_search:
template <class BidirectionalIterator, class Allocator, 
          class charT, class traits>
    bool regex_search(BidirectionalIterator first, BidirectionalIterator last, 
                     match_results<BidirectionalIterator, Allocator>& m, 
                     const basic_regex<charT, traits>& e,
**regex_constants::match_flag_type flags =
regex_constants::match_default);**

template <class BidirectionalIterator, class charT, class traits>
bool regex_search(BidirectionalIterator first, BidirectionalIterator last,
const basic_regex<charT, traits>& e,
regex_constants::match_flag_type flags =
regex_constants::match_default);

template <class charT, class Allocator, class traits>
bool regex_search(const charT* str,
match_results<const charT*, Allocator>& m,
const basic_regex<charT, traits>& e,
regex_constants::match_flag_type flags =
regex_constants::match_default);

template <class charT, class traits>
bool regex_search(const charT* str,
const basic_regex<charT, traits>& e,
regex_constants::match_flag_type flags =
regex_constants::match_default);

template <class ST, class SA, class charT, class traits>
bool regex_search(const basic_string<charT, ST, SA>& s,
const basic_regex<charT, traits>& e,
regex_constants::match_flag_type flags =
regex_constants::match_default);

template <class ST, class SA, class Allocator, class charT, class traits>
bool regex_search(const basic_string<charT, ST, SA>& s,
match_results<typename basic_string<charT, ST, SA>::const_iterator,
Allocator>& m,
const basic_regex<charT, traits>& e,
regex_constants::match_flag_type flags =
regex_constants::match_default);

// **28.11.4, function template regex_replace:**
template <class OutputIterator, class BidirectionalIterator,
class traits, class charT>
OutputIterator
regex_replace(OutputIterator out,
BidirectionalIterator first, BidirectionalIterator last,
const basic_regex<charT, traits>& e,
const basic_string<charT>& fmt,
regex_constants::match_flag_type flags =
regex_constants::match_default);

template <class traits, class charT>
basic_string<charT>
regex_replace(const basic_string<charT>& s,
const basic_regex<charT, traits>& e,
const basic_string<charT>& fmt,
regex_constants::match_flag_type flags =
regex_constants::match_default);
The namespace `tr1::regex_constants` holds symbolic constants used by the regular expression library. This namespace provides three types, `syntax_option_type`, `match_flag_type`, and `error_type`, along with several constants of these types.

### 28.5.1 Bitmask Type `syntax_option_type`

```cpp
namespace regex_constants {
    typedef bitmask_type syntax_option_type;
    static const syntax_option_type icase;
    static const syntax_option_type nosubs;
    static const syntax_option_type optimize;
    static const syntax_option_type collate;
    static const syntax_option_type ECMAScript;
    static const syntax_option_type basic;
    static const syntax_option_type extended;
    static const syntax_option_type awk;
    static const syntax_option_type grep;
    static const syntax_option_type egrep;
} // namespace regex_constants
```

The type `syntax_option_type` is an implementation defined bitmask type ([lib.bitmask.types]). Setting its elements has the effects listed in table 117. A valid value of type `syntax_option_type` shall have exactly one of the elements
### Table 117: syntax_option_type effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Effect(s) if set</th>
</tr>
</thead>
<tbody>
<tr>
<td>icase</td>
<td>Specifies that matching of regular expressions against a character container se-</td>
</tr>
<tr>
<td></td>
<td>quence shall be performed without regard to case.</td>
</tr>
<tr>
<td>nosubs</td>
<td>Specifies that when a regular expression is matched against a character container</td>
</tr>
<tr>
<td></td>
<td>sequence, no sub-expression matches are to be stored in the supplied match_ -</td>
</tr>
<tr>
<td></td>
<td>results structure.</td>
</tr>
<tr>
<td>optimize</td>
<td>Specifies that the regular expression engine should pay more attention to the</td>
</tr>
<tr>
<td></td>
<td>speed with which regular expressions are matched, and less to the speed with</td>
</tr>
<tr>
<td></td>
<td>which regular expression objects are constructed. Otherwise it has no detectable</td>
</tr>
<tr>
<td></td>
<td>effect on the program output.</td>
</tr>
<tr>
<td>collate</td>
<td>Specifies that character ranges of the form “[a-b]” should be locale sensitive.</td>
</tr>
<tr>
<td>ECMAScript</td>
<td>Specifies that the grammar recognized by the regular expression engine is that</td>
</tr>
<tr>
<td></td>
<td>used by ECMAScript in ECMA-262, as modified in [28.13].</td>
</tr>
<tr>
<td>basic</td>
<td>Specifies that the grammar recognized by the regular expression engine is that</td>
</tr>
<tr>
<td></td>
<td>used by basic regular expressions in POSIX, Base Definitions and Headers, Sec-</td>
</tr>
<tr>
<td></td>
<td>tion 9, Regular Expressions.</td>
</tr>
<tr>
<td>extended</td>
<td>Specifies that the grammar recognized by the regular expression engine is that</td>
</tr>
<tr>
<td></td>
<td>used by extended regular expressions in POSIX, Base Definitions and Headers,</td>
</tr>
<tr>
<td></td>
<td>Section 9, Regular Expressions.</td>
</tr>
<tr>
<td>awk</td>
<td>Specifies that the grammar recognized by the regular expression engine is that</td>
</tr>
<tr>
<td></td>
<td>used by the utility awk in POSIX.</td>
</tr>
<tr>
<td>grep</td>
<td>Specifies that the grammar recognized by the regular expression engine is that</td>
</tr>
<tr>
<td></td>
<td>used by the utility grep in POSIX.</td>
</tr>
<tr>
<td>egrep</td>
<td>Specifies that the grammar recognized by the regular expression engine is that</td>
</tr>
<tr>
<td></td>
<td>used by the utility grep when given the -E option in POSIX.</td>
</tr>
</tbody>
</table>
ECMAScript, basic, extended, awk, grep, egrep, set.

28.5.2 Bitmask Type regex_constants::match_flag_type

namespace regex_constants{
    typedef bitmask_type regex_constants::match_flag_type;

    static const match_flag_type match_default = 0;
    static const match_flag_type match_not_bol;
    static const match_flag_type match_not_eol;
    static const match_flag_type match_not_bow;
    static const match_flag_type match_not_eow;
    static const match_flag_type match_any;
    static const match_flag_type match_not_null;
    static const match_flag_type match_continuous;
    static const match_flag_type match_prev_avail;
    static const match_flag_type format_default = 0;
    static const match_flag_type format_sed;
    static const match_flag_type format_no_copy;
    static const match_flag_type format_first_only;
}

The type regex_constants::match_flag_type is an implementation defined bitmask type ([lib.bitmask.types]). Matching a regular expression against a sequence of characters [first, last) proceeds according to the rules of the grammar specified for the regular expression object, modified according to the effects listed in table 118 for any bitmask elements set.

<table>
<thead>
<tr>
<th>Element</th>
<th>Effect(s) if set</th>
</tr>
</thead>
<tbody>
<tr>
<td>match_not_bol</td>
<td>The first character in the sequence [first, last) is treated as though it is not at the beginning of a line, so the character &quot;^&quot; in the regular expression shall not match [first, first).</td>
</tr>
<tr>
<td>match_not_eol</td>
<td>The last character in the sequence [first, last) is treated as though it is not at the end of a line, so the character &quot;$&quot; in the regular expression shall not match [last, last).</td>
</tr>
<tr>
<td>match_not_bow</td>
<td>The expression \b is not matched against the sub-sequence [first,first).</td>
</tr>
<tr>
<td>match_not_eow</td>
<td>The expression \b should not be matched against the sub-sequence [last,last).</td>
</tr>
<tr>
<td>match_any</td>
<td>If more than one match is possible then any match is an acceptable result.</td>
</tr>
<tr>
<td>match_not_null</td>
<td>The expression does not match an empty sequence.</td>
</tr>
<tr>
<td>match_continuous</td>
<td>The expression only matches a sub-sequence that begins at first.</td>
</tr>
<tr>
<td>match_prev_avail</td>
<td>Second first is a valid iterator position. When this flag is set then the flags match_not_bol and match_not_bow are ignored by the regular expression algorithms 28.11 and iterators 28.12.</td>
</tr>
</tbody>
</table>
When a regular expression match is to be replaced by a new string, the new string is constructed using the rules used by the ECMAScript replace function in ECMA-262, part 15.4.11 String.prototype.replace. In addition, during search and replace operations all non-overlapping occurrences of the regular expression are located and replaced, and sections of the input that did not match the expression are copied unchanged to the output string.

When a regular expression match is to be replaced by a new string, the new string is constructed using the rules used by the sed utility in POSIX.

During a search and replace operation, sections of the character container sequence being searched that do not match the regular expression shall not be copied to the output string.

When specified during a search and replace operation, only the first occurrence of the regular expression shall be replaced.

### Implementation defined `error_type`

```cpp
namespace regex_constants {
    typedef implementation defined error_type;

    static const error_type error_collate;
    static const error_type error_ctype;
    static const error_type error_escape;
    static const error_type error_backref;
    static const error_type error_brack;
    static const error_type error_paren;
    static const error_type error_brace;
    static const error_type error_badbrace;
    static const error_type error_range;
    static const error_type error_space;
    static const error_type error_badrepeat;
    static const error_type error_complexity;
    static const error_type error_stack;
} // namespace regex_constants
```

The type `error_type` is an implementation defined enumeration type ([lib.enumerated.types]). Values of type `error_type` represent the error conditions described in table 119:

<table>
<thead>
<tr>
<th>Value</th>
<th>Error condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>error_collate</td>
<td>The expression contained an invalid collating element name.</td>
</tr>
<tr>
<td>error_ctype</td>
<td>The expression contained an invalid character class name.</td>
</tr>
<tr>
<td>error_escape</td>
<td>The expression contained an invalid escaped character, or a trailing escape.</td>
</tr>
<tr>
<td>error_backref</td>
<td>The expression contained an invalid back reference.</td>
</tr>
<tr>
<td>error_brack</td>
<td>The expression contained mismatched <code>[ and </code>].</td>
</tr>
<tr>
<td>error_paren</td>
<td>The expression contained mismatched <code>( and </code>).</td>
</tr>
</tbody>
</table>

Draft
The expression contained mismatched \{ and \}.

The expression contained an invalid range in a \{ expression.

The expression contained an invalid character range, such as \[b-a\] in most encodings.

There was insufficient memory to convert the expression into a finite state machine.

One of *?+{ was not preceded by a valid regular expression.

The complexity of an attempted match against a regular expression exceeded a pre-set level.

There was insufficient memory to determine whether the regular expression could match the specified character sequence.

### 28.6 Class `regex_error` [lib.re.badexp]

```cpp
class regex_error : public std::runtime_error
{
    public:
        explicit regex_error(regex_constants::error_type ecode);
        regex_constants::error_type code() const;
    };
```

1. The class `regex_error` defines the type of objects thrown as exceptions to report errors from the regular expression library.

```cpp
regex_error(regex_constants::error_type ecode);
```

*Effects:* Constructs an object of class `regex_error`.

*Postcondition:* `ecode == code()`

```cpp
regex_constants::error_type code() const;
```

*Returns:* The error code that was passed to the constructor.

### 28.7 Class template `regex_traits` [lib.re.traits]

```cpp
template <class charT>
struct regex_traits
{
    public:
        typedef charT char_type;
        typedef std::basic_string<char_type> string_type;
        typedef std::locale locale_type;
        typedef bitmask_type char_class_type;

        regex_traits();
        static std::size_t length(const char_type* p);
        charT translate(charT c) const;
};
```

Draft
The specializations `regex_traits<char>` and `regex_traits<wchar_t>` shall be valid and shall satisfy the requirements for a regular expression traits class (28.2).

typedef bitmask_type char_class_type;

The type `char_class_type` is used to represent a character classification and is capable of holding an implementation-specific set returned by `lookup_classname`.

```
static std::size_t length(const char_type* p);
```

Returns: `char_traits<charT>::length(p);`

```
charT translate(charT c) const;
```

Returns: `(c)`.

```
charT translate_nocase(charT c) const;
```

Returns: `use_facet<ctype<charT>>>(getloc()).tolower(c).`

```
template <class ForwardIterator>
  string_type transform(ForwardIterator first, ForwardIterator last) const;
```

Effects:

```
string_type str(first, last);
return use_facet<collate<charT>>>(
    getloc()).transform(&str.begin(), &str.end());
```

```
template <class ForwardIterator>
  string_type transform_primary(ForwardIterator first, ForwardIterator last) const;
```

Effects: if `typeid(use_facet<collate<charT>>) == typeid(collate_byname<charT>)` and the form of the sort key returned by `collate_byname<charT>::transform(first, last)` is known and can be converted into a primary sort key then returns that key, otherwise returns an empty string.
28.7 Class template `regex_traits`  

TR1: Regular expressions library 896

```
template <class ForwardIterator>
string_type lookup_collatename(ForwardIterator first, ForwardIterator last) const;

Returns: a sequence of one or more characters that represents the collating element consisting of the character sequence designated by the iterator range `[first, last)`. Returns an empty string if the character sequence is not a valid collating element.

template <class ForwardIterator>
char_class_type lookup_classname(ForwardIterator first, ForwardIterator last) const;

Returns: an unspecified value that represents the character classification named by the character sequence designated by the iterator range `[first, last)`. The value returned shall be independent of the case of the characters in the character sequence. If the name is not recognized then returns a value that compares equal to 0.

Remarks: For `regex_traits<char>`, at least the names "d", "w", "s", "alnum", "alpha", "blank", "cntrl", "digit", "graph", "lower", "print", "punct", "space", "upper" and "xdigit" shall be recognized. For `regex_traits<wchar_t>`, at least the names L"d", L"w", L"s", L"alnum", L"alpha", L"blank", L"cntrl", L"digit", L"graph", L"lower", L"print", L"punct", L"space", L"upper" and L"xdigit" shall be recognized.

bool isctype(charT c, char_class_type f) const;

Effects: Determines if the character `c` is a member of the character classification represented by `f`.

Returns: Converts `f` into a value `m` of type `std::ctype_base::mask` in an unspecified manner, and returns true if `use_facet<ctype<charT>>(getloc()).is(c, m)` is true. Otherwise returns true if `f` bitwise or'ed with the result of calling `lookup_classname` with an iterator pair that designates the character sequence "w" is not equal to 0 and `c == '_'`, or if `f` bitwise or'ed with the result of calling `lookup_classname` with an iterator pair that designates the character sequence "blank" is not equal to 0 and `c` is one of an implementation-defined subset of the characters for which `isspace(c, getloc())` returns true, otherwise returns false.

int value(charT ch, int radix) const;

Precondition: The value of `radix` shall be 8, 10, or 16.

Returns: The value represented by the digit `ch` in base `radix` if the character `ch` is a valid digit in base `radix`; otherwise returns -1.

locale_type imbue(locale_type loc);

Effects: Imbues this with a copy of the locale `loc`. [Note: calling `imbue` with a different locale than the one currently in use invalidates all cached data held by `*this`. —end note]

Returns: if no locale has been previously imbued then a copy of the global locale in effect at the time of construction of `*this`, otherwise a copy of the last argument passed to `imbue`.

Postcondition: `getloc() == loc`.

locale_type getloc() const;

Returns: if no locale has been imbued then a copy of the global locale in effect at the time of construction of `*this`, otherwise a copy of the last argument passed to `imbue`.
```
For a char-like type charT, specializations of class template basic_regex represent regular expressions constructed from character sequences of charT characters. In the rest of 28.8, charT denotes a given char-like type. Storage for a regular expression is allocated and freed as necessary by the member functions of class basic_regex.

Objects of type specialization of basic_regex are responsible for converting the sequence of charT objects to an internal representation. It is not specified what form this representation takes, nor how it is accessed by algorithms that operate on regular expressions. [Note: implementations will typically declare some function templates as friends of basic_regex to achieve this — end note ]

The functions described in this clause report errors by throwing exceptions of type regex_error.

```cpp
template <class charT,
         class traits = regex_traits<charT> >
class basic_regex
{
  public:
    // types:
    typedef charT value_type;
    typedef regex_constants::syntax_option_type flag_type;
    typedef typename traits::locale_type locale_type;

    // 28.8.1, constants:
    static const regex_constants::syntax_option_type icase = regex_constants::icase;
    static const regex_constants::syntax_option_type nosubs = regex_constants::nosubs;
    static const regex_constants::syntax_option_type optimize = regex_constants::optimize;
    static const regex_constants::syntax_option_type collate = regex_constants::collate;
    static const regex_constants::syntax_option_type ECMAScript = regex_constants::ECMAScript;
    static const regex_constants::syntax_option_type basic = regex_constants::basic;
    static const regex_constants::syntax_option_type extended = regex_constants::extended;
    static const regex_constants::syntax_option_type awk = regex_constants::awk;
    static const regex_constants::syntax_option_type grep = regex_constants::grep;
    static const regex_constants::syntax_option_type egrep = regex_constants::egrep;

    // 28.8.2, construct/copy/destroy:
    basic_regex();
    explicit basic_regex(const charT* p,
                         flag_type f = regex_constants::ECMAScript);
    basic_regex(const charT* p, size_t len, flag_type f);
    basic_regex(const basic_regex&);
}
```
template <class ST, class SA>
  explicit basic_regex(const basic_string<charT, ST, SA>& p,
    flag_type f = regex_constants::ECMAScript);

template <class InputIterator>
  basic_regex(InputIterator first, InputIterator last,
    flag_type f = regex_constants::ECMAScript);

~basic_regex();

basic_regex& operator=(const basic_regex&);

basic_regex& operator=(const charT* ptr);

template <class ST, class SA>
  basic_regex& operator=(const basic_string<charT, ST, SA>& p);

// 28.8.3, assign:
  basic_regex& assign(const basic_regex& that);
  basic_regex& assign(const charT* ptr,
    flag_type f = regex_constants::ECMAScript);
  basic_regex& assign(const charT* p, size_t len, flag_type f);

template <class string_traits, class A>
  basic_regex& assign(const basic_string<charT, string_traits, A>& s,
    flag_type f = regex_constants::ECMAScript);

template <class InputIterator>
  basic_regex& assign(InputIterator first, InputIterator last,
    flag_type f = regex_constants::ECMAScript);

// 28.8.4, const operations:
  unsigned mark_count() const;
  flag_type flags() const;

// 28.8.5, locale:
  locale_type imbue(locale_type loc);
  locale_type getloc() const;

// 28.8.6, swap:
  void swap(basic_regex&);
};

28.8.1 basic_regex constants

static const regex_constants::syntax_option_type
  icase = regex_constants::icase;
static const regex_constants::syntax_option_type
  nosubs = regex_constants::nosubs;
static const regex_constants::syntax_option_type
  optimize = regex_constants::optimize;
static const regex_constants::syntax_option_type
  collate = regex_constants::collate;
static const regex_constants::syntax_option_type
  ECMAScript = regex_constants::ECMAScript;
static const regex_constants::syntax_option_type
  basic = regex_constants::basic;
static const regex_constants::syntax_option_type
  extended = regex_constants::extended;
static const regex_constants::syntax_option_type
  awk = regex_constants::awk;
static const regex_constants::syntax_option_type
  grep = regex_constants::grep;
static const regex_constants::syntax_option_type
  egrep = regex_constants::egrep;

The static constant members are provided as synonyms for the constants declared in namespace regex_constants.

28.8.2 basic_regex constructors [lib.re.regex.construct]

basic_regex();
   Effects: Constructs an object of class basic_regex that does not match any character sequence.

basic_regex(const charT* p, flag_type f = regex_constants::ECMAScript);
   Requires: p shall not be a null pointer.
   Throws: regex_error if p is not a valid regular expression.
   Effects: Constructs an object of class basic_regex; the object’s internal finite state machine is constructed from the regular expression contained in the array of charT of length char_traits<charT>::length(p) whose first element is designated by p, and interpreted according to the flags f.
   Postconditions: flags() returns f. mark_count() returns the number of marked sub-expressions within the expression.

basic_regex(const charT* p, size_t len, flag_type f);
   Requires: p shall not be a null pointer.
   Throws: regex_error if p is not a valid regular expression.
   Effects: Constructs an object of class basic_regex; the object’s internal finite state machine is constructed from the regular expression contained in the sequence of characters [p, p+len), and interpreted according the flags specified in f.
   Postconditions: flags() returns f. mark_count() returns the number of marked sub-expressions within the expression.

basic_regex(const basic_regex& e);
   Effects: Constructs an object of class basic_regex as a copy of the object e.
   Postconditions: flags() and mark_count() return e.flags() and e.mark_count(), respectively.

template <class ST, class SA>
  basic_regex(const basic_string<charT, ST, SA>& s,
               flag_type f = regex_constants::ECMAScript);
28.8 Class template `basic_regex`  

**Throws:** `regex_error` if `s` is not a valid regular expression.

**Effects:** Constructs an object of class `basic_regex`; the object’s internal finite state machine is constructed from the regular expression contained in the string `s`, and interpreted according to the flags specified in `f`.

**Postconditions:** `flags()` returns `f`. `mark_count()` returns the number of marked sub-expressions within the expression.

```cpp
template <class ForwardIterator>
basic_regex(ForwardIterator first, ForwardIterator last,
            flag_type f = regex_constants::ECMAScript);
```

**Throws:** `regex_error` if the sequence `[first, last)` is not a valid regular expression.

**Effects:** Constructs an object of class `basic_regex`; the object’s internal finite state machine is constructed from the regular expression contained in the sequence of characters `[first, last)`, and interpreted according to the flags specified in `f`.

**Postconditions:** `flags()` returns `f`. `mark_count()` returns the number of marked sub-expressions within the expression.

```cpp
basic_regex& operator=(const basic_regex& e);
```

**Effects:** Returns the result of `assign(e)`.

```cpp
basic_regex& operator=(const charT* ptr);
```

**Requires:** `ptr` shall not be a null pointer.

**Effects:** Returns the result of `assign(ptr)`.

```cpp
template <class ST, class SA>
basic_regex& operator=(const basic_string<charT, ST, SA>& p);
```

**Effects:** Returns the result of `assign(p)`.

### 28.8.3 `basic_regex` assign

```cpp
basic_regex& assign(const basic_regex& that);
```

**Effects:** Copies that into `*this` and returns `*this`.

**Postconditions:** `flags()` and `mark_count()` return `that.flags()` and `that.mark_count()`, respectively.

```cpp
basic_regex& assign(const charT* ptr, flag_type f = regex_constants::ECMAScript);
```

**Returns:** `assign(string_type(ptr), f)`.

```cpp
basic_regex& assign(const charT* ptr, size_t len,
                    flag_type f = regex_constants::ECMAScript);
```

**Returns:** `assign(string_type(ptr, len), f)`.
template <class string_traits, class A>
    basic_regex& assign(const basic_string<charT, string_traits, A>& s, 
    flag_type f = regex_constants::ECMAScript);

    Throws: regex_error if s is not a valid regular expression.

    Returns: *this.

    Effects: Assigns the regular expression contained in the string s, interpreted according the flags specified in f. If an exception is thrown, *this is unchanged.

    Postconditions: If no exception is thrown, flags() returns f and mark_count() returns the number of marked sub-expressions within the expression.

template <class InputIterator>
    basic_regex& assign(InputIterator first, InputIterator last, 
    flag_type f = regex_constants::ECMAScript);

    Requires: The type InputIterator corresponds to the Input Iterator requirements ([lib.input.iterators]).

    Returns: assign(string_type(first, last), f).

### 28.8.4 basic_regex constant operations

unsigned mark_count() const;

    Effects: Returns the number of marked sub-expressions within the regular expression.

    flag_type flags() const;

    Effects: Returns a copy of the regular expression syntax flags that were passed to the object’s constructor or to the last call to assign.

### 28.8.5 basic_regex locale

locale_type imbue(locale_type loc);

    Effects: Returns the result of traits_inst.imbue(loc) where traits_inst is a (default initialized) instance of the template type argument traits stored within the object. After a call to imbue the basic_regex object does not match any character sequence.

locale_type getloc() const;

    Effects: Returns the result of traits_inst.getloc() where traits_inst is a (default initialized) instance of the template parameter traits stored within the object.

### 28.8.6 basic_regex swap

void swap(basic_regex& e);
28.8.7 basic_regex non-member functions

28.8.7.1 basic_regex non-member swap

```cpp
template <class charT, class traits>
void swap(basic_regex<charT, traits>& lhs, basic_regex<charT, traits>& rhs);
```

1. **Effects:** Calls `lhs.swap(rhs)`.

28.9 Class template `sub_match`

Class template `sub_match` denotes the sequence of characters matched by a particular marked sub-expression.

```cpp
template <class BidirectionalIterator>
class sub_match : public std::pair<BidirectionalIterator, BidirectionalIterator>
{
public:
    typedef typename iterator_traits<BidirectionalIterator>::
        value_type value_type;
    typedef typename iterator_traits<BidirectionalIterator>::
        difference_type difference_type;
    typedef BidirectionalIterator iterator;

    bool matched;

    difference_type length() const;
    operator basic_string<value_type>() const;
    basic_string<value_type> str() const;

    int compare(const sub_match& s) const;
    int compare(const basic_string<value_type>& s) const;
    int compare(const value_type* s) const;
};
```

28.9.1 sub_match members

```cpp
difference_type length();
```

1. **Returns:** `(matched ? distance(first, second) : 0)`.

operator basic_string<value_type>()const;

2. **Returns:** `matched ? basic_string<value_type>(first, second) : basic_string<value_type>()`. Draft
basic_string<value_type> str() const;

Returns: matched ? basic_string<value_type>((first, second) : basic_string<value_type>().

int compare(const sub_match & s) const;

Returns: str().compare(s.str()).

int compare(const basic_string<value_type> & s) const;

Returns: str().compare(s).

int compare(const value_type * s) const;

Returns: str().compare(s).

28.9.2 sub_match non-member operators

[lib.re.submatch.op]

template <class BiIter>
bool operator==(const sub_match<BiIter> & lhs, const sub_match<BiIter> & rhs);

Returns: lhs.compare(rhs) == 0.

template <class BiIter>
bool operator!=(const sub_match<BiIter> & lhs, const sub_match<BiIter> & rhs);

Returns: lhs.compare(rhs) != 0.

template <class BiIter>
bool operator<(const sub_match<BiIter> & lhs, const sub_match<BiIter> & rhs);

Returns: lhs.compare(rhs) < 0.

template <class BiIter>
bool operator<=(const sub_match<BiIter> & lhs, const sub_match<BiIter> & rhs);

Returns: lhs.compare(rhs) <= 0.

template <class BiIter>
bool operator>=(const sub_match<BiIter> & lhs, const sub_match<BiIter> & rhs);

Returns: lhs.compare(rhs) >= 0.

template <class BiIter>
bool operator>(const sub_match<BiIter> & lhs, const sub_match<BiIter> & rhs);

Returns: lhs.compare(rhs) > 0.

template <class BiIter, class ST, class SA>
bool operator==(const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& s, const sub_match<BiIter>& rhs);
28.9 Class template sub_match

Returns: \( \text{lhs} == \text{rhs}.\str() \).

template <class BiIter, class ST, class SA>
bool operator!= (const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

Returns: \( \text{lhs} \neq \text{rhs}.\str() \).

template <class BiIter, class ST, class SA>
bool operator< (const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

Returns: \( \text{lhs} < \text{rhs}.\str() \).

template <class BiIter, class ST, class SA>
bool operator> (const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

Returns: \( \text{lhs} > \text{rhs}.\str() \).

template <class BiIter, class ST, class SA>
bool operator>= (const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

Returns: \( \text{lhs} \geq \text{rhs}.\str() \).

template <class BiIter, class ST, class SA>
bool operator<= (const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& lhs,
    const sub_match<BiIter>& rhs);

Returns: \( \text{lhs} \leq \text{rhs}.\str() \).

template <class BiIter, class ST, class SA>
bool operator==(const sub_match<BiIter>& lhs,
    const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

Returns: \( \text{lhs}.\str() == \text{rhs} \).

template <class BiIter, class ST, class SA>
bool operator!=(const sub_match<BiIter>& lhs,
    const basic_string<
    typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

Draft
Returns: lhs.str() != rhs.

template <class BiIter, class ST, class SA>
bool operator<(const sub_match<BiIter>& lhs, const basic_string<
typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

Returns: lhs.str() < rhs.

template <class BiIter, class ST, class SA>
bool operator>(const sub_match<BiIter>& lhs, const basic_string<
typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

Returns: lhs.str() > rhs.

template <class BiIter, class ST, class SA>
bool operator>=(const sub_match<BiIter>& lhs, const basic_string<
typename iterator_traits<BiIter>::value_type, ST, SA>& rhs);

Returns: lhs.str() >= rhs.

template <class BiIter, class ST, class SA>
bool operator<(typename iterator_traits<BiIter>::value_type const* lhs, const sub_match<BiIter>& rhs);

Returns: lhs == rhs.str().

template <class BiIter>
bool operator!=(typename iterator_traits<BiIter>::value_type const* lhs, const sub_match<BiIter>& rhs);

Returns: lhs != rhs.str().

template <class BiIter>
bool operator<(typename iterator_traits<BiIter>::value_type const* lhs, const sub_match<BiIter>& rhs);

Returns: lhs < rhs.str().

template <class BiIter>
bool operator>(typename iterator_traits<BiIter>::value_type const* lhs, const sub_match<BiIter>& rhs);

Returns: lhs > rhs.str().
template <class BiIter>
bool operator>=(typename iterator_traits<BiIter>::value_type const* lhs,
const sub_match<BiIter>& rhs);

Returns: lhs >= rhs.str().

template <class BiIter>
bool operator<=(typename iterator_traits<BiIter>::value_type const* lhs,
const sub_match<BiIter>& rhs);

Returns: lhs <= rhs.str().

template <class BiIter>
bool operator==(const sub_match<BiIter>& lhs,
typename iterator_traits<BiIter>::value_type const* rhs);

Returns: lhs.str() == rhs.

template <class BiIter>
bool operator!=(const sub_match<BiIter>& lhs,
typename iterator_traits<BiIter>::value_type const* rhs);

Returns: lhs.str() != rhs.

template <class BiIter>
bool operator<(const sub_match<BiIter>& lhs,
typename iterator_traits<BiIter>::value_type const* rhs);

Returns: lhs.str() < rhs.

template <class BiIter>
bool operator>(const sub_match<BiIter>& lhs,
typename iterator_traits<BiIter>::value_type const* rhs);

Returns: lhs.str() > rhs.

template <class BiIter>
bool operator>=(const sub_match<BiIter>& lhs,
typename iterator_traits<BiIter>::value_type const* rhs);

Returns: lhs.str() >= rhs.

template <class BiIter>
bool operator<=(const sub_match<BiIter>& lhs,
typename iterator_traits<BiIter>::value_type const* rhs);

Returns: lhs.str() <= rhs.

template <class BiIter>
bool operator==(typename iterator_traits<BiIter>::value_type const& lhs,
const sub_match<BiIter>& rhs);

Returns: lhs == rhs.str().

template <class BiIter>
bool operator!=(typename iterator_traits<BiIter>::value_type const& lhs,  
const sub_match<BiIter>& rhs);
32
   \textit{Returns:} \texttt{lhs \neq rhs.str() }.

template <class BiIter>
bool operator<(typename iterator_traits<BiIter>::value_type const& lhs,  
const sub_match<BiIter>& rhs);
33
   \textit{Returns:} \texttt{lhs < rhs.str() }.

template <class BiIter>
bool operator>(typename iterator_traits<BiIter>::value_type const& lhs,  
const sub_match<BiIter>& rhs);
34
   \textit{Returns:} \texttt{lhs > rhs.str() }.

template <class BiIter>
bool operator>=(typename iterator_traits<BiIter>::value_type const& lhs,  
const sub_match<BiIter>& rhs);
35
   \textit{Returns:} \texttt{lhs \geq rhs.str() }.

template <class BiIter>
bool operator<=(typename iterator_traits<BiIter>::value_type const& lhs,  
const sub_match<BiIter>& rhs);
36
   \textit{Returns:} \texttt{lhs \leq rhs.str() }.

template <class BiIter>
bool operator==(const sub_match<BiIter>& lhs, 
typename iterator_traits<BiIter>::value_type const& rhs);
37
   \textit{Returns:} \texttt{lhs.str() == rhs }.

template <class BiIter>
bool operator!=(const sub_match<BiIter>& lhs, 
typename iterator_traits<BiIter>::value_type const& rhs);
38
   \textit{Returns:} \texttt{lhs.str() \neq rhs }.

template <class BiIter>
bool operator<(const sub_match<BiIter>& lhs, 
type_name iterator_traits<BiIter>::value_type const& rhs);
39
   \textit{Returns:} \texttt{lhs.str() < rhs }.

template <class BiIter>
bool operator>(const sub_match<BiIter>& lhs, 
type_name iterator_traits<BiIter>::value_type const& rhs);
40
   \textit{Returns:} \texttt{lhs.str() > rhs }.
28.10 Class template match_results

Class template match_results denotes a collection of character sequences representing the result of a regular expression match. Storage for the collection is allocated and freed as necessary by the member functions of class template match_results.

The class template match_results shall satisfy the requirements of a Sequence, as specified in [lib.sequence.reqmts], except that only operations defined for const-qualified Sequences are supported.

The sub_match object stored at index 0 represents sub-expression 0, i.e. the whole match. In this case the sub_match member matched is always true. The sub_match object stored at index n denotes what matched the marked sub-expression n within the matched expression. If the sub-expression n participated in a regular expression match then the sub_match member matched evaluates to true, and members first and second denote the range of characters [first, second) which formed that match. Otherwise matched is false, and members first and second point to the end of the sequence that was searched. [Note: The sub_match objects representing different sub-expressions that did not participate in a regular expression match need not be distinct. — end note ]

template <class BidirectionalIterator,  
class Allocator = allocator<sub_match<BidirectionalIterator> > >  
class match_results  
{  
  public:  
    typedef sub_match<BidirectionalIterator>  
      value_type;  
    typedef typename Allocator::const_reference const_reference;  
    typedef const_reference reference;  
    typedef implementation defined  
      const_iterator;  
    typedef const_iterator iterator;  
    typedef typename iterator_traits<BidirectionalIterator>::difference_type difference_type;  
    typedef typename Allocator::size_type size_type;  
    typedef Allocator allocator_type;  
    typedef typename iterator_traits<BidirectionalIterator>::value_type char_type;  
    typedef basic_string<char_type> string_type;
// 28.10.1, construct/copy/destroy:
explicit match_results(const Allocator& a = Allocator());
match_results(const match_results& m);
match_results& operator=(const match_results& m);
~match_results();

// 28.10.2, size:
size_type size() const;
size_type max_size() const;
bool empty() const;

// 28.10.3, element access:
difference_type length(size_type sub = 0) const;
difference_type position(size_type sub = 0) const;
string_type str(size_type sub = 0) const;
const_reference operator[](size_type n) const;

const_reference prefix() const;
const_reference suffix() const;
const_iterator begin() const;
const_iterator end() const;

// 28.10.4, format:
template <class OutputIter>
OutputIter
format(OutputIter out,
const string_type& fmt,
regex_constants::match_flag_type flags =
regex_constants::format_default) const;
string_type
format(const string_type& fmt,
regex_constants::match_flag_type flags =
regex_constants::format_default) const;

// 28.10.5, allocator:
allocator_type get_allocator() const;

// 28.10.6, swap:
void swap(match_results& that);
};

28.10.1 match_results constructors

1 In all match_results constructors, a copy of the Allocator argument shall be used for any memory allocation performed by the constructor or member functions during the lifetime of the object.

match_results(const Allocator& a = Allocator());

2 Effects: Constructs an object of class match_results.

3 Postconditions: size() returns 0. str() returns basic_string<charT>().
match_results(const match_results& m);

Effects: Constructs an object of class match_results, as a copy of m.

match_results& operator=(const match_results& m);

Effects: Assigns m to *this. The postconditions of this function are indicated in Table 120

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>size()</td>
<td>m.size()</td>
</tr>
<tr>
<td>str(n)</td>
<td>m.str(n) for all integers n &lt; m.size</td>
</tr>
<tr>
<td>prefix()</td>
<td>m.prefix()</td>
</tr>
<tr>
<td>suffix()</td>
<td>m.suffix()</td>
</tr>
<tr>
<td>(*this)[n]</td>
<td>m[n] for all integers n &lt; m.size</td>
</tr>
<tr>
<td>length(n)</td>
<td>m.length(n) for all integers n &lt; m.size</td>
</tr>
<tr>
<td>position(n)</td>
<td>m.position(n) for all integers n &lt; m.size</td>
</tr>
</tbody>
</table>

28.10.2 match_results size

size_type size() const;

Returns: One plus the number of marked sub-expressions in the regular expression that was matched if *this represents the result of a successful match. Otherwise returns 0. [Note: The state of a match_results object can be modified only by passing that object to regex_match or regex_search. Sections 28.11.2 and 28.11.3 specify the effects of those algorithms on their match_results arguments. —end note]

size_type max_size() const;

Returns: The maximum number of sub_match elements that can be stored in *this.

bool empty() const;

Returns: size() == 0.

28.10.3 match_results element access

difference_type length(size_type sub = 0) const;

Returns: (*this)[sub].length().

difference_type position(size_type sub = 0) const;

Returns: The distance from the start of the target sequence to (*this)[sub].first.

string_type str(size_type sub = 0) const;

Returns: string_type((*this)[sub]).
const_reference operator[](size_type n) const;

Returns: A reference to the sub_match object representing the character sequence that matched marked sub-expression n. If n == 0 then returns a reference to a sub_match object representing the character sequence that matched the whole regular expression. If n >= size() then returns a sub_match object representing an unmatched sub-expression.

const_reference prefix() const;

Returns: A reference to the sub_match object representing the character sequence from the start of the string being matched/searched to the start of the match found.

const_reference suffix() const;

Returns: A reference to the sub_match object representing the character sequence from the end of the match found to the end of the string being matched/searched.

const_iterator begin() const;

Returns: A starting iterator that enumerates over all the sub-expressions stored in *this.

const_iterator end() const;

Returns: A terminating iterator that enumerates over all the sub-expressions stored in *this.

### 28.10.4 match_results formatting

```cpp
template <class OutputIter>
OutputIter format(OutputIter out, const string_type& fmt,
regex_constants::match_flag_type flags =
regex_constants::format_default);
```

Requires: The type OutputIter conforms to the Output Iterator requirements [24.1.2].

Effects: Copies the character sequence [fmt.begin(), fmt.end()) to OutputIter out. Replaces each format specifier or escape sequence in fmt with either the character(s) it represents or the sequence of characters within *this to which it refers. The bitmasks specified in flags determines what format specifiers and escape sequences are recognized.

Returns: out.

```cpp
string_type format(const string_type& fmt,
regex_constants::match_flag_type flags =
regex_constants::format_default);
```

Effects: Returns a copy of the string fmt. Replaces each format specifier or escape sequence in fmt with either the character(s) it represents or the sequence of characters within *this to which it refers. The bitmasks specified in flags determines what format specifiers and escape sequences are recognized.

### 28.10.5 match_results allocator

Draft
allocator_type get_allocator() const;

    Effects: Returns a copy of the Allocator that was passed to the object’s constructor.

28.10.6  match_results swap

void swap(match_results& that);

    Effects: Swaps the contents of the two sequences.

    Postcondition: *this contains the sequence of matched sub-expressions that were in that, that contains the
sequence of matched sub-expressions that were in *this.

    Complexity: constant time.

template <class BidirectionalIterator, class Allocator>
void swap(match_results<BidirectionalIterator, Allocator>& m1, 
          match_results<BidirectionalIterator, Allocator>& m2);

    Effects: m1.swap(m2).

28.11  Regular expression algorithms

28.11.1  exceptions

The algorithms described in this subclause may throw an exception of type regex_error. If such an exception e
is thrown, e.code() shall return either regex_constants::error_complexity or regex_constants::error_-stack.

28.11.2  regex_match

template <class BidirectionalIterator, class Allocator, class charT, class traits>
bool regex_match(BidirectionalIterator first, BidirectionalIterator last, 
                 match_results<BidirectionalIterator, Allocator>& m, 
                 const basic_regex<charT, traits>& e, 
                 regex_constants::match_flag_type flags = 
                 regex_constants::match_default);

    Requires: The type BidirectionalIterator shall satisfy the requirements of a Bidirectional Iterator
([lib.bidirectional.iterators]).

    Effects: Determines whether there is a match between the regular expression e, and all of the character sequence
[first, last). The parameter flags is used to control how the expression is matched against the character
sequence. Returns true if such a match exists, false otherwise.

    Postconditions: If the function returns false, then the effect on parameter m is unspecified except that m.size() returns 0 and m.empty() returns true. Otherwise the effects on parameter m are given in table 121.

Table 121: Effects of regex_match algorithm

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
</table>

Draft
m.size() 1 + e.mark_count()
m.empty() false
m.prefix().first first
m.prefix().second first
m.prefix().matched false
m.suffix().first last
m.suffix().second last
m.suffix().matched false
m[0].first first
m[0].second last
m[0].matched true if a full match was found.
m[n].first For all integers \( n < m.size() \), the start of the sequence that matched sub-expression \( n \). Alternatively, if sub-expression \( n \) did not participate in the match, then last.
m[n].second For all integers \( n < m.size() \), the end of the sequence that matched sub-expression \( n \). Alternatively, if sub-expression \( n \) did not participate in the match, then last.
m[n].matched For all integers \( n < m.size() \), true if sub-expression \( n \) participated in the match, false otherwise.

template <class BidirectionalIterator, class charT, class traits>
bool regex_match(BidirectionalIterator first, BidirectionalIterator last,
        const basic_regex<charT, traits>& e,
        regex_constants::match_flag_type flags =
        regex_constants::match_default);
4 Effects: Behaves “as if” by constructing an instance of match_results<BidirectionalIterator> what, and then returning the result of regex_match(first, last, what, e, flags).

template <class charT, class Allocator, class traits>
bool regex_match(const charT* str,
        match_results<const charT*, Allocator>& m,
        const basic_regex<charT, traits>& e,
        regex_constants::match_flag_type flags =
        regex_constants::match_default);
5 Returns: regex_match(str, str + char_traits<charT>::length(str), m, e, flags).

template <class ST, class SA, class Allocator, class charT, class traits>
bool regex_match(const basic_string<charT, ST, SA>& s,
        match_results<
        typename basic_string<charT, ST, SA>::const_iterator,
        Allocator>& m,
        const basic_regex<charT, traits>& e,
        regex_constants::match_flag_type flags =
        regex_constants::match_default);
28.11 Regular expression algorithms

Returns: `regex_match(s.begin(), s.end(), m, e, flags).`

```cpp
template <class charT, class traits>
bool regex_match(const charT* str,
                 const basic_regex<charT, traits>& e,
                 regex_constants::match_flag_type flags =
                 regex_constants::match_default);
```

Returns: `regex_match(str, str + char_traits<charT>::length(str), e, flags)`

```cpp
template <class ST, class SA, class charT, class traits>
bool regex_match(const basic_string<charT, ST, SA>& s,
                 const basic_regex<charT, traits>& e,
                 regex_constants::match_flag_type flags =
                 regex_constants::match_default);
```

Returns: `regex_match(s.begin(), s.end(), e, flags).`

28.11.3 regex_search

```
template <class BidirectionalIterator, class Allocator, class charT, class traits>
bool regex_search(BidirectionalIterator first, BidirectionalIterator last,
                  match_results<BidirectionalIterator, Allocator>& m,
                  const basic_regex<charT, traits>& e,
                  regex_constants::match_flag_type flags =
                  regex_constants::match_default);
```

Requires: Type `BidirectionalIterator` shall satisfy the requirements of a Bidirectional Iterator (24.1.4).

Effects: Determines whether there is some sub-sequence within `[first, last)` that matches the regular expression `e`. The parameter `flags` is used to control how the expression is matched against the character sequence. Returns `true` if such a sequence exists, `false` otherwise.

Postconditions: If the function returns `false`, then the effect on parameter `m` is unspecified except that `m.size()` returns `0` and `m.empty()` returns `true`. Otherwise the effects on parameter `m` are given in table 122.

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>m.size()</td>
<td>1 + e.mark_count()</td>
</tr>
<tr>
<td>m.empty()</td>
<td>false</td>
</tr>
<tr>
<td>m.prefix().first</td>
<td>first</td>
</tr>
<tr>
<td>m.prefix().second</td>
<td>m[0].first</td>
</tr>
<tr>
<td>m.prefix().matched</td>
<td>m.prefix().first != m.prefix().second</td>
</tr>
<tr>
<td>m.suffix().first</td>
<td>m[0].second</td>
</tr>
<tr>
<td>m.suffix().second</td>
<td>last</td>
</tr>
<tr>
<td>m.suffix().matched</td>
<td>m.suffix().first != m.suffix().second</td>
</tr>
<tr>
<td>m[0].first</td>
<td>The start of the sequence of characters that matched the regular expression</td>
</tr>
</tbody>
</table>

Draft
<table>
<thead>
<tr>
<th>m[0].second</th>
<th>The end of the sequence of characters that matched the regular expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>m[0].matched</td>
<td>true if a match was found, and false otherwise.</td>
</tr>
<tr>
<td>m[n].first</td>
<td>For all integers n &lt; m.size(), the start of the sequence that matched sub-expression n. Alternatively, if sub-expression n did not participate in the match, then last.</td>
</tr>
<tr>
<td>m[n].second</td>
<td>For all integers n &lt; m.size(), the end of the sequence that matched sub-expression n. Alternatively, if sub-expression n did not participate in the match, then last.</td>
</tr>
<tr>
<td>m[n].matched</td>
<td>For all integers n &lt; m.size(), true if sub-expression n participated in the match, false otherwise.</td>
</tr>
</tbody>
</table>

```
template <class charT, class Allocator, class traits>
bool regex_search(const charT* str, match_results<const charT*, Allocator>& m,
    const basic_regex<charT, traits>& e,
    regex_constants::match_flag_type flags = regex_constants::match_default);
```

**Returns:** The result of `regex_search(str, str + char_traits<charT>::length(str), m, e, flags)`.

```
template <class ST, class SA, class Allocator, class charT, class traits>
bool regex_search(const basic_string<charT, ST, SA>& s,
    match_results<typename basic_string<charT, ST, SA>::const_iterator, Allocator>& m,
    const basic_regex<charT, traits>& e,
    regex_constants::match_flag_type flags = regex_constants::match_default);
```

**Returns:** The result of `regex_search(s.begin(), s.end(), m, e, flags)`.

```
template <class iterator, class charT, class traits>
bool regex_search(iterator first, iterator last,
    const basic_regex<charT, traits>& e,
    regex_constants::match_flag_type flags = regex_constants::match_default);
```

**Effects:** Behaves “as if” by constructing an object what of type `match_results<iterator>` and then returning the result of `regex_search(first, last, what, e, flags)`.

```
template <class charT, class traits>
bool regex_search(const charT* str,
    const basic_regex<charT, traits>& e,
    regex_constants::match_flag_type flags = regex_constants::match_default);
```

**Returns:** `regex_search(str, str + char_traits<charT>::length(str), e, flags)`
bool regex_search(const basic_string<charT, ST, SA>& s,
    const basic_regex<charT, traits>& e,
    regex_constants::match_flag_type flags =
    regex_constants::match_default);

Returns: regex_search(s.begin(), s.end(), e, flags).

28.11.4 regex_replace

template <class OutputIterator, class BidirectionalIterator,
    class traits, class charT>
OutputIterator
regex_replace(OutputIterator out,
    BidirectionalIterator first, BidirectionalIterator last,
    const basic_regex<charT, traits>& e,
    const basic_string<charT>& fmt,
    regex_constants::match_flag_type flags =
    regex_constants::match_default);

Effects: Constructs a regex_iterator object i as if by regex_iterator<BidirectionalIterator, charT,
traits> i(first, last, e, flags), and uses i to enumerate through all of the matches m of type match_results<BidirectionalIterator> that occur within the sequence [first, last). If no such matches are found and !(flags & regex_constants::format_no_copy) then calls std::copy(first, last, out). If any matches are found then, for each such match, if !(flags & regex_constants::format_no_copy) calls std::copy(m.prefix().first, m.prefix().second, out), and then calls m.format(out, fmt, flags). Finally, if such a match is found and !(flags & regex_constants::format_no_copy), calls std::copy(last_m.suffix().first, last_m.suffix().second, out) where last_m is a copy of the last match found. If flags & regex_constants::format_first_only is non-zero then only the first match found is replaced.

Returns: out.

template <class traits, class charT>
basic_string<charT>
regex_replace(const basic_string<charT>& s,
    const basic_regex<charT, traits>& e,
    const basic_string<charT>& fmt,
    regex_constants::match_flag_type flags =
    regex_constants::match_default);

Effects: Constructs an empty string result of type basic_string<charT>, calls regex_replace(back_inserter(result), s.begin(), s.end(), e, fmt, flags), and then returns result.

28.12 Regular expression Iterators

28.12.1 Class template regex_iterator

The class template regex_iterator is an iterator adapter. It represents a new view of an existing iterator sequence, by enumerating all the occurrences of a regular expression within that sequence. A regex_iterator uses regex_
search to find successive regular expression matches within the sequence from which it was constructed. After the iterator is constructed, and every time operator++ is used, the iterator finds and stores a value of match_results<BidirectionalIterator>. If the end of the sequence is reached (regex_search returns false), the iterator becomes equal to the end-of-sequence iterator value. The default constructor constructs an end-of-sequence iterator object, which is the only legitimate iterator to be used for the end condition. The result of operator* on an end-of-sequence iterator is not defined. For any other iterator value a const match_results<BidirectionalIterator>& is returned. The result of operator-> on an end-of-sequence iterator is not defined. For any other iterator value a const match_results<BidirectionalIterator>** is returned. It is impossible to store things into regex_iterators. Two end-of-sequence iterators are always equal. An end-of-sequence iterator is not equal to a non-end-of-sequence iterator. Two non-end-of-sequence iterators are equal when they are constructed from the same arguments.

```cpp
template <class BidirectionalIterator, 
    class charT = typename iterator_traits<BidirectionalIterator>::value_type, 
    class traits = regex_traits<charT> >

class regex_iterator
{
public:
    typedef basic_regex<charT, traits> regex_type;
    typedef match_results<BidirectionalIterator> value_type;
    typedef std::ptrdiff_t difference_type;
    typedef const value_type* pointer;
    typedef const value_type& reference;
    typedef std::forward_iterator_tag iterator_category;

    regex_iterator();
    regex_iterator(BidirectionalIterator a, BidirectionalIterator b, 
        const regex_type& re, 
        regex_constants::match_flag_type m = 
        regex_constants::match_default);
    regex_iterator(const regex_iterator&);
    regex_iterator& operator=(const regex_iterator&);
    bool operator==(const regex_iterator&);
    bool operator!=(const regex_iterator&);
    const value_type& operator*();
    regex_iterator& operator++();
    regex_iterator operator++(int);

private:
    // these members are shown for exposition only:
    BidirectionalIterator begin;
    BidirectionalIterator end;
    const regex_type* pregex;
    regex_constants::match_flag_type flags;
    match_results<BidirectionalIterator> match;
};
```

A regex_iterator object that is not an end-of-sequence iterator holds a zero-length match if match[0].matched == true and match[0].first == match[0].second. [Note: for example, this can occur when the part of the regular
expression that matched consists only of an assertion (such as ‘^’, ‘$’, ‘\b’, ‘\B’). — end note]

28.12.1.1 regex_iterator constructors [lib.re.regex.iter.cnstr]

regex_iterator();

Effects: Constructs an end-of-sequence iterator.

regex_iterator(BidirectionalIterator a, BidirectionalIterator b,
               const regex_type& re,           
               regex_constants::match_flag_type m = regex_constants::match_default);

Effects: Initializes begin and end to point to the beginning and the end of the target sequence, sets pregex to \&re, sets flags to f, then calls regex_search(begin, end, match, *pregex, flags). If this call returns false the constructor sets *this to the end-of-sequence iterator.

28.12.1.2 regex_iterator comparisons [lib.re.regex.iter.comp]

bool operator==(const regex_iterator& right);

Returns: true if *this and right are both end-of-sequence iterators or if begin == right.begin, end == right.end, pregex == right.pregex, flags == right.flags, and match[0] == right.match[0], otherwise false.

bool operator!=(const regex_iterator& right);

Returns: !(this == right).

28.12.1.3 regex_iterator dereference [lib.re.regex.iter.deref]

const value_type& operator*();

Returns: match.

const value_type* operator->();

Returns: &match.

28.12.1.4 regex_iterator increment [lib.re.regex.iter.incr]

regex_iterator& operator++();

Effects: Constructs a local variable start of type BidirectionalIterator and initializes it with the value of match[0].second.

If the iterator holds a zero-length match and start == end the operator sets *this to the end-of-sequence iterator and returns *this.

Otherwise, if the iterator holds a zero-length match the operator calls regex_search(start, end, match, *pregex, flags | regex_constants::match_not_null | regex_constants::match_continuous). If
the call returns true the operator returns *this. Otherwise the operator increments start and continues as if
the most recent match was not a zero-length match.

4 If the most recent match was not a zero-length match, the operator sets flags to flags | regex_constants
::match_prev_avail and calls regex_search(start, end, match, *pregex, flags). If the call returns
false the iterator sets *this to the end-of-sequence iterator. The iterator then returns *this.

5 In all cases in which the call to regex_search returns true, match.prefix().first shall be equal to the
previous value of match[0].second, and for each index i in the half-open range [0, match.size()) for which
match[i].matched is true, match[i].position() shall return distance(begin, match[i].first)).

[Note: this means that match[i].position() gives the offset from the beginning of the target sequence, which
is often not the same as the offset from the sequence passed in the call to regex_search. — end note]

6 It is unspecified how the implementation makes these adjustments.

7 [Note: this means that a compiler may call an implementation-specific search function, in which case a user-
defined specialization of regex_search will not be called. — end note]

regex_iterator operator++(int);

Effects:

regex_iterator tmp = *this;
++(*this);
return tmp;

28.12.2 Class template regex_token_iterator

The class template regex_token_iterator is an iterator adapter; that is to say it represents a new view of an existing
iterator sequence, by enumerating all the occurrences of a regular expression within that sequence, and presenting one
or more sub-expressions for each match found. Each position enumerated by the iterator is a sub_match class template
instance that represents what matched a particular sub-expression within the regular expression.

2 When class regex_token_iterator is used to enumerate a single sub-expression with index -1 the iterator performs
field splitting: that is to say it enumerates one sub-expression for each section of the character container sequence that
does not match the regular expression specified.

3 After it is constructed, the iterator finds and stores a value match_results<BidirectionalIterator> position
and sets the internal count N to zero. It also maintains a sequence subs which contains a list of the sub-expressions which
will be enumerated. Every time operator++ is used the count N is incrementred; if N exceeds or equals subs.size(),
then the iterator increments member position and sets count N to zero.

4 If the end of sequence is reached (position is equal to the end of sequence iterator), the iterator becomes equal to
the end-of-sequence iterator value, unless the sub-expression being enumerated has index -1, in which case the iterator
enumerates one last sub-expression that contains all the characters from the end of the last regular expression match to
the end of the input sequence being enumerated, provided that this would not be an empty sub-expression.

5 The default constructor constructs an end-of-sequence iterator object, which is the only legitimate iterator to be used for
the end condition. The result of operator* on an end-of-sequence iterator is not defined. For any other iterator value
a const sub_match<BidirectionalIterator>& is returned. The result of operator-> on an end-of-sequence iterator is not defined. For any other iterator value a const sub_match<BidirectionalIterator>* is returned.

6 It is impossible to store things into regex_iterators. Two end-of-sequence iterators are always equal. An end-of-sequence iterator is not equal to a non-end-of-sequence iterator. Two non-end-of-sequence iterators are equal when they are constructed from the same arguments.

```cpp
template <class BidirectionalIterator,
    class charT = typename iterator_traits<BidirectionalIterator>::value_type,
    class traits = regex_traits<charT> >
class regex_token_iterator
{
    public:
    typedef basic_regex<charT, traits> regex_type;
    typedef sub_match<BidirectionalIterator> value_type;
    typedef std::ptrdiff_t difference_type;
    typedef const value_type* pointer;
    typedef const value_type& reference;
    typedef std::forward_iterator_tag iterator_category;
    regex_token_iterator();
    regex_token_iterator(BidirectionalIterator a, BidirectionalIterator b,
                        const regex_type& re,
                        int submatch = 0,
                        regex_constants::match_flag_type m =
                        regex_constants::match_default);
    regex_token_iterator(BidirectionalIterator a, BidirectionalIterator b,
                        const regex_type& re,
                        const std::vector<int>& submatches,
                        regex_constants::match_flag_type m =
                        regex_constants::match_default);
    template <std::size_t N>
    regex_token_iterator(BidirectionalIterator a, BidirectionalIterator b,
                        const regex_type& re,
                        const int (&submatches)[N],
                        regex_constants::match_flag_type m =
                        regex_constants::match_default);
    regex_token_iterator(const regex_token_iterator&);
    regex_token_iterator& operator=(const regex_token_iterator&);
    bool operator==(const regex_token_iterator&);
    bool operator!=(const regex_token_iterator&);
    const value_type& operator*();
    const value_type* operator->();
    regex_token_iterator& operator++();
    regex_token_iterator operator++(int);
    private:
    // data members for exposition only:
    typedef regex_iterator<BidirectionalIterator, charT, traits> position_iterator;
    position_iterator position;
    const value_type *result;
}```
A suffix iterator is a `regex_token_iterator` object that points to a final sequence of characters at the end of the target sequence. In a suffix iterator the member `result` holds a pointer to the data member `suffix`, the value of the member `suffix.match` is `true`, `suffix.first` points to the beginning of the final sequence, and `suffix.second` points to the end of the final sequence.

[Note: for a suffix iterator, data member `suffix.first` is the same as the end of the last match found, and `suffix.second` is the same as the end of the target sequence — end note]

The current match is `(*position).prefix()` if `subs[N] == -1`, or `(*position)[subs[N]]` for any other value of `subs[N].`

### 28.12.2.1 regex_token_iterator constructors

```cpp
regex_token_iterator();
```

**Effects:** Constructs the end-of-sequence iterator.

```cpp
regex_token_iterator(BidirectionalIterator a, BidirectionalIterator b,
const regex_type& re,
int submatch = 0,
regex_constants::match_flag_type m =
regex_constants::match_default);
```

```cpp
regex_token_iterator(BidirectionalIterator a, BidirectionalIterator b,
const regex_type& re,
const std::vector<int>& submatches,
regex_constants::match_flag_type m =
regex_constants::match_default);
```

```cpp
template <std::size_t N>
regex_token_iterator(BidirectionalIterator a, BidirectionalIterator b,
const regex_type& re,
const int (&submatches)[R],
regex_constants::match_flag_type m =
regex_constants::match_default);
```

**Effects:** The first constructor initializes the member `subs` to hold the single value `submatch`. The second constructor initializes the member `subs` to hold a copy of the argument `submatches`. The third constructor initializes the member `subs` to hold a copy of the sequence of integer values pointed to by the iterator range `[&submatches, &submatches + R)`.

Each constructor then sets `N` to 0, and `position` to `position_iterator(a, b, re, f)`. If `position` is not an end-of-sequence iterator the constructor sets `result` to the address of the current match. Otherwise if any of the values stored in `subs` is equal to -1 the constructor sets `*this` to a suffix iterator that points to the range `[a, b)`, otherwise the constructor sets `*this` to an end-of-sequence iterator.
28.12.2 regex_token_iterator comparisons

bool operator==(const regex_token_iterator& right);  

Returns: true if *this and right are both end-of-sequence iterators, or if *this and right are both suffix iterators and suffix == right.suffix; otherwise returns false if *this or right is an end-of-sequence iterator or a suffix iterator. Otherwise returns true if position == right.position, N == right.N, and subs == right.subs. Otherwise returns false.

bool operator!=(const regex_token_iterator& right);  

Returns: !(*this == right).

28.12.3 regex_token_iterator dereference

const value_type& operator*();  

Returns: *result.

const value_type* operator->();  

Returns: result.

28.12.4 regex_token_iterator increment

regex_token_iterator& operator++();  

Effects: Constructs a local variable prev of type position_iterator, initialized with the value of position.

If *this is a suffix iterator, sets *this to an end-of-sequence iterator.

Otherwise, if N + 1 < subs.size(), increments N and sets result to the address of the current match.

Otherwise, sets N to 0 and increments position. If position is not an end-of-sequence iterator the operator sets result to the address of the current match.

Otherwise, if any of the values stored in subs is equal to -1 and prev->suffix().length() is not 0 the operator sets *this to a suffix iterator that points to the range [prev->suffix().first, prev->suffix().second).

Otherwise, sets *this to an end-of-sequence iterator.

Returns: *this

regex_token_iterator& operator++(int);  

Effects: Constructs a copy tmp of *this, then calls ++(*this).

Returns: tmp.
28.13 Modified ECMAScript regular expression grammar

The regular expression grammar recognized by basic_regex objects constructed with the ECMAScript flag is that specified by ECMA-262, except as specified below.

Objects of type specialization of basic_regex store within themselves a default-constructed instance of their traits template parameter, henceforth referred to as traits_inst. This traits_inst object is used to support localization of the regular expression; basic_regex object member functions shall not call any locale dependent C or C++ API, including the formatted string input functions. Instead they shall call the appropriate traits member function to achieve the required effect.

The following productions within the ECMAScript grammar are modified as follows:

- The productions `CharacterClass`, `ClassAtom`, `ClassAtomNoDash`, `ClassAtomExClass`, `ClassAtomCollatingElement`, and `ClassAtomEquivalence` provide functionality equivalent to that of the same features in regular expressions in POSIX.

- The regular expression grammar may be modified by any `regex_constants::syntax_option_type` flags specified when constructing an object of type specialization of basic_regex according to the rules in table 117.

A ClassName production, when used in ClassAtomExClass, is not valid if traits_inst.lookup_classname returns zero for that name. The names recognized as valid ClassNames are determined by the type of the traits class, but at least the following names shall be recognized: alnum, alpha, blank, cntrl, digit, graph, lower, print, punct, space, upper, xdigit, d, s, w. In addition the following expressions shall be equivalent:

Draft
8 A ClassAtomCollatingElement production when used in a ClassAtomCollatingElement production is not valid if the value returned by \texttt{traits\_inst.lookup\_collatename} for that name is an empty string.

9 The results from multiple calls to \texttt{traits\_inst.lookup\_classname} can be bitwise OR’ed together and subsequently passed to \texttt{trait\_inst.isctype}.

10 A ClassAtomEquivalence production when used in a ClassAtomEquivalence production is not valid if the value returned by \texttt{traits\_inst.lookup\_collatename} for that name is an empty string or if the value returned by \texttt{traits\_inst.transform\_primary} for the result of the call to \texttt{traits\_inst.lookup\_collatename} is an empty string.

11 When the sequence of characters being transformed to a finite state machine contains an invalid class name the translator shall throw an exception object of type \texttt{regex\_error}.

12 If the CV of a \texttt{UnicodeEscapeSequence} is greater than the largest value that can be held in an object of type \texttt{charT} the translator shall throw an exception object of type \texttt{regex\_error}. [Note: this means that values of the form "uxxxx" that do not fit in a character are invalid. —end note]

13 Where the regular expression grammar requires the conversion of a sequence of characters to an integral value, this is accomplished by calling \texttt{traits\_inst.value}.

14 The behavior of the internal finite state machine representation when used to match a sequence of characters is as described in ECMA-262. The behavior is modified according to any match flag type flags 28.5.2 specified when using the regular expression object in one of the regular expression algorithms 28.11. The behavior is also localized by interaction with the traits class template parameter as follows:

- During matching of a regular expression finite state machine against a sequence of characters, two characters $c$ and $d$ are compared using the following rules:
  1. if (flags() & regex\_constants::icase) the two characters are equal if \texttt{traits\_inst.translate\_nocase(c)} == \texttt{traits\_inst.translate\_nocase(d)};
  2. otherwise, if flags() & regex\_constants::collate) the two characters are equal if \texttt{traits\_inst.translate(c)} == \texttt{traits\_inst.translate(d)};
  3. otherwise, the two characters are equal if $c$ == $d$.

- During matching of a regular expression finite state machine against a sequence of characters, comparison of a collating element range $c1$-$c2$ against a character $c$ is conducted as follows: if flags() & regex\_constants::collate is false then the character $c$ is matched if $c1$ <= $c$ && $c$ <= $c2$, otherwise $c$ is matched in accordance with the following algorithm:
925  TR1: Regular expressions library  28.13  Modified ECMAScript regular expression grammar

```cpp
string_type str1 = string_type(1,
    flags() & icase ?
    traits_inst.translate_nocase(c1) : traits_inst.translate(c1);
string_type str2 = string_type(1,
    flags() & icase ?
    traits_inst.translate_nocase(c2) : traits_inst.translate(c2);
string_type str = string_type(1,
    flags() & icase ?
    traits_inst.translate_nocase(c) : traits_inst.translate(c);
return traits_inst.transform(str1.begin(), str1.end())
<= traits_inst.transform(str.begin(), str.end())
&& traits_inst.transform(str2.begin(), str2.end())
```

— During matching of a regular expression finite state machine against a sequence of characters, testing whether a collating element is a member of a primary equivalence class is conducted by first converting the collating element and the equivalence class to sort keys using `traits::transform_primary`, and then comparing the sort keys for equality.

— During matching of a regular expression finite state machine against a sequence of characters, a character `c` is a member of a character class designated by an iterator range `[first, last)` if `traits_inst.isctype(c, traits_inst.lookup_classname(first, last))` is true.
Draft
This summary of C++ syntax is intended to be an aid to comprehension. It is not an exact statement of the language. In particular, the grammar described here accepts a superset of valid C++ constructs. Disambiguation rules (6.8, 7.1, 10.2) must be applied to distinguish expressions from declarations. Further, access control, ambiguity, and type rules must be used to weed out syntactically valid but meaningless constructs.

A.1 Keywords

New context-dependent keywords are introduced into a program by typedef (7.1.3), namespace (7.3.1), class (clause 9), enumeration (7.2), and template (clause 14) declarations.

```
typedef-name:
    identifier
namespace-name:
    original-namespace-name
    namespace-alias
original-namespace-name:
    identifier
namespace-alias:
    identifier
class-name:
    identifier
template-id
enum-name:
    identifier
template-name:
    identifier
```

Note that a typedef-name naming a class is also a class-name (9.1).

A.2 Lexical conventions

```
hex-quad:
    hexadecimal-digit hexadecimal-digit hexadecimal-digit hexadecimal-digit
```


universal-character-name:
  \u hex-quad
  \U hex-quad hex-quad

preprocessing-token:
  header-name
  identifier
  pp-number
  character-literal
  string-literal
  preprocessing-op-or-punc
each non-white-space character that cannot be one of the above
token:
  identifier
  keyword
  literal
  operator
  punctuator

header-name:
  < h-char-sequence >
  " q-char-sequence "

h-char-sequence:
  h-char
  h-char-sequence h-char

h-char:
  any member of the source character set except new-line and >

q-char-sequence:
  q-char
  q-char-sequence q-char

q-char:
  any member of the source character set except new-line and "

pp-number:
  digit
  . digit
  pp-number digit
  pp-number nondigit
  pp-number a sign
  pp-number E sign
  pp-number .

identifier:
  identifier-nondigit
  identifier identifier-nondigit
  identifier digit

identifier-nondigit:
  nondigit
  universal-character-name
  other implementation-defined characters

Draft
nondigit: one of
    a b c d e f g h i j k l m
    n o p q r s t u v w x y z
    A B C D E F G H I J K L M
    N O P Q R S T U V W X Y Z

digit: one of
    0 1 2 3 4 5 6 7 8 9

literal:
    integer-literal
    character-literal
    floating-literal
    string-literal
    boolean-literal

integer-literal:
    decimal-literal integer-suffix_opt
    octal-literal integer-suffix_opt
    hexadecimal-literal integer-suffix_opt

decimal-literal:
    nonzero-digit
    decimal-literal digit

octal-literal:
    0
    octal-literal octal-digit

hexadecimal-literal:
    0x hexadecimal-digit
    0X hexadecimal-digit
    hexadecimal-literal hexadecimal-digit

nonzero-digit: one of
    1 2 3 4 5 6 7 8 9

octal-digit: one of
    0 1 2 3 4 5 6 7

hexadecimal-digit: one of
    0 1 2 3 4 5 6 7 8 9
    a b c d e f A B C D E F

integer-suffix:
    unsigned-suffix long-suffix_opt
    unsigned-suffix long-long-suffix_opt
    long-suffix unsigned-suffix_opt
    long-long-suffix unsigned-suffix_opt

unsigned-suffix: one of
    u U

long-suffix: one of
    1 L

long-long-suffix: one of
    11 LL

Draft
character-literal:
\ c-char-sequence \L\ c-char-sequence \'

C-char-sequence:
c-char
c-char-sequence c-char

c-char:
any member of the source character set except
the single-quote , backslash \, or new-line character

escape-sequence
universal-character-name

escape-sequence:
simple-escape-sequence
octal-escape-sequence
hexadecimal-escape-sequence

simple-escape-sequence: one of
\a \b \f \n \r \t \v

octal-escape-sequence:
\ octal-digit
\ octal-digit octal-digit
\ octal-digit octal-digit octal-digit

hexadecimal-escape-sequence:
\x hexadecimal-digit
hexadecimal-escape-sequence hexadecimal-digit

floating-literal:
fractional-constant exponent-part_opt floating-suffix_opt
digit-sequence exponent-part floating-suffix_opt

fractional-constant:
digit-sequence_opt . digit-sequence
digit-sequence

exponent-part:
\ sign_opt digit-sequence
E sign_opt digit-sequence

sign: one of
+ -

digit-sequence:
digit
digit-sequence digit

floating-suffix: one of
f l F L

string-literal:
"s-char-sequence_opt"
L"s-char-sequence_opt"
Grammar summary

A.3 Basic concepts

s-char-sequence:
   s-char
   s-char-sequence s-char

s-char:
   any member of the source character set except
   the double-quote "," , backslash \, or new-line character
   escape-sequence
   universal-character-name

boolean.literal:
   false
   true

A.3 Basic concepts

translation-unit:
   declaration-seq_opt

A.4 Expressions

primary-expression:
   literal
   this
   ( expression )
   id-expression

id-expression:
   unqualified-id
   qualified-id

unqualified-id:
   identifier
   operator-function-id
   conversion-function-id
   ~ class-name
   template-id

qualified-id:
   :: opt nested-name-specifier template_opt unqualified-id
   :: identifier
   :: operator-function-id
   :: template-id

nested-name-specifier:
   type-name ::
   namespace-name ::
   nested-name-specifier identifier ::
   nested-name-specifier template_opt template-id ::

Draft
A.4 Expressions

postfix-expression:
  primary-expression
  postfix-expression [ expression ]
  postfix-expression ( expression-list opt )
  simple-type-specifier ( expression-list opt )
  typename-specifier ( expression-list opt )
  postfix-expression . template opt id-expression
  postfix-expression -> template opt id-expression
  postfix-expression . pseudo-destructor-name
  postfix-expression -> pseudo-destructor-name
  postfix-expression ++
  postfix-expression --
  dynamic_cast < type-id > ( expression )
  static_cast < type-id > ( expression )
  reinterpret_cast < type-id > ( expression )
  const_cast < type-id > ( expression )
  typeid ( expression )
  typeid ( type-id )

expression-list:
  assignment-expression
  expression-list , assignment-expression

pseudo-destructor-name:
  :: opt nested-name-specifier opt type-name :: ~ type-name
  :: opt nested-name-specifier template template-id :: ~ type-name
  :: opt nested-name-specifier opt ~ type-name

unary-expression:
  postfix-expression
  ++ cast-expression
  -- cast-expression
  unary-operator cast-expression
  sizeof unary-expression
  sizeof ( type-id )
  new-expression
  delete-expression

unary-operator: one of
  * & + - ! ~

new-expression:
  :: opt new new-placement opt new-type-id new-initializer opt
  :: opt new new-placement ( type-id ) new-initializer opt

new-placement:
  ( expression-list )

new-type-id:
  type-specifier-seq new-declarator opt

new-declarator:
  ptr-operator new-declarator opt
  direct-new-declarator

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direct-new-declarator:
  [ expression ]
  direct-new-declarator [ constant-expression ]

new-initializer:
  ( expression-list_opt )

delete-expression:
  ::opt delete cast-expression
  ::opt delete [ ] cast-expression

cast-expression:
  unary-expression
  ( type-id ) cast-expression

pm-expression:
  cast-expression
  pm-expression . * cast-expression
  pm-expression ->* cast-expression

multiplicative-expression:
  pm-expression
  multiplicative-expression * pm-expression
  multiplicative-expression / pm-expression
  multiplicative-expression % pm-expression

additive-expression:
  multiplicative-expression
  additive-expression + multiplicative-expression
  additive-expression - multiplicative-expression

shift-expression:
  additive-expression
  shift-expression << additive-expression
  shift-expression >> additive-expression

relational-expression:
  shift-expression
  relational-expression < shift-expression
  relational-expression > shift-expression
  relational-expression <= shift-expression
  relational-expression >= shift-expression

equality-expression:
  relational-expression
  equality-expression == relational-expression
  equality-expression != relational-expression

and-expression:
  equality-expression
  and-expression & equality-expression
exclusive-or-expression:
    and-expression
    exclusive-or-expression ^ and-expression
inclusive-or-expression:
    exclusive-or-expression
    inclusive-or-expression | exclusive-or-expression
logical-and-expression:
    inclusive-or-expression
    logical-and-expression && inclusive-or-expression
logical-or-expression:
    logical-and-expression
    logical-or-expression || logical-and-expression
conditional-expression:
    logical-or-expression
    logical-or-expression ? expression : assignment-expression
assignment-expression:
    conditional-expression
    logical-or-expression assignment-operator assignment-expression
    throw-expression
assignment-operator: one of
    = *= /= %= += -= >>= <<= &= ^= |=
expression:
    assignment-expression
    expression , assignment-expression
constant-expression:
    conditional-expression

A.5 Statements

statement:
    labeled-statement
    expression-statement
    compound-statement
    selection-statement
    iteration-statement
    jump-statement
    declaration-statement
    try-block
labeled-statement:
    identifier : statement
    case constant-expression : statement
    default : statement
expression-statement:
    expression_{opt} ;
compound-statement:
    { statement-seq_{opt} }

Draft
statement-seq:
    statement
    statement-seq statement

selection-statement:
    if ( condition ) statement
    if ( condition ) statement else statement
    switch ( condition ) statement

condition:
    expression
type-specifier-seq declarator = assignment-expression

iteration-statement:
    while ( condition ) statement
    do statement while ( expression ) ;
    for ( for-init-statement condition_opt ; expression_opt ) statement

for-init-statement:
    expression-statement
    simple-declaration

jump-statement:
    break ;
    continue ;
    return expression_opt ;
    goto identifier ;

declaration-statement:
    block-declaration

A.6 Declarations

declaration-seq:
    declaration
    declaration-seq declaration

declaration:
    block-declaration
    function-definition
    template-declaration
    explicit-instantiation
    explicit-specialization
    linkage-specification
    namespace-definition

block-declaration:
    simple-declaration
    asm-definition
    namespace-alias-definition
    using-declaration
    using-directive
    static_assert-declaration

simple-declaration:
    decl-specifier-seq_opt init-declarator-list_opt ;
static_assert-declaration:
  static_assert ( constant-expression , string-literal ) ;

dcl-specifier:
  storage-class-specifier
  type-specifier
  function-specifier
  friend
typedef
dcl-specifier-seq:
  dcl-specifier-seq_opt dcl-specifier

storage-class-specifier:
  auto 
  register 
  static 
  extern 
  mutable

function-specifier:
  inline
  virtual
  explicit

typedef-name:
  identifier
type-specifier:
  simple-type-specifier
  class-specifier
  enum-specifier
  elaborated-type-specifier
typename-specifier
cv-qualifier

simple-type-specifier:
  ::opt nested-name-specifier_opt type-name
  ::opt nested-name-specifier template template-id
  char
  wchar_t
  bool
  short
  int
  long
  signed
  unsigned
  float
double
void
auto
type-name:
  class-name
enum-name
typedef-name

elaborated-type-specifier:
  class-key :: opt nested-name-specifier opt identifier
class-key :: opt nested-name-specifier opt template opt template-id
enum :: opt nested-name-specifier opt identifier

enum-name:
  identifier
enum-specifier:
  enum identifier opt { enumerator-list opt } 
enum identifier opt { enumerator-list , }
enumerator-list:
  enumerator-definition
  enumerator-list , enumerator-definition
enumerator-definition:
  enumerator
  enumerator = constant-expression
enumerator:
  identifier
namespace-name:
  original-namespace-name
namespace-alias
original-namespace-name:
  identifier
namespace-definition:
  named-namespace-definition
  unnamed-namespace-definition
named-namespace-definition:
  original-namespace-definition
  extension-namespace-definition
original-namespace-definition:
  namespace identifier { namespace-body }
extension-namespace-definition:
  namespace original-namespace-name { namespace-body }
unnamed-namespace-definition:
  namespace { namespace-body }
namespace-body:
  declaration-seq opt
namespace-alias:
  identifier
namespace-alias-definition:
  namespace identifier = qualified-name-specifier ;
qualified-name-specifier:
  :: opt nested-name-specifier opt namespace-name
using-declaration:
  using typename opt :: opt nested-name-specifier unqualified-id ;
  using :: unqualified-id ;
A.7  Declarators

using-directive:
    using namespace ::opt nested-name-specifier opt namespace-name ;

asm-definition:
    asm ( string-literal ) ;

linkage-specification:
    extern string-literal { declaration-seq opt }
    extern string-literal declaration

A.7  Declarators

init-declarator-list:
    init-declarator
    init-declarator-list , init-declarator

init-declarator:
    declarator initializer opt

declarator:
    direct-declarator
    ptr-operator declarator

direct-declarator:
    declarator-id
    direct-declarator ( parameter-declaration-clause ) cv-qualifier-seq opt exception-specification opt
    ( declarator )

ptr-operator:
    * cv-qualifier-seq opt
    &
    ::opt nested-name-specifier * cv-qualifier-seq opt

cv-qualifier-seq:
    cv-qualifier cv-qualifier-seq opt

cv-qualifier:
    const
    volatile

declarator-id:
    id-expression
    ::opt nested-name-specifier opt class-name

type-id:
    type-specifier-seq abstract-declarator opt

type-specifier-seq:
    type-specifier type-specifier-seq opt

abstract-declarator:
    ptr-operator abstract-declarator opt
direct-abstract-declarator

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direct-abstract-declarator:
  direct-abstract-declarator_opt
  ( parameter-declaration-clause ) cv-qualifier-seq_opt exception-specification_opt
direct-abstract-declarator_opt [ constant-expression_opt ]
  ( abstract-declarator )

parameter-declaration-clause:
  parameter-declaration-list_opt ..._opt
  parameter-declaration-list , ...

parameter-declaration-list:
  parameter-declaration
  parameter-declaration-list , parameter-declaration

parameter-declaration:
  decl-specifier-seq declarator
  decl-specifier-seq declarator = assignment-expression
  decl-specifier-seq abstract-declarator_opt
  decl-specifier-seq abstract-declarator_opt = assignment-expression

function-definition:
  decl-specifier-seq_opt declarator ctor-initializer_opt function-body
  decl-specifier-seq_opt declarator function-try-block

function-body:
  compound-statement

initializer:
  = initializer-clause
  ( expression-list )

initializer-clause:
  assignment-expression
  { initializer-list ,opt }
  { }

initializer-list:
  initializer-clause
  initializer-list , initializer-clause

A.8 Classes

class-name:
  identifier
  template-id

class-specifier:
  class-head { member-specification_opt }

class-head:
  class-key identifier_opt base-clause_opt
class-key nested-name-specifier identifier base-clause_opt
class-key nested-name-specifier_opt template-id base-clause_opt

class-key:
  class
  struct
  union

Draft
A.9 Derived classes

```
member-specification:
  member-declaration member-specification opt
access-specifier : member-specification opt

member-declaration:
  decl-specifier-seq opt member-declarator-list opt ;
function-definition ; opt
:: opt nested-name-specifier template opt unqualified-id ;
using-declaration
static_assert-declaration
template-declaration

member-declarator-list:
  member-declarator
  member-declarator-list , member-declarator

member-declarator:
  declspecifier opt
  declspecifier constant-initializer opt
  identifier opt : constant-expression

pure-specifier:
  = 0

custom-initializer:
  = constant-expression
```

A.10 Special member functions

```
conversion-function-id:
  operator conversion-type-id
conversion-type-id:
  type-specifier-seq conversion-declarator opt
conversion-declarator:
  ptr-operator conversion-declarator opt
```

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ctor-initializer:
  : mem-initializer-list

mem-initializer-list:
  mem-initializer
  mem-initializer , mem-initializer-list

mem-initializer:
  mem-initializer-id ( expression-list_opt )

mem-initializer-id:
  ::opt nested-name-specifier_opt class-name
  identifier

A.11 Overloading
[gram.over]

operator-function-id:
  operator operator
  operator operator < template-argument-list_opt >

A.12 Templates
[gram.temp]

template-declaration:
  export_opt template < template-parameter-list > declaration

template-parameter-list:
  template-parameter
  template-parameter-list , template-parameter

template-parameter:
  type-parameter
  parameter-declaration

type-parameter:
  class identifier_opt
  class identifier_opt = type-id
  typename identifier_opt
  typename identifier_opt = type-id
  template < template-parameter-list > class identifier_opt
  template < template-parameter-list > class identifier_opt = id-expression

template-id:
  template-name < template-argument-list_opt >

template-name:
  identifier

template-argument-list:
  template-argument
  template-argument-list , template-argument

template-argument:
  assignment-expression
  type-id
  id-expression

Draft
A.13 Exception handling

```
typename-specifier:
    typename ::opt nested-name-specifier identifier
    typename ::opt nested-name-specifier templateopt template-id

explicit-instantiation:
    externopt template declaration

explicit-specialization:
    template < > declaration
```

A.13 Exception handling

```
try-block:
    try compound-statement handler-seq

function-try-block:
    try ctor-initializeropt function-body handler-seq

handler-seq:
    handler handler-seqopt

handler:
    catch ( exception-declaration ) compound-statement

exception-declaration:
    type-specifier-seq declarator
    type-specifier-seq abstract-declarator
    type-specifier-seq
    . . .

throw-expression:
    throw assignment-expressionopt

exception-specification:
    throw ( type-id-listopt )

type-id-list:
    type-id
    type-id-list , type-id
```

A.14 Preprocessing directives

```
preprocessing-file:
    groupopt

group:
    group-part
group group-part

group-part:

    if-section
    control-line
    text-line
    # non-directive

if-section:
    if-group elif-groups opt else-group opt endif-line

Draft
if-group:
  # if constant-expression new-line group_opt
  # ifdef identifier new-line group_opt
  # ifndef identifier new-line group_opt

elif-groups:
  elif-group
  elif-groups elif-group

elif-group:
  # elif constant-expression new-line group_opt

else-group:
  # else new-line group_opt

endif-line:
  # endif new-line

draft
Draft
Because computers are finite, C++ implementations are inevitably limited in the size of the programs they can successfully process. Every implementation shall document those limitations where known. This documentation may cite fixed limits where they exist, say how to compute variable limits as a function of available resources, or say that fixed limits do not exist or are unknown.

The limits may constrain quantities that include those described below or others. The bracketed number following each quantity is recommended as the minimum for that quantity. However, these quantities are only guidelines and do not determine compliance.

- Nesting levels of compound statements, iteration control structures, and selection control structures [256].
- Nesting levels of conditional inclusion [256].
- Pointer, array, and function declarators (in any combination) modifying an arithmetic, structure, union, or incomplete type in a declaration [256].
- Nesting levels of parenthesized expressions within a full expression [256].
- Number of characters in an internal identifier or macro name [1 024].
- Number of characters in an external identifier [1 024].
- External identifiers in one translation unit [65 536].
- Identifiers with block scope declared in one block [1 024].
- Macro identifiers simultaneously defined in one translation unit [65 536].
- Parameters in one function definition [256].
- Arguments in one function call [256].
- Parameters in one macro definition [256].
- Arguments in one macro invocation [256].
- Characters in one logical source line [65 536].
- Characters in a character string literal or wide string literal (after concatenation) [65 536].
— Size of an object [262 144].
— Nesting levels for #include files [256].
— Case labels for a switch statement (excluding those for any nested switch statements) [16 384].
— Data members in a single class, structure, or union [16 384].
— Enumeration constants in a single enumeration [4 096].
— Levels of nested class, structure, or union definitions in a single struct-declaration-list [256].
— Functions registered by atexit() [32].
— Direct and indirect base classes [16 384].
— Direct base classes for a single class [1 024].
— Members declared in a single class [4 096].
— Final overriding virtual functions in a class, accessible or not [16 384].
— Direct and indirect virtual bases of a class [1 024].
— Static members of a class [1 024].
— Friend declarations in a class [4 096].
— Access control declarations in a class [4 096].
— Member initializers in a constructor definition [6 144].
— Scope qualifications of one identifier [256].
— Nested external specifications [1 024].
— Template arguments in a template declaration [1 024].
— Recursively nested template instantiations [17].
— Handlers per try block [256].
— Throw specifications on a single function declaration [256].
Appendix C
(informative)
Compatibility

C.1  C++ and ISO C

The subclauses of this subclause list the differences between C++ and ISO C, by the chapters of this document.

C.1.1 Clause 2: lexical conventions

2.3  Change: C++ style comments (//) are added
A pair of slashes now introduce a one-line comment.
Rationale: This style of comments is a useful addition to the language.
Effect on original feature: Change to semantics of well-defined feature. A valid ISO C expression containing a division operator followed immediately by a C-style comment will now be treated as a C++ style comment. For example:

```c
{       int a = 4;
       int b = 8             // divide by a*/ a;
             *a;
}
```

Difficulty of converting: Syntactic transformation. Just add white space after the division operator.
How widely used: The token sequence //* probably occurs very seldom.

2.11  Change: New Keywords New keywords are added to C++; see 2.11.
Rationale: These keywords were added in order to implement the new semantics of C++.
Effect on original feature: Change to semantics of well-defined feature. Any ISO C programs that used any of these keywords as identifiers are not valid C++ programs.
Difficulty of converting: Syntactic transformation. Converting one specific program is easy. Converting a large collection of related programs takes more work.
How widely used: Common.
2.13.2
Change: Type of character literal is changed from `int` to `char`  
Rationale: This is needed for improved overloaded function argument type matching. For example:

```c
int function( int i );  
int function( char c );  
function( 'x' );
```

It is preferable that this call match the second version of `function` rather than the first.  

Effect on original feature: Change to semantics of well-defined feature. ISO C programs which depend on
```
sizeof('x') == sizeof(int)
```
will not work the same as C++ programs.

Difficulty of converting: Simple.

How widely used: Programs which depend upon `sizeof('x')` are probably rare.

Subclause 2.13.4:
Change: String literals made const The type of a string literal is changed from “array of `char`” to “array of const `char`.” The type of a wide string literal is changed from “array of `wchar_t`” to “array of const `wchar_t`.”
Rationale: This avoids calling an inappropriate overloaded function, which might expect to be able to modify its argument.

Effect on original feature: Change to semantics of well-defined feature.

Difficulty of converting: Simple syntactic transformation, because string literals can be converted to `char*`; (4.2). The most common cases are handled by a new but deprecated standard conversion:
```
char* p = "abc";  // valid in C, deprecated in C++  
char* q = expr ? "abc" : "de";  // valid in C, invalid in C++
```

How widely used: Programs that have a legitimate reason to treat string literals as pointers to potentially modifiable memory are probably rare.

C.1.2 Clause 3: basic concepts

3.1
Change: C++ does not have “tentative definitions” as in C E.g., at file scope,
```
int i;  
int i;
```
is valid in C, invalid in C++. This makes it impossible to define mutually referential file-local static objects, if initializers are restricted to the syntactic forms of C. For example,
```
struct X { int i; struct X *next; };  
static struct X a;  
static struct X b = { 0, &a };  
static struct X a = { 1, &b };  
```

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Rationale: This avoids having different initialization rules for built-in types and user-defined types.
Effect on original feature: Deletion of semantically well-defined feature.
Difficulty of converting: Semantic transformation.
Rationale: In C++, the initializer for one of a set of mutually-referential file-local static objects must invoke a function
call to achieve the initialization.
How widely used: Seldom.

3.3
Change: A struct is a scope in C++, not in C
Rationale: Class scope is crucial to C++, and a struct is a class.
Effect on original feature: Change to semantics of well-defined feature.
Difficulty of converting: Semantic transformation.
How widely used: C programs use struct extremely frequently, but the change is only noticeable when struct,
enumeration, or enumerator names are referred to outside the struct. The latter is probably rare.

3.5 [also 7.1.5]
Change: A name of file scope that is explicitly declared const, and not explicitly declared extern, has internal linkage,
while in C it would have external linkage
Rationale: Because const objects can be used as compile-time values in C++, this feature urges programmers to provide
explicit initializer values for each const. This feature allows the user to put const objects in header files that are
included in many compilation units.
Effect on original feature: Change to semantics of well-defined feature.
Difficulty of converting: Semantic transformation.
How widely used: Seldom

3.6
Change: Main cannot be called recursively and cannot have its address taken
Rationale: The main function may require special actions.
Effect on original feature: Deletion of semantically well-defined feature
Difficulty of converting: Trivial: create an intermediary function such as mymain(argc, argv.
How widely used: Seldom

3.9
Change: C allows “compatible types” in several places, C++ does not For example, otherwise-identical struct types
with different tag names are “compatible” in C but are distinctly different types in C++.
Rationale: Stricter type checking is essential for C++.
Effect on original feature: Deletion of semantically well-defined feature.
Difficulty of converting: Semantic transformation. The “typesafe linkage” mechanism will find many, but not all, of
such problems. Those problems not found by typesafe linkage will continue to function properly, according to the
“layout compatibility rules” of this International Standard.
How widely used: Common.

4.10
Change: Converting void* to a pointer-to-object type requires casting

```c
char a[10];
void *b=a;
void foo() {
```

Draft
ISO C will accept this usage of pointer to void being assigned to a pointer to object type. C++ will not.

**Rationale:** C++ tries harder than C to enforce compile-time type safety.

**Effect on original feature:** Deletion of semantically well-defined feature.

**Difficulty of converting:** Could be automated. Violations will be diagnosed by the C++ translator. The fix is to add a cast For example:

```c
char *c = (char *) b;
```

**How widely used:** This is fairly widely used but it is good programming practice to add the cast when assigning pointer-to-void to pointer-to-object. Some ISO C translators will give a warning if the cast is not used.

### 4.10

**Change:** Only pointers to non-const and non-volatile objects may be implicitly converted to `void*`

**Rationale:** This improves type safety.

**Effect on original feature:** Deletion of semantically well-defined feature.

**Difficulty of converting:** Could be automated. A C program containing such an implicit conversion from (e.g.) pointer-to-const-object to `void*` will receive a diagnostic message. The correction is to add an explicit cast.

**How widely used:** Seldom.

### C.1.3 Clause 5: expressions

**5.2.2**

**Change:** Implicit declaration of functions is not allowed

**Rationale:** The type-safe nature of C++.

**Effect on original feature:** Deletion of semantically well-defined feature. Note: the original feature was labeled as “obsolete” in ISO C.

**Difficulty of converting:** Syntactic transformation. Facilities for producing explicit function declarations are fairly widespread commercially.

**How widely used:** Common.

### 5.3.3, 5.4

**Change:** Types must be declared in declarations, not in expressions In C, a `sizeof` expression or cast expression may create a new type. For example,

```c
p = (void*)(struct {int i;}) *0;
```

declares a new type, struct x.

**Rationale:** This prohibition helps to clarify the location of declarations in the source code.

**Effect on original feature:** Deletion of a semantically well-defined feature.

**Difficulty of converting:** Syntactic transformation.

**How widely used:** Seldom.

### 5.16, 5.17, 5.18

**Change:** The result of a conditional expression, an assignment expression, or a comma expression may be an Ivalue
Rationale: C++ is an object-oriented language, placing relatively more emphasis on lvalues. For example, functions may return lvalues.

Effect on original feature: Change to semantics of well-defined feature. Some C expressions that implicitly rely on lvalue-to-rvalue conversions will yield different results. For example,

```c
char arr[100];
sizeof(0, arr)
```

yields 100 in C++ and sizeof(char*) in C.

Difficulty of converting: Programs must add explicit casts to the appropriate rvalue.

How widely used: Rare.

C.1.4 Clause 6: statements

6.4.2, 6.6.4 (switch and goto statements)

Change: It is now invalid to jump past a declaration with explicit or implicit initializer (except across entire block not entered)

Rationale: Constructors used in initializers may allocate resources which need to be de-allocated upon leaving the block. Allowing jump past initializers would require complicated run-time determination of allocation. Furthermore, any use of the uninitialized object could be a disaster. With this simple compile-time rule, C++ assures that if an initialized variable is in scope, then it has assuredly been initialized.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Semantic transformation.

How widely used: Seldom.

6.6.3

Change: It is now invalid to return (explicitly or implicitly) from a function which is declared to return a value without actually returning a value

Rationale: The caller and callee may assume fairly elaborate return-value mechanisms for the return of class objects. If some flow paths execute a return without specifying any value, the implementation must embody many more complications. Besides, promising to return a value of a given type, and then not returning such a value, has always been recognized to be a questionable practice, tolerated only because very-old C had no distinction between void functions and int functions.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Semantic transformation. Add an appropriate return value to the source code, e.g. zero.

How widely used: Seldom. For several years, many existing C implementations have produced warnings in this case.

C.1.5 Clause 7: declarations

7.1.1

Change: In C++, the static or extern specifiers can only be applied to names of objects or functions. Using these specifiers with type declarations is illegal in C++. In C, these specifiers are ignored when used on type declarations.

Example:

```c
static struct S {
// valid C, invalid in C++
    int i;
    // ...
};
```

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Rationale: Storage class specifiers don’t have any meaning when associated with a type. In C++, class members can be declared with the static storage class specifier. Allowing storage class specifiers on type declarations could render the code confusing for users.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Syntactic transformation.

How widely used: Seldom.

7.1.3

Change: A C++ typedef name must be different from any class type name declared in the same scope (except if the typedef is a synonym of the class name with the same name). In C, a typedef name and a struct tag name declared in the same scope can have the same name (because they have different name spaces)

Example:

```c
typedef struct name1 { /*...*/ } name1;  // valid C and C++
struct name { /*...*/ };                  // valid C, invalid C++
typedef int name;                        // valid C, invalid C++
```

Rationale: For ease of use, C++ doesn’t require that a type name be prefixed with the keywords class, struct or union when used in object declarations or type casts.

Example:

```c
class name { /*...*/ };                  // i has type class name
name i;                                 // i has type class name
```

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Semantic transformation. One of the 2 types has to be renamed.

How widely used: Seldom.

7.1.5 [see also 3.5]

Change: const objects must be initialized in C++ but can be left uninitialized in C

Rationale: A const object cannot be assigned to so it must be initialized to hold a useful value.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Semantic transformation.

How widely used: Seldom.

7.1.5 (type specifiers)

Change: Banning implicit int

In C++ a decl-specifier-seq must contain a type-specifier. In the following example, the left-hand column presents valid C; the right-hand column presents equivalent C++:

```c
void f(const parm);                void f(const int parm);
const n = 3;                      const int n = 3;
main()                            int main()
    /* ... */                    /* ... */
```
Rationale: In C++, implicit int creates several opportunities for ambiguity between expressions involving function-like casts and declarations. Explicit declaration is increasingly considered to be proper style. Liaison with WG14 (C) indicated support for (at least) deprecating implicit int in the next revision of C.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Syntactic transformation. Could be automated.

How widely used: Common.

7.2
Change: C++ objects of enumeration type can only be assigned values of the same enumeration type. In C, objects of enumeration type can be assigned values of any integral type

Example:
```c
enum color { red, blue, green };  
color c = 1;  // valid C, invalid C++
```

Rationale: The type-safe nature of C++.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Syntactic transformation. (The type error produced by the assignment can be automatically corrected by applying an explicit cast.)

How widely used: Common.

7.2
Change: In C++, the type of an enumerator is its enumeration. In C, the type of an enumerator is int.

Example:
```c
enum e { A };  
sizeof(A) == sizeof(int)  // in C
sizeof(A) == sizeof(e)  // in C++
/* and sizeof(int) is not necessarily equal to sizeof(e) */
```

Rationale: In C++, an enumeration is a distinct type.

Effect on original feature: Change to semantics of well-defined feature.

Difficulty of converting: Semantic transformation.

How widely used: Seldom. The only time this affects existing C code is when the size of an enumerator is taken. Taking the size of an enumerator is not a common C coding practice.

C.1.6 Clause 8: declarators

8.3.5
Change: In C++, a function declared with an empty parameter list takes no arguments. In C, an empty parameter list means that the number and type of the function arguments are unknown

Example:
```c
int f();  // means int f(void) in C++
// int f( unknown ) in C
```
Rationale: This is to avoid erroneous function calls (i.e. function calls with the wrong number or type of arguments).

Effect on original feature: Change to semantics of well-defined feature. This feature was marked as “obsolescent” in C.

Difficulty of converting: Syntactic transformation. The function declarations using C incomplete declaration style must be completed to become full prototype declarations. A program may need to be updated further if different calls to the same (non-prototype) function have different numbers of arguments or if the type of corresponding arguments differed.

How widely used: Common.

8.3.5 [see 5.3.3]
Change: In C++, types may not be defined in return or parameter types. In C, these type definitions are allowed

Example:
```c
void f( struct S { int a; } arg ) {} // valid C, invalid C++
enum E { A, B, C } f() {} // valid C, invalid C++
```

Rationale: When comparing types in different compilation units, C++ relies on name equivalence when C relies on structural equivalence. Regarding parameter types: since the type defined in an parameter list would be in the scope of the function, the only legal calls in C++ would be from within the function itself.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Semantic transformation. The type definitions must be moved to file scope, or in header files.

How widely used: Seldom. This style of type definitions is seen as poor coding style.

8.4
Change: In C++, the syntax for function definition excludes the “old-style” C function. In C, “old-style” syntax is allowed, but deprecated as “obsolescent.”

Rationale: Prototypes are essential to type safety.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Syntactic transformation.

How widely used: Common in old programs, but already known to be obsolescent.

8.5.2
Change: In C++, when initializing an array of character with a string, the number of characters in the string (including the terminating ‘\0’) must not exceed the number of elements in the array. In C, an array can be initialized with a string even if the array is not large enough to contain the string-terminating ‘\0’

Example:
```c
char array[4] = "abcd"; // valid C, invalid C++
```

Rationale: When these non-terminated arrays are manipulated by standard string routines, there is potential for major catastrophe.

Effect on original feature: Deletion of semantically well-defined feature.

Difficulty of converting: Semantic transformation. The arrays must be declared one element bigger to contain the string terminating ‘\0’.

Draft
How widely used: Seldom. This style of array initialization is seen as poor coding style.

C.1.7 Clause 9: classes

9.1 [see also 7.1.3]
Change: In C++, a class declaration introduces the class name into the scope where it is declared and hides any object, function or other declaration of that name in an enclosing scope. In C, an inner scope declaration of a struct tag name never hides the name of an object or function in an outer scope.

Example:

```c
int x[99];
void f()
{
    struct x { int a; };
    sizeof(x); /* size of the array in C */
    /
    / size of the struct in C++ */
}
```

Rationale: This is one of the few incompatibilities between C and C++ that can be attributed to the new C++ name space definition where a name can be declared as a type and as a non-type in a single scope causing the non-type name to hide the type name and requiring that the keywords class, struct, union or enum be used to refer to the type name. This new name space definition provides important notational conveniences to C++ programmers and helps making the use of the user-defined types as similar as possible to the use of built-in types. The advantages of the new name space definition were judged to outweigh by far the incompatibility with C described above.

Effect on original feature: Change to semantics of well-defined feature.

Difficulty of converting: Semantic transformation. If the hidden name that needs to be accessed is at global scope, the :: C++ operator can be used. If the hidden name is at block scope, either the type or the struct tag has to be renamed.

How widely used: Seldom.

9.7
Change: In C++, the name of a nested class is local to its enclosing class. In C the name of the nested class belongs to the same scope as the name of the outermost enclosing class.

Example:

```c
struct X {
    struct Y { /* ... */ } y;
};
struct Y yy;  // valid C, invalid C++
```

Rationale: C++ classes have member functions which require that classes establish scopes. The C rule would leave classes as an incomplete scope mechanism which would prevent C++ programmers from maintaining locality within a class. A coherent set of scope rules for C++ based on the C rule would be very complicated and C++ programmers would be unable to predict reliably the meanings of nontrivial examples involving nested or local functions.

Effect on original feature: Change of semantics of well-defined feature.

Difficulty of converting: Semantic transformation. To make the struct type name visible in the scope of the enclosing class,
struct, the struct tag could be declared in the scope of the enclosing struct, before the enclosing struct is defined. Example:

```c
struct Y;  // struct Y and struct X are at the same scope
struct X {
    struct Y { /* ... */ } y;
};
```

All the definitions of C struct types enclosed in other struct definitions and accessed outside the scope of the enclosing struct could be exported to the scope of the enclosing struct. Note: this is a consequence of the difference in scope rules, which is documented in 3.3.

**How widely used:** Seldom.

### 9.9

**Change:** In C++, a typedef name may not be redeclared in a class definition after being used in that definition

Example:

```c
typedef int I;
struct S {
    I i;
    int I; // valid C, invalid C++
};
```

**Rationale:** When classes become complicated, allowing such a redefinition after the type has been used can create confusion for C++ programmers as to what the meaning of ‘I’ really is.

**Effect on original feature:** Deletion of semantically well-defined feature.

**Difficulty of converting:** Semantic transformation. Either the type or the struct member has to be renamed.

**How widely used:** Seldom.

### C.1.8 Clause 12: special member functions

**12.8 (copying class objects)**

**Change:** Copying volatile objects

The implicitly-declared copy constructor and implicitly-declared copy assignment operator cannot make a copy of a volatile lvalue. For example, the following is valid in ISO C:

```c
struct X { int i; );
struct X x1, x2;
volatile struct X x3 = {0};
x1 = x3; // invalid C++
x2 = x3; // also invalid C++
```

**Rationale:** Several alternatives were debated at length. Changing the parameter to `volatile const X&` would greatly complicate the generation of efficient code for class objects. Discussion of providing two alternative signatures for these implicitly-defined operations raised unanswered concerns about creating ambiguities and complicating the rules that specify the formation of these operators according to the bases and members.

**Effect on original feature:** Deletion of semantically well-defined feature.
**Compatibility**

**C.2 Standard C library**

**Difficulty of converting:** Semantic transformation. If volatile semantics are required for the copy, a user-declared constructor or assignment must be provided. If non-volatile semantics are required, an explicit `const_cast` can be used.

**How widely used:** Seldom.

**C.1.9 Clause 16: preprocessing directives**

16.8 (predefined names)

**Change:** Whether `__STDC__` is defined and if so, what its value is, are implementation-defined

**Rationale:** C++ is not identical to ISO C. Mandating that `__STDC__` be defined would require that translators make an incorrect claim. Each implementation must choose the behavior that will be most useful to its marketplace.

**Effect on original feature:** Change to semantics of well-defined feature.

**Difficulty of converting:** Semantic transformation.

**How widely used:** Programs and headers that reference `__STDC__` are quite common.

**C.2 Standard C library**

This subclause summarizes the contents of the C++ Standard library included from the Standard C library. It also summarizes the explicit changes in definitions, declarations, or behavior from the ISO/IEC 9899:1990 and ISO/IEC 9899:1990/DAM 1 noted in other subclauses (17.4.1.2, 18.1, 21.4).

The C++ Standard library provides 54 standard macros from the C library, as shown in Table 123.

The header names (enclosed in `< and >`) indicate that the macro may be defined in more than one header. All such definitions are equivalent (3.2).

**Table 123: Standard Macros**

<table>
<thead>
<tr>
<th>Macro</th>
<th>Definition</th>
<th>Library</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>assert</td>
<td>FOPEN_MAX</td>
<td>NULL</td>
<td>SIGFPE</td>
</tr>
<tr>
<td>BUFSIZ</td>
<td>HUGE_VAL</td>
<td>NULL</td>
<td>SIGILL</td>
</tr>
<tr>
<td>CLOCKS_PER_SEC</td>
<td>LC_ALL</td>
<td>NULL</td>
<td>SIGINT</td>
</tr>
<tr>
<td>EOF</td>
<td>LC_COLLATE_LOCAL</td>
<td>NULL</td>
<td>SIGSEGV</td>
</tr>
<tr>
<td>EILSEQ</td>
<td>LCCTYPE</td>
<td>offset</td>
<td>SIGTERM</td>
</tr>
<tr>
<td>EILSEQ</td>
<td>LC_MONETARY</td>
<td>RAND_MAX</td>
<td>SIG_DFL</td>
</tr>
<tr>
<td>EILSEQ</td>
<td>LC_NUMERIC_LOCAL</td>
<td>SEEK_CUR</td>
<td>SIG_ERR</td>
</tr>
<tr>
<td>EILSEQ</td>
<td>LC_TIME</td>
<td>SEEK_END</td>
<td>SIG_IGN</td>
</tr>
<tr>
<td>EILSEQ</td>
<td>MB_CUR_MAX</td>
<td>setjmp</td>
<td>WEOF</td>
</tr>
<tr>
<td>EXIT_FAILURE</td>
<td>L_tmpnam</td>
<td>SEEK_SET</td>
<td>WEOF</td>
</tr>
<tr>
<td>EXIT_SUCCESS</td>
<td>MB_CUR_MAX</td>
<td>setjmp</td>
<td>SIGABRT</td>
</tr>
<tr>
<td>FILENAME_MAX</td>
<td>NULL</td>
<td>stdio</td>
<td>stdio</td>
</tr>
</tbody>
</table>

The C++ Standard library provides 45 standard values from the C library, as shown in Table 124.

The C++ Standard library provides 19 standard types from the C library, as shown in Table 125.

The C++ Standard library provides 2 standard structures from the C library, as shown in Table 126.

The C++ Standard library provides 209 standard functions from the C library, as shown in Table 127.
Table 124: Standard Values

<table>
<thead>
<tr>
<th>Character</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAR_BIT</td>
<td>FLT_DIG</td>
</tr>
<tr>
<td>CHAR_MAX</td>
<td>FLT_EPSILON</td>
</tr>
<tr>
<td>CHAR_MIN</td>
<td>FLT_MANT_DIG</td>
</tr>
<tr>
<td>DBL_DIG</td>
<td>FLT_MAX</td>
</tr>
<tr>
<td>DBL_EPSILON</td>
<td>FLT_MAX_10_EXP</td>
</tr>
<tr>
<td>DBL_MANT_DIG</td>
<td>FLT_MAX_EXP</td>
</tr>
<tr>
<td>DBL_MAX</td>
<td>FLT_MAX</td>
</tr>
<tr>
<td>DBL_MAX_10_EXP</td>
<td>FLT_MIN_10_EXP</td>
</tr>
<tr>
<td>DBL_MAX_EXP</td>
<td>FLT_MIN_EXP</td>
</tr>
<tr>
<td>DBL_MIN</td>
<td>FLT_MIN</td>
</tr>
<tr>
<td>DBL_MIN_10_EXP</td>
<td>FLT_ROUNDS</td>
</tr>
<tr>
<td>DBL_MIN_EXP</td>
<td>INT_MAX</td>
</tr>
<tr>
<td>MB_LEN_MAX</td>
<td>INT_MIN</td>
</tr>
<tr>
<td>SCHAR_MAX</td>
<td>LDBL_DIG</td>
</tr>
<tr>
<td>SCHAR_MIN</td>
<td>LDBL_EPSILON</td>
</tr>
<tr>
<td>SHRT_MAX</td>
<td>LDBL_MANT_DIG</td>
</tr>
<tr>
<td>SHRT_MIN</td>
<td>LDBL_MAX</td>
</tr>
<tr>
<td>UCHAR_MAX</td>
<td>LDBL_MAX_10_EXP</td>
</tr>
<tr>
<td>USRT_MAX</td>
<td>LDBL_MAX_EXP</td>
</tr>
<tr>
<td>UCHAR_MIN</td>
<td>LDBL_MAX</td>
</tr>
<tr>
<td>UCHAR_MIN</td>
<td>LDBL_MAX_EXP</td>
</tr>
<tr>
<td>ULONG_MAX</td>
<td>LDBL_MIN_10_EXP</td>
</tr>
</tbody>
</table>

Table 125: Standard Types

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>clock_t</td>
<td>size_t &lt;cstdio&gt;</td>
</tr>
<tr>
<td>div_t</td>
<td>size_t &lt;cstdlib&gt;</td>
</tr>
<tr>
<td>FILE</td>
<td>size_t &lt;cstring&gt;</td>
</tr>
<tr>
<td>fpos_t</td>
<td>size_t &lt;ctime&gt;</td>
</tr>
<tr>
<td>jmp_buf</td>
<td>size_t &lt;cstddef&gt;</td>
</tr>
<tr>
<td>sig_atomic_t</td>
<td>size_t &lt;cstring&gt;</td>
</tr>
<tr>
<td>tm</td>
<td>size_t &lt;cwctype&gt;</td>
</tr>
<tr>
<td>va_list</td>
<td>size_t &lt;cstring&gt;</td>
</tr>
<tr>
<td>wctrans_t</td>
<td>size_t &lt;cctype&gt;</td>
</tr>
<tr>
<td>wctype_t</td>
<td>size_t &lt;cwctype&gt;</td>
</tr>
</tbody>
</table>

Table 126: Standard Structs

<table>
<thead>
<tr>
<th>Struct</th>
</tr>
</thead>
<tbody>
<tr>
<td>lconv</td>
</tr>
<tr>
<td>tm</td>
</tr>
</tbody>
</table>

Draft
Table 127: Standard Functions

<table>
<thead>
<tr>
<th>Function 1</th>
<th>Function 2</th>
<th>Function 3</th>
<th>Function 4</th>
<th>Function 5</th>
<th>Function 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>abort</td>
<td>fmod</td>
<td>isupper</td>
<td>mktime</td>
<td>strftime</td>
<td>wcrtomb</td>
</tr>
<tr>
<td>abs</td>
<td>fopen</td>
<td>iswalnum</td>
<td>modf</td>
<td>strlen</td>
<td>wcscat</td>
</tr>
<tr>
<td>acos</td>
<td>fprintf</td>
<td>iswalpha</td>
<td>perror</td>
<td>strncat</td>
<td>wcshrs</td>
</tr>
<tr>
<td>asctime</td>
<td>fputc</td>
<td>iswcntrl</td>
<td>pow</td>
<td>strncmp</td>
<td>wcscmp</td>
</tr>
<tr>
<td>asin</td>
<td>fprintf</td>
<td>iswctype</td>
<td>printf</td>
<td>strncpy</td>
<td>wcscoll</td>
</tr>
<tr>
<td>atan</td>
<td>fprintf</td>
<td>iswdigit</td>
<td>putc</td>
<td>strpbrk</td>
<td>wcscpy</td>
</tr>
<tr>
<td>atan2</td>
<td>fprintf</td>
<td>iswdouble</td>
<td>putwc</td>
<td>strftime</td>
<td>wcscspn</td>
</tr>
<tr>
<td>atexit</td>
<td>fread</td>
<td>iswlower</td>
<td>puts</td>
<td>strspn</td>
<td>wcftime</td>
</tr>
<tr>
<td>atof</td>
<td>free</td>
<td>iswprint</td>
<td>putwc</td>
<td>strstr</td>
<td>wcslen</td>
</tr>
<tr>
<td>atoi</td>
<td>freopen</td>
<td>iswpunct</td>
<td>putwchar</td>
<td>strtod</td>
<td>wcscat</td>
</tr>
<tr>
<td>atol</td>
<td>frexp</td>
<td>iswalpha</td>
<td>printf</td>
<td>strtok</td>
<td>wcscmp</td>
</tr>
<tr>
<td>bsearch</td>
<td>fscanf</td>
<td>iswspace</td>
<td>qsort</td>
<td>strlen</td>
<td>wcscmp</td>
</tr>
<tr>
<td>bswap</td>
<td>fseek</td>
<td>iswdouble</td>
<td>rand</td>
<td>strtof</td>
<td>wcspbrk</td>
</tr>
<tr>
<td>calloc</td>
<td>fsetpos</td>
<td>isxdigit</td>
<td>realloc</td>
<td>strxfrm</td>
<td>wcsrchr</td>
</tr>
<tr>
<td>ceil</td>
<td>ftell</td>
<td>labs</td>
<td>remove</td>
<td>swprintf</td>
<td>wcsrtombs</td>
</tr>
<tr>
<td>clearerr</td>
<td>fwide</td>
<td>ldexp</td>
<td>rename</td>
<td>swscanf</td>
<td>wcspn</td>
</tr>
<tr>
<td>clock</td>
<td>fwprintf</td>
<td>ldexp</td>
<td>rename</td>
<td>system</td>
<td>wcstr</td>
</tr>
<tr>
<td>cos</td>
<td>fwrite</td>
<td>localeconv</td>
<td>scanf</td>
<td>tan</td>
<td>wcstod</td>
</tr>
<tr>
<td>cosh</td>
<td>fscanf</td>
<td>localtime</td>
<td>setbuf</td>
<td>tanh</td>
<td>wcstok</td>
</tr>
<tr>
<td>ctime</td>
<td>getc</td>
<td>log</td>
<td>setlocale</td>
<td>time</td>
<td>wcstol</td>
</tr>
<tr>
<td>difftime</td>
<td>getchar</td>
<td>log10</td>
<td>setvbuf</td>
<td>tmpfile</td>
<td>wcstombs</td>
</tr>
<tr>
<td>div</td>
<td>getenv</td>
<td>longjmp</td>
<td>signal</td>
<td>tmpnam</td>
<td>wcstoul</td>
</tr>
<tr>
<td>exit</td>
<td>gets</td>
<td>malloc</td>
<td>sin</td>
<td>tolower</td>
<td>wcxsfm</td>
</tr>
<tr>
<td>exp</td>
<td>getwchar</td>
<td>mblen</td>
<td>sinh</td>
<td>toupper</td>
<td>wctob</td>
</tr>
<tr>
<td>fabs</td>
<td>getwchar</td>
<td>mblen</td>
<td>sprintf</td>
<td>towctrans</td>
<td>wcrtomb</td>
</tr>
<tr>
<td>fclose</td>
<td>gmtime</td>
<td>mbtowc</td>
<td>sqrt</td>
<td>towlower</td>
<td>wctrans</td>
</tr>
<tr>
<td>feof</td>
<td>isalnum</td>
<td>mbsinit</td>
<td>srand</td>
<td>towupper</td>
<td>wctype</td>
</tr>
<tr>
<td>ferror</td>
<td>isalpha</td>
<td>mbsrtowcs</td>
<td>sscanf</td>
<td>ungetc</td>
<td>wmemchr</td>
</tr>
<tr>
<td>fflush</td>
<td>iscntrl</td>
<td>mbstowcs</td>
<td>strcat</td>
<td>ungetwc</td>
<td>wmemcmp</td>
</tr>
<tr>
<td>fgetc</td>
<td>isdigit</td>
<td>mbtowc</td>
<td>strchr</td>
<td>vfprintf</td>
<td>wmemcmp</td>
</tr>
<tr>
<td>fgetpos</td>
<td>isgraph</td>
<td>memchr</td>
<td>strcmp</td>
<td>vfprintf</td>
<td>wmemmove</td>
</tr>
<tr>
<td>fgetpos</td>
<td>isgraph</td>
<td>memchr</td>
<td>strcoll</td>
<td>vfprintf</td>
<td>wmemset</td>
</tr>
<tr>
<td>fgetwc</td>
<td>isprintf</td>
<td>memcmp</td>
<td>strcpys</td>
<td>vsprintf</td>
<td>wprintf</td>
</tr>
<tr>
<td>fgetws</td>
<td>ispunct</td>
<td>memmove</td>
<td>strcspn</td>
<td>vswprintf</td>
<td>wcsanf</td>
</tr>
<tr>
<td>floor</td>
<td>isspace</td>
<td>memset</td>
<td>strerror</td>
<td>vfprintf</td>
<td>wprintf</td>
</tr>
</tbody>
</table>

Draft
C.2 Standard C library Compatibility

C.2.1 Modifications to headers

For compatibility with the Standard C library, the C++ Standard library provides the 18 C headers (D.5), but their use is deprecated in C++.

C.2.2 Modifications to definitions

C.2.2.1 Type wchar_t

wchar_t is a keyword in this International Standard (2.11). It does not appear as a type name defined in any of <cstdlib>, <cstring>, or <cwchar> (21.4).

C.2.2.2 Header <iso646.h>

The tokens and, and_eq, bitand, bitor, compl, not_eq, not, or, or_eq, xor, and xor_eq are keywords in this International Standard (2.11). They do not appear as macro names defined in <ciso646>.

C.2.2.3 Macro NULL

The macro NULL, defined in any of <clocale>, <cstdlib>, <cstdio>, <cstdlib>, <cstring>, <ctime>, or <cwchar>, is an implementation-defined C++ null pointer constant in this International Standard (18.1).

C.2.3 Modifications to declarations

Header <cstring>: The following functions have different declarations:

- strchr
- strpbrk
- strrchr
- strstr
- memchr

21.4 describes the changes.

C.2.4 Modifications to behavior

Header <cstdlib>: The following functions have different behavior:

- atexit
- exit
- abort

18.4 describes the changes.

Header <csetjmp>: The following functions have different behavior:

- longjmp

18.8 describes the changes.
C.2.4.1 Macro offsetof(type, member-designator)  

The macro offsetof, defined in `<cstddef>`, accepts a restricted set of type arguments in this International Standard. 18.1 describes the change.

C.2.4.2 Memory allocation functions  

The functions `calloc`, `malloc`, and `realloc` are restricted in this International Standard. 20.6.7 describes the changes.
Appendix D
(normative)
Compatibility features

This clause describes features of the C++ Standard that are specified for compatibility with existing implementations.

These are deprecated features, where **deprecated** is defined as: Normative for the current edition of the Standard, but not guaranteed to be part of the Standard in future revisions.

### D.1 Increment operator with bool operand

The use of an operand of type bool with the ++ operator is deprecated (see 5.3.2 and 5.2.6).

### D.2 static keyword

The use of the static keyword is deprecated when declaring objects in namespace scope (see 3.3.5).

### D.3 Access declarations

Access declarations are deprecated (see 11.3).

### D.4 Implicit conversion from const strings

The implicit conversion from const to non-const qualification for string literals (4.2) is deprecated.

### D.5 Standard C library headers

For compatibility with the Standard C library, the C++ Standard library provides the 18 C headers, as shown in Table 128.

| <assert.h> | <iso646.h> | <setjmp.h> | <stdio.h> | <wchar.h> |
| <ctype.h> | <limits.h> | <signal.h> | <stdlib.h> | <wctype.h> |
| <errno.h> | <locale.h> | <stdarg.h> | <string.h> |
| <float.h> | <math.h> | <stddef.h> | <time.h> |

Every C header, each of which has a name of the form name . h, behaves as if each name placed in the Standard library namespace by the corresponding cname header is also placed within the namespace scope of the namespace std and is followed by an explicit using-declaration (7.3.3).
Example: The header `<cstdlib>` provides its declarations and definitions within the namespace `std`. The header `<stdlib.h>` makes these available also in the global namespace, much as in the C Standard. — end example

D.6 Old iostreams members

The following member names are in addition to names specified in clause 27:

```cpp
namespace std {
    class ios_base {
    public:
        typedef T1 io_state;
        typedef T2 open_mode;
        typedef T3 seek_dir;
        typedef OFF_T streamoff;
        typedef POS_T streampos;
        // remainder unchanged
    }
}
```

1. The type `io_state` is a synonym for an integer type (indicated here as `T1`) that permits certain member functions to overload others on parameters of type `iostate` and provide the same behavior.

2. The type `open_mode` is a synonym for an integer type (indicated here as `T2`) that permits certain member functions to overload others on parameters of type `openmode` and provide the same behavior.

3. The type `seek_dir` is a synonym for an integer type (indicated here as `T3`) that permits certain member functions to overload others on parameters of type `seekdir` and provide the same behavior.

4. The type `streamoff` is an implementation-defined type that satisfies the requirements of type `OFF_T` (27.4.1).

5. The type `streampos` is an implementation-defined type that satisfies the requirements of type `POS_T` (27.2).

An implementation may provide the following additional member function, which has the effect of calling `sbumpc()` (27.5.2.2.3):

```cpp
namespace std {
    template<class charT, class traits = char_traits<charT> >
    class basic_streambuf { public:
    void stossc();
    // remainder unchanged
    }
}
```

6. An implementation may provide the following member functions that overload signatures specified in clause 27:

```cpp
namespace std {
    template<class charT, class Traits> class basic_ios { public:
        void clear(io_state state);
        void setstate(io_state state);
        void exceptions(io_state);
    }
}
```

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The effects of these functions is to call the corresponding member function specified in clause 27.

D.7 char* streams

The header `<strstream>` defines three types that associate stream buffers with character array objects and assist reading and writing such objects.

D.7.1 Class `strstreambuf`
namespace std {
    class strstreambuf : public basic_streambuf<char> {
    public:
        explicit strstreambuf(streamsize alsize_arg = 0);
        strstreambuf(void* (*palloc_arg)(size_t), void (*pfree_arg)(void*));
        strstreambuf(char* gnext_arg, streamsize n, char* pbeg_arg = 0);
        strstreambuf(const char* gnext_arg, streamsize n);
        strstreambuf(const signed char* gnext_arg, streamsize n);
        strstreambuf(signed char* gnext_arg, streamsize n,
                     signed char* pbeg_arg = 0);
        strstreambuf(const signed char* gnext_arg, streamsize n);
        strstreambuf(unsinged char* gnext_arg, streamsize n, 
                     unsigned char* pbeg_arg = 0);
        strstreambuf(const unsigned char* gnext_arg, streamsize n);

        virtual ~strstreambuf();

        void freeze(bool freezefl = true);
        char* str();
        int pcount();

    protected:
        virtual int_type overflow (int_type c = EOF);
        virtual int_type pbackfail(int_type c = EOF);
        virtual int_type underflow();
        virtual pos_type seekoff(off_type off, ios_base::seekdir way, 
                                ios_base::openmode which = ios_base::in | ios_base::out); 
        virtual pos_type seekpos(pos_type sp, ios_base::openmode which 
                                = ios_base::in | ios_base::out);
        virtual streambuf* setbuf(char* s, streamsize n);

    private:
        // typedef T1 strstate; exposition only
        // static const strstate allocated; exposition only
        // static const strstate constant; exposition only
        // static const strstate dynamic; exposition only
        // static const strstate frozen; exposition only
        // strstate strmode;
        // streamsize alsize;
        // void* (*palloc)(size_t); exposition only
        // void (*pfree)(void*); exposition only
    };
}

The class strstreambuf associates the input sequence, and possibly the output sequence, with an object of some character array type, whose elements store arbitrary values. The array object has several attributes.

[Note: For the sake of exposition, these are represented as elements of a bitmask type (indicated here as T1) called strstate. The elements are:]

Draft
D.7 Compatibility features

---

 allocated, set when a dynamic array object has been allocated, and hence should be freed by the destructor for the strstreambuf object;

 constant, set when the array object has const elements, so the output sequence cannot be written;

dynamic, set when the array object is allocated (or reallocated) as necessary to hold a character sequence that can change in length;

 frozen, set when the program has requested that the array object not be altered, reallocated, or freed.

---

Note: For the sake of exposition, the maintained data is presented here as:

---

 strstate strmode, the attributes of the array object associated with the strstreambuf object;

 int alsize, the suggested minimum size for a dynamic array object;

 void* palloc)(size_t), points to the function to call to allocate a dynamic array object;

 void(* pfree)(void*), points to the function to call to free a dynamic array object.

---

[Note: For the sake of exposition, the maintained data is presented here as:

---

 D.7.1.1 strstreambuf constructors

 explicit strstreambuf(streamsize alsize_arg = 0);

 Effects: Constructs an object of class strstreambuf, initializing the base class with streambuf(). The postconditions of this function are indicated in Table 129.

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>strmode</td>
<td>dynamic</td>
</tr>
<tr>
<td>alsize</td>
<td>alsize_arg</td>
</tr>
<tr>
<td>palloc</td>
<td>a null pointer</td>
</tr>
<tr>
<td>pfree</td>
<td>a null pointer</td>
</tr>
</tbody>
</table>

---

strstreambuf(void* (*palloc_arg)(size_t), void (*pfree_arg)(void*));

 Effects: Constructs an object of class strstreambuf, initializing the base class with streambuf(). The postconditions of this function are indicated in Table 130.

strstreambuf(char* gnext_arg, streamsize n, char *pbeg_arg = 0);
strstreambuf(signed char* gnext_arg, streamsize n, signed char *pbeg_arg = 0);
strstreambuf(unsigned char* gnext_arg, streamsize n, signed char *pbeg_arg = 0);

---

Draft
Table 130: `strstreambuf(void* (*)(size_t), void (*)(void*))` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>strmode</code></td>
<td><code>dynamic</code></td>
</tr>
<tr>
<td><code>alsize</code></td>
<td>an unspecified value</td>
</tr>
<tr>
<td><code>palloc</code></td>
<td><code>palloc_arg</code></td>
</tr>
<tr>
<td><code>pfree</code></td>
<td><code>pfree_arg</code></td>
</tr>
</tbody>
</table>

unsigned char *pbeg_arg = 0);

Effects: Constructs an object of class `strstreambuf`, initializing the base class with `streambuf()`. The post-conditions of this function are indicated in Table 131.

Table 131: `strstreambuf(charT*, streamsize, charT*)` effects

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>strmode</code></td>
<td>0</td>
</tr>
<tr>
<td><code>alsize</code></td>
<td>an unspecified value</td>
</tr>
<tr>
<td><code>palloc</code></td>
<td>a null pointer</td>
</tr>
<tr>
<td><code>pfree</code></td>
<td>a null pointer</td>
</tr>
</tbody>
</table>

`gnext_arg` shall point to the first element of an array object whose number of elements \( N \) is determined as follows:

- If \( n > 0 \), \( N = n \).
- If \( n == 0 \), \( N = \text{std::strlen}(\text{gnext_arg}) \).
- If \( n < 0 \), \( N = \text{INT_MAX} \).\(^{334}\)

If `pbeg_arg` is a null pointer, the function executes:

\[
\text{setg}(\text{gnext_arg}, \text{gnext_arg}, \text{gnext_arg} + N);
\]

Otherwise, the function executes:

\[
\begin{align*}
\text{setg}(\text{gnext_arg}, \text{gnext_arg}, \text{pbeg_arg}); \\
\text{setp}(\text{pbeg_arg}, \text{pbeg_arg} + N);
\end{align*}
\]

`strstreambuf(const char* gnext_arg, streamsize n);`
`strstreambuf(const signed char* gnext_arg, streamsize n);`
`strstreambuf(const unsigned char* gnext_arg, streamsize n);`

Effects: Behaves the same as `strstreambuf((char*)gnext_arg, n)`, except that the constructor also sets `constant` in `strmode`.

\[^{334}\text{ The function signature \text{strlen(const char*)} is declared in <cstring> (21.4). The macro \text{INT_MAX} is defined in <climits> (18.2).}\]

Draft
Effects: Destroys an object of class `strstreambuf`. The function frees the dynamically allocated array object only if `strmode & allocated` != 0 and `strmode & frozen` == 0. (D.7.1.3 describes how a dynamically allocated array object is freed.)

D.7.1.2 Member functions

```cpp
void freeze(bool freezefl = true);
```

Effects: If `strmode & dynamic` is non-zero, alters the freeze status of the dynamic array object as follows:

- If `freezefl` is true, the function sets `frozen` in `strmode`.
- Otherwise, it clears `frozen` in `strmode`.

```cpp
char* str();
```

Effects: Calls `freeze()`, then returns the beginning pointer for the input sequence, `gbeg`.

Remarks: The return value can be a null pointer.

```cpp
int pcount() const;
```

Effects: If the next pointer for the output sequence, `pnext`, is a null pointer, returns zero. Otherwise, returns the current effective length of the array object as the next pointer minus the beginning pointer for the output sequence, `pnext - pbeg`.

D.7.1.3 `strstreambuf` overridden virtual functions

```cpp
int_type overflow(int_type c = EOF);
```

Effects: Appends the character designated by `c` to the output sequence, if possible, in one of two ways:

- If `c` != `EOF` and if either the output sequence has a write position available or the function makes a write position available (as described below), assigns `c` to `*pnext++`.
- Returns `(unsigned char)c`.
- If `c` == `EOF`, there is no character to append.
- Returns a value other than `EOF`.

Remarks: The function can alter the number of write positions available as a result of any call.

To make a write position available, the function reallocates (or initially allocates) an array object with a sufficient number of elements `n` to hold the current array object (if any), plus at least one additional write position. How many additional write positions are made available is otherwise unspecified. If `palloc` is not a null pointer, the function calls `(palloc)(n)` to allocate the new dynamic array object. Otherwise, it evaluates the expression `new charT*[n]`. In either case, if the allocation fails, the function returns `EOF`. Otherwise, it sets `allocated` in `strmode`.

335) An implementation should consider `alsize` in making this decision.
To free a previously existing dynamic array object whose first element address is \( p \): If \( pfree \) is not a null pointer, the function calls \((\*pfree)(p)\). Otherwise, it evaluates the expression \( delete[] \ p \).

If \( strmode \ & \ dynamic == 0 \), or if \( strmode \ & \ frozen != 0 \), the function cannot extend the array (reallocate it with greater length) to make a write position available.

\[
\text{int_type pbackfail(int_type } c = EOF);\]

Puts back the character designated by \( c \) to the input sequence, if possible, in one of three ways:

- If \( c != EOF \), if the input sequence has a putback position available, and if \( (\text{char})c == gnext[-1] \), assigns \( gnext - 1 \) to \( gnext \).
  
  Returns \( c \).

- If \( c != EOF \), if the input sequence has a putback position available, and if \( strmode \ & \ constant \) is zero, assigns \( c \) to \( *-gnext \).
  
  Returns \( c \).

- If \( c == EOF \) and if the input sequence has a putback position available, assigns \( gnext - 1 \) to \( gnext \).
  
  Returns a value other than \( EOF \).

Returns \( EOF \) to indicate failure.

Remarks: If the function can succeed in more than one of these ways, it is unspecified which way is chosen. The function can alter the number of putback positions available as a result of any call.

\[
\text{int_type underflow();}\]

Effects: Reads a character from the input sequence, if possible, without moving the stream position past it, as follows:

- If the input sequence has a read position available, the function signals success by returning \((\text{unsigned char})*gnext\).

- Otherwise, if the current write next pointer \( pnext \) is not a null pointer and is greater than the current read end pointer \( gend \), makes a read position available by assigning to \( gend \) a value greater than \( gnext \) and no greater than \( pnext \).
  
  Returns \((\text{unsigned char})*gnext\).

Returns \( EOF \) to indicate failure.

Remarks: The function can alter the number of read positions available as a result of any call.

\[
\text{pos_type seekoff(off_type } off, \text{ seekdir } way, \text{ openmode } which = \text{ in | out});\]

Effects: Alters the stream position within one of the controlled sequences, if possible, as indicated in Table 132.

For a sequence to be positioned, if its next pointer is a null pointer, the positioning operation fails. Otherwise, the function determines \( newoff \) as indicated in Table 133.

Otherwise, the function assigns \( xbeg + newoff + off \) to the next pointer \( xnext \).
### Table 132: `seekoff` positioning

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(which &amp; ios::in) != 0</code></td>
<td>positions the input sequence</td>
</tr>
<tr>
<td><code>(which &amp; ios::out) != 0</code></td>
<td>positions the output sequence</td>
</tr>
<tr>
<td>`(which &amp; (ios::in</td>
<td>ios::out)) == (ios::in</td>
</tr>
<tr>
<td>Otherwise</td>
<td>the positioning operation fails.</td>
</tr>
</tbody>
</table>

### Table 133: `newoff` values

<table>
<thead>
<tr>
<th>Condition</th>
<th><code>newoff</code> Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>way == ios::beg</code></td>
<td>0</td>
</tr>
<tr>
<td><code>way == ios::cur</code></td>
<td>the next pointer minus the beginning pointer (<code>xnext - xbeg</code>).</td>
</tr>
<tr>
<td><code>way == ios::end</code></td>
<td><code>seekhigh</code> minus the beginning pointer (<code>seekhigh - xbeg</code>).</td>
</tr>
<tr>
<td>If <code>newoff + off &lt; (seeklow - xbeg)</code>, or <code>seekhigh - xbeg &lt; (newoff + off)</code></td>
<td>the positioning operation fails</td>
</tr>
</tbody>
</table>
### D.7 char* streams

**Compatibility features**

Returns: `pos_type(newoff)`, constructed from the resultant offset `newoff` (of type `off_type`), that stores the resultant stream position, if possible. If the positioning operation fails, or if the constructed object cannot represent the resultant stream position, the return value is `pos_type(off_type(-1))`.

```cpp
pos_type seekpos(pos_type sp, ios_base::openmode which = ios_base::in | ios_base::out);
```

**Effects:** Alters the stream position within one of the controlled sequences, if possible, to correspond to the stream position stored in `sp` (as described below).

- If `(which & ios::in) != 0`, positions the input sequence.
- If `(which & ios::out) != 0`, positions the output sequence.
- If the function positions neither sequence, the positioning operation fails.

For a sequence to be positioned, if its next pointer is a null pointer, the positioning operation fails. Otherwise, the function determines `newoff` from `sp.offset()`:

- If `newoff` is an invalid stream position, has a negative value, or has a value greater than `(seekhigh - seeklow)`, the positioning operation fails
- Otherwise, the function adds `newoff` to the beginning pointer `xbeg` and stores the result in the next pointer `xnext`.

Returns: `pos_type(newoff)`, constructed from the resultant offset `newoff` (of type `off_type`), that stores the resultant stream position, if possible. If the positioning operation fails, or if the constructed object cannot represent the resultant stream position, the return value is `pos_type(off_type(-1))`.

```cpp
streambuf<char>* setbuf(char* s, streamsize n);
```

**Effects:** Implementation defined, except that `setbuf(0, 0)` has no effect.

#### D.7.2 Class istrstream

**[depr.istrstream]**

```cpp
namespace std {
    class istrstream : public basic_istream<char> {
        public:
            explicit istrstream(const char* s);
            explicit istrstream(char* s);
            istrstream(const char* s, streamsize n);
            istrstream(char* s, streamsize n);
            virtual "istrstream();

            strstreambuf* rdbuf() const;
            char *str();
        private:
            // strstreambuf sb;
            exposition only
    };
}
```

Draft
The class `istrstream` supports the reading of objects of class `strstreambuf`. It supplies a `strstreambuf` object to control the associated array object. For the sake of exposition, the maintained data is presented here as:

— `sb`, the `strstreambuf` object.

### D.7.2.1 istrstream constructors

[depr.istrstream.cons]

```cpp
effect explicit istrstream(const char* s);
effect explicit istrstream(char* s);
```

Effects: Constructs an object of class `istrstream`, initializing the base class with `istream(&sb)` and initializing `sb` with `strstreambuf(s,0)`. `s` shall designate the first element of an NTBS.

```cpp
explicit istrstream(const char* s, streamsize n);
```

Effects: Constructs an object of class `istrstream`, initializing the base class with `istream(&sb)` and initializing `sb` with `strstreambuf(s,n)`.. `s` shall designate the first element of an array whose length is `n` elements, and `n` shall be greater than zero.

### D.7.2.2 Member functions

[depr.istrstream.members]

```cpp
strstreambuf* rdbuf() const;
```

Returns: `const_cast<strstreambuf*>(sb)`.

```cpp
char* str();
```

Returns: `rdbuf()->str()`.

### D.7.3 Class ostrstream

[depr.ostrstream]

```cpp
namespace std {
    class ostrstream : public basic_ostream<char> {
        public:
            ostrstream();
            ostrstream(char* s, int n, ios_base::openmode mode = ios_base::out);
            virtual ~ostrstream();

            strstreambuf* rdbuf() const;
            void freeze(bool freezefl = true);
            char* str();
            int pcount() const;
        private:
            // strstreambuf sb;
            exposition only
        }
    }
}
```

The class `ostrstream` supports the writing of objects of class `strstreambuf`. It supplies a `strstreambuf` object to control the associated array object. For the sake of exposition, the maintained data is presented here as:
D.7 char* streams

— \( \text{sb} \), the \( \text{strstreambuf} \) object.

D.7.3.1 ostrstream constructors [depr.ostrstream.cons]

\begin{verbatim}
ostrstream();
1 Effects: Constructs an object of class ostrstream, initializing the base class with ostream(\&sb) and initializing \( \text{sb} \) with \( \text{strstreambuf}() \).

ostrstream(char* \( s \), int \( n \), ios_base::openmode \( \text{mode} = \text{ios_base}\::\text{out} \));
2 Effects: Constructs an object of class ostrstream, initializing the base class with ostream(\&sb), and initializing \( \text{sb} \) with one of two constructors:

— If \( (\text{mode} \& \text{app}) == 0 \), then \( s \) shall designate the first element of an array of \( n \) elements.

The constructor is \( \text{strstreambuf}(s, n, s) \).

— If \( (\text{mode} \& \text{app}) != 0 \), then \( s \) shall designate the first element of an array of \( n \) elements that contains an NTBS whose first element is designated by \( s \). The constructor is \( \text{strstreambuf}(s, n, s + \text{std}:\text{strlen}(s)) \).\[336]
\end{verbatim}

D.7.3.2 Member functions [depr.ostrstream.members]

\begin{verbatim}
strstreambuf* rdbuf() const;
1 Returns: (strstreambuf*)\&sb.

void freeze(bool freezefl = true);
2 Effects: Calls rdbuf()->freeze(freezefl).

char* str();
3 Returns: rdbuf()->str().

int pcount() const;
4 Returns: rdbuf()->pcount().
\end{verbatim}

D.7.4 Class strstream [depr.strstream]

\begin{verbatim}
namespace std {
class strstream
 : public basic_iostream<char> {
public:
   // Types
typedef char char_type;
typedef typename char_traits<char>::int_type int_type;

\[336]\text{The function signature strlen(const char*) is declared in <cstring> (21.4).}
\end{verbatim}

Draft
The class `strstream` supports reading and writing from objects of class `strstreambuf`. It supplies a `strstreambuf` object to control the associated array object. For the sake of exposition, the maintained data is presented here as `sb`, the `strstreambuf` object.

### D.7.4.1 strstream constructors

```c++
strstream();
```

**Effects:** Constructs an object of class `strstream`, initializing the base class with `iostream(&sb)`.

```c++
strstream(char* s, int n,
    ios_base::openmode mode = ios_base::in|ios_base::out);
```

**Effects:** Constructs an object of class `strstream`, initializing the base class with `iostream(&sb)` and initializing `sb` with one of the two constructors:

- If `(mode & app) == 0`, then `s` shall designate the first element of an array of `n` elements. The constructor is `strstreambuf(s,n,s)`.
- If `(mode & app) != 0`, then `s` shall designate the first element of an array of `n` elements that contains an `NTBS` whose first element is designated by `s`. The constructor is `strstreambuf(s,n,s + std::strlen(s))`.

### D.7.4.2 strstream destructor

```c++
virtual ~strstream();
```

**Effects:** Destroys an object of class `strstream`. 

Draft
D.8 Binders

The binders `binder1st`, `bind1st`, `binder2nd`, and `bind2nd` are deprecated. [Note: The template function `bind (20.5.10)` provides a better solution. — end note]

D.8.1 Class template binder1st

```cpp
template <class OperationFn>
class binder1st
    : public unary_function<typename OperationFn::second_argument_type,
                              typename OperationFn::result_type> {
protected:
    OperationFn fn;
    typename OperationFn::first_argument_type value;
public:
    binder1st(const OperationFn& z,
              const typename OperationFn::first_argument_type& y);
    typename OperationFn::result_type operator()(const typename OperationFn::second_argument_type& x) const;
    typename OperationFn::result_type operator()(typename OperationFn::second_argument_type& z) const;
};
```

1 The constructor initializes `opfn` with `x` and value with `y`.

2 `operator()` returns `opfn` with `x`.

D.8.2 bind1st

```cpp
template <class OperationFn, class T>
binder1st<OperationFn> bind1st(const OperationFn& opfn, const T& z);
```

1 `Returns: binder1st<Fn>(fn, typename Fn::first_argument_type(z)).`

Draft
D.8.3 Class template binder2nd

```cpp
template <class OperationFn>
class binder2nd
  : public unary_function<typename OperationFn::first_argument_type,
                           typename OperationFn::result_type> {
protected:
  OperationFn opfn;
  typename OperationFn::second_argument_type value;
public:
  binder2nd(const OperationFn& x,
            const typename OperationFn::second_argument_type& y);
  typename OperationFn::result_type operator()(const typename OperationFn::first_argument_type& x) const;
  typename OperationFn::result_type operator()(typename OperationFn::first_argument_type& x) const;
};
```

1. The constructor initializes `opfn` with `x` and `value` with `y`.
2. `operator()` returns `opfn(x, value)`.

D.8.4 bind2nd

```cpp
template <class OperationFn, class T>
binder2nd<OperationFn> bind2nd(const OperationFn& op, const T& x);
```

1. Returns: `binder2nd<Fn>(op, typename Fn::second_argument_type(x))`.
2. [Example:
   ```cpp
   find_if(v.begin(), v.end(), bind2nd(greater<int>(), 5));
   ```
   finds the first integer in vector v greater than 5:
   ```cpp
   find_if(v.begin(), v.end(), bind1st(greater<int>(), 5));
   ```
   finds the first integer in v less than 5. — end example]
## Appendix E
(normative)

### Universal-character-names

This clause lists the complete set of hexadecimal code values that are valid in universal-character-names in C++ identifiers (2.10).

This table is reproduced unchanged from ISO/IEC PDTR 10176, produced by ISO/IEC JTC1/SC22/WG20, except that the ranges 0041–005a and 0061–007a designate the upper and lower case English alphabets, which are part of the basic source character set, and are not repeated in the table below.

<table>
<thead>
<tr>
<th>Character Set</th>
<th>Code Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latin</td>
<td>00c0–00d6, 00d8–00f6, 00f8–01f5, 01fa–0217, 0250–02a8, 1e00–1e9a, 1ea0–1ef9</td>
</tr>
<tr>
<td>Greek</td>
<td>0384, 0388–038a, 038c, 038e–03a1, 03a3–03ee, 03d0–03d6, 03da, 03de, 03e0, 03e2–03f3, 1f00–1f15, 1f18–1f1d, 1f20–1f45, 1f48–1f4d, 1f50–1f57, 1f59, 1f5b, 1f5d, 1f5f–1f7d, 1f80–1f84, 1f86–1fbc, 1fc2–1fc4, 1fc6–1fccc, 1fd0–1fd3, 1fd6–1fdbc, 1fde0–1fec, 1ff2–1ff4, 1ff6–1ffc</td>
</tr>
<tr>
<td>Cyrillic</td>
<td>0401–040d, 040f–044f, 0451–045c, 045e–0481, 0490–04c4, 04c7–04c8, 04cb–04cc, 04d0–04eb, 04ee–04f5, 04f8–04f9</td>
</tr>
<tr>
<td>Armenian</td>
<td>0531–0556, 0561–0587</td>
</tr>
<tr>
<td>Hebrew</td>
<td>05d0–05ea, 05f0–05f4</td>
</tr>
<tr>
<td>Arabic</td>
<td>0621–063a, 0640–0652, 0670–06b7, 06ba–06be, 06c0–06ce, 06e5–06e7</td>
</tr>
<tr>
<td>Devanagari</td>
<td>0905–0939, 0958–0962</td>
</tr>
<tr>
<td>Bengali</td>
<td>0985–098c, 098f–0990, 0993–09a8, 09aa–09b0, 09b2, 09b6–09b9, 09dc–09dd, 09df–09e1, 09f0–09f1</td>
</tr>
<tr>
<td>Gurmukhi</td>
<td>0a05–0a0a, 0a0f–0a10, 0a13–0a28, 0a2a–0a30, 0a32–0a33, 0a35–0a36, 0a38–0a39, 0a59–0a5c, 0a5e</td>
</tr>
<tr>
<td>Gujarati</td>
<td>0a85–0a8b, 0a8d, 0a8f–0a91, 0a93–0a98, 0aaa–0ab0, 0ab2–0ab3, 0ab5–0ab9, 0ae0</td>
</tr>
<tr>
<td>Oriya</td>
<td>0b05–0b0c, 0b0f–0b10, 0b13–0b28, 0b2a–0b30, 0b32–0b33, 0b36–0b39, 0b5c–0b5d, 0b5f–0b61</td>
</tr>
<tr>
<td>Tamil</td>
<td>0b85–0b8a, 0b8e–0b90, 0b92–0b95, 0b99–0b9a, 0b9c, 0b9e–0b9f, 0ba3–0ba4, 0ba8–0baa, 0bae–0bb5, 0bb7–0bb9</td>
</tr>
<tr>
<td>Telugu</td>
<td>0c05–0c0c, 0c0e–0c10, 0c12–0c28, 0c2a–0c33, 0c35–0c39, 0c60–0c61</td>
</tr>
<tr>
<td>Kannada</td>
<td>0c85–0c8c, 0c8e–0c90, 0c92–0ca8, 0caa–0cb3, 0cb5–0cb9, 0ce0–0ce1</td>
</tr>
</tbody>
</table>
Malayalam: 0d05–0d0c, 0d0e–0d10, 0d12–0d28, 0d2a–0d39, 0d60–0d61
Thai: 0e01–0e30, 0e32–0e33, 0e40–0e46, 0e4f–0e5b
Lao: 0e81–0e82, 0e84, 0e87, 0e88, 0e8a, 0e8d, 0e94–0e97, 0e99–0e9f, 0ea1–0ea3, 0ea5, 0ea7, 0eaa, 0eab, 0ead–0eb0, 0eb2, 0eb3, 0ebd, 0ec0–0ec4, 0ec6
Georgian: 10a0–10c5, 10d0–10f6
Hiragana: 3041–3094, 309b–309e
Katakana: 30a1–30fe
Bopomofo: 3105–312c
Hangul: 1100–1159, 1161–11a2, 11a8–11f9
CJK Unified Ideographs: f900–fa2d, fb1f–fb36, fb38–fb3c, fb3e, fb40–fb41, fb42–fb44, fb46–fbb1, fbd3–fd3f, fd50–fd8f, fd92–fdec7, fdf0–fdb, fe70–fe72, fe74, fe76–fe81, ffe1–ff3a, ff41–ff5a, ff66–ffbe, ffc2–ffc7, ffc8–ffcf, ffd2–ffd7, ffda–fdec, 4e00–9fa5
Index

!, see logical negation operator
! =, see inequality operator
(), see function call operator
    function declarator, 158
*, see indirection operator, see multiplication operator
    pointer declarator, 153
+, see unary plus operator, see addition operator
++, see increment operator
    , , see comma operator
-, see unary minus operator, see subtraction operator
->, see class member access operator
->*, see pointer to member operator
-, see decrement operator
    , , see class member access operator
.*, see pointer to member operator
    , . . , see ellipsis
/, see division operator
    : field declaration, 187
    label specifier, 107
::, see scope resolution operator
::*
    pointer to member declarator, 156
<, see less than operator
    template and, 281, 282
< =<, see left shift operator
<=, see less than or equal to operator
=, see assignment operator
==, see equality operator
>, see greater than operator
>=, see greater than or equal operator
>>, see right shift operator
? : , see conditional expression operator
[] , see subscripting operator
    array declarator, 156
#define, 366
#define, 366
#endif, 364
#include, 364, 386
#line, 369
#include, 364, 386
#pragma, 364
#undef, 368, 387
% , see modulus operator
&, see address-of operator, see bitwise AND operator

    reference declarator, 154
&&, see logical AND operator
^ , see bitwise exclusive OR operator

# operator, 367
# operator, 367
basic_ios::failure argument
    implementation-defined, 819
const object
    undefined change to, 125
exception::what message
    implementation-defined, 415
friend function
    nested class, 189
delete, 92, 95
new, 92
operator bool
    basic_ios, 819
\, see backslash
__cplusplus, 372
__DATE__, 372
__FILE__, 372
__LINE__, 372
__STDC_HOSTED__, 372
__STDC_ISO_10646__, 372
implementation-defined, 372

\_ \_STDC\_VERSION\_\_, 372

implementation-defined, 372

\_ \_STDC\_\_, 372

implementation-defined, 372

\_ \_TIME\_\_, 372

{}

block statement, 107
class declaration, 175
class definition, 175
enum declaration, 129
initializer list, 168
\~\_, see one’s complement operator, see destructor
\~Init
    ios_base::Init, 811
\~auto\_ptr
    auto\_ptr, 477
\~basic\_filebuf
    basic\_filebuf, 869
\~basic\_iostream
    basic\_iostream, 846
\~basic\_ostream
    basic\_ostream, 849
\~ctype\_char>
    ctype\_char>, 546
\~exception
    exception, 414
\~locale
    locale, 538
\~sentry
    basic\_istream, 837
    basic\_ostream, 850
\~strstream
    strstream, 975
\~strstreambuf
    strstreambuf, 968
\~valarray
    valarray, 775
\_ \_see character, underscore
\|, 101

0, see also zero, null
    null character, 22
    string terminator, 22
\_1, 461

abort, 53, 112, 386, 405, 411, 416
abs, 781, 794, 795
    complex, 742
abstract-declarator, 150, 938
access
    struct default member, 175
    union default member, 175
    adjusting base class member, 210
    base class, 208
    base class member, 191
    class member, 79
    member name, 205
    overloading and, 250
    virtual function, 216
access-specifier, 191, 940
access control, 205
    anonymous union, 186
    member function and, 219
    overloading resolution and, 195
access specifier, 207, 208
accumulate, 791
acos, 781, 795
    complex, 743
acosh, 795
    complex, 743
addition operator, 98, 933
additive-expression, 98, 933
address, 64, 101
    address of member function unspecified, 391
adjacent_difference, 793
adjacent_find, 708
advance, 678
aggregate, 168
algorithm
    stable, 377
    \<algorithm>, 697
alias, 135
alignment requirement
    implementation-defined, 61
allocation
    alignment storage, 92
    implementation defined bit-field, 187
    unspecified, 179, 207
allocator, 654, 657, 660, 663, 911
allocator, 471
alpha, 769
always_noconv, 550
ambiguity
base class member, 194
class conversion, 197
declaration type, 119
declaration versus cast, 151
declaration versus expression, 114
function declaration, 166
member access, 194
parentheses and, 91
ambiguity detection
overloaded function, 251
Ambendment 1, 388
any
bitset, 651
append
basic_string, 510
apply
valarray, 778
arg, 744
complex, 742
argc, 51
argument, 2, 390, 391, 421
access checking and default, 206
binding of default, 162
evaluation of default, 162, 163
example of default, 161, 162
overloaded operator and default, 270
reference, 78
scope of default, 163
template, 283
type checking of default, 162
arguments
implementation-defined order of evaluation of function, 163
argument and name hiding
default, 163
argument and virtual function
default, 164
argument list
empty, 158
variable, 158
argument passing, 78
reference and, 172
argument substitution, 366
argument type
unknown, 158
argv, 51
arithmetic
pointer, 98
unsigned, 62
array, 159
bound, 157
const, 64
delete, 94
multidimensional, 157
new, 91
overloading and pointer versus, 248
sizeof, 90
storage of, 158
<array>, 601
array, 605, 607
as aggregate, 605
begin, 605
contiguous storage, 605
data, 606
default, 605
end, 605
get, 607
initialization, 605, 606
max_size, 605
size, 605, 606
swap, 606
tuple interface to, 607
zero sized, 607
array size
default, 157
arrow operator, see class member access operator
asin, 781, 795
complex, 743
asinh, 795
complex, 743
asm
implementation-defined, 145
assembler, 145
<assert.h>, 386
assign
basic_string, 511
deque, 610
list, 615
vector, 626
basic_regex, 900, 901
assignment
and lvalue, 104
conversion by, 104
reference, 172
assignment-expression, 104, 934
assignment-operator, 104, 934
assignment operator
copy, 242
overloaded, 270
associative containers
unordered, see unordered associative containers
at
basic_string, 510
map, 635
atan, 781, 795
complex, 743
atan2, 781, 795
atanh, 795
complex, 743
atexit, 53, 386, 405
auto
destruction of, 112, 113
auto_ptr, 475, 481
auto_ptr, 476
awk, 891
back_insert_iterator, 685
back_insert_iterator, 685
back_inserter, 686
backslash character, 20
bad
basic_ios, 820
bad_alloc, 92, 407, 411
bad_alloc::what
implementation-defined, 410
bad_cast, 82, 412
bad_cast, 412, 413
bad_cast::what
implementation-defined, 413
bad_exception, 358, 415
bad_exception, 415
bad_exception::what
implementation-defined, 415
bad_function_call, 464
bad_function_call, 465
bad_typeid, 83, 413
bad_typeid, 413
bad_typeid::what
implementation-defined, 413
bad_weak_ptr, 478
bad_weak_ptr, 478
what, 478
base
discard_block, 759
base-specifier, 191, 940
base-specifier-list, 191, 940
base1
ox_or_combine, 760
base2
xor_combine, 760
base class, 191, 192
direct, 191
indirect, 191
private, 208
protected, 208
public, 208
base class virtual, see virtual base class
basic_filebuf, 799, 868
basic_filebuf, 869
basic_filebuf<char>, 867
basic_filebuf<wchar_t>, 867
basic_fstream, 799, 877
basic_fstream, 878
basic_ifstream, 799, 874
basic_ifstream, 874
basic_ifstream<char>, 867
basic_ifstream<wchar_t>, 867
basic_ios, 799, 815
basic_ios, 817
basic_ios<char>, 805
basic_ios<wchar_t>, 805
basic_iostream, 846
basic_iostream, 846
basic_istream, 799, 834
basic_istream, 836
basic_istream<char>, 833
basic_istream<wchar_t>, 833
basic_istreambuf_iterator, 799
basic_istringstream, 799, 863
basic_istringstream, 864
basic_istringstream<char>, 858
basic_istringstream<wchar_t>, 858
basic_ofstream, 799, 875
    basic_ofstream<char>, 867
    basic_ofstream<wchar_t>, 867
basic_ostream, 799, 908
    basic_ostream<char>, 849
    basic_ostream<wchar_t>, 834
basic_ostreambuf_iterator, 799
basic_ostringstream, 799, 864
    basic_ostringstream<char>, 858
    basic_ostringstream<wchar_t>, 858
basic_regex, 883
    assign, 900, 901
    constants, 898, 899
    operator=, 900
    swap, 901, 902
basic_streambuf, 799, 824
    basic_streambuf<char>, 823
    basic_streambuf<wchar_t>, 823
basic_string, 500, 521, 858
    basic_stringbuf, 505
    basic_stringbuf<char>, 858
    basic_stringbuf<wchar_t>, 858
basic_stringbuf, 859
    basic_stringbuf<char>, 858
    basic_stringbuf<wchar_t>, 858
basic_stringstream, 799, 866
    basic_stringstream, 866
before
    type_info, 412
begin
    basic_string, 508
    array, 605
    match_results, 911
    unordered associative containers, 600
behavior
    conditionally-supported, 2, 5
    default, 376, 380
    implementation-defined, 2, 570
    locale-specific, 3
    required, 377, 380
    undefined, 3
    unspecified, 3
Ben, 250
bernoulli_distribution, 763
    p, 764
bidirectional_iterator_tag, 677
binary function, 454, 455, 464
binary_function, 453
binary_negate, 459
binary_search, 722
binary operator
    interpretation of, 270
    overloaded, 270
bind, 460–461
bind1st, 976
bind2nd, 977
binder1st, 976
binder2nd, 977
binding
    reference, 172
binomial_distribution, 765
    p, 766
t, 766
bit-field, 187
    address of, 187
    alignment of, 187
    implementation-defined sign of, 187
    implementation-defined alignment of, 187
    type of, 187
    unnamed, 187
    zero width of, 187
<bitset>, 646
bitset, 646
    bitset, 648
    block
        initialization in, 113
        block scope; see local scope, 31
        block structure, 113
        body
            function, 164
        bool()
            basic_istream operator, 837
            basic_ostream operator, 850

Draft
boolalpha, 820
Boolean, 187
Boolean literal, 23
boolean-literal, 23, 931
Boolean type, 62
bound arguments, 460
bound, of array, 157
bucket
  unordered associative containers, 600
bucket_count
  unordered associative containers, 599
bucket_size
  unordered associative containers, 600
buckets, 596
built-in type; see fundamental type, 62
byte, 89

C
  linkage to, 146
c-char, 20, 930
c-char-sequence, 20, 930
c_str
  basic_string, 516
cabs
  complex, 742
cacos
  complex, 743
cacosh
  complex, 743
catn
  complex, 743
catch, 349, 942
category
  locale, 534
cbrt, 795
<ccomplex>, 745
cerr, 803
<cerrno>, 388
<cfenv>, 734
char
  implementation-defined sign of, 62
char_class_type
  regex_traits, 895
  Regular Expression Traits, 882
character, 376
decimal-point, 382
multibyte, 3
set
basic execution, 5
basic source, 12
signed, 62
underscore, 387, 388
in identifier, 17
character-literal, 20, 930
character string, 22
checking
  point of error, 305
  syntax, 305
cin, 803
<ciso646>, 960
class, 63, 175
  abstract, 202
  base, 388, 392
  cast to incomplete, 96
  constructor and abstract, 203
  definition, 27
  derived, 392
  linkage of, 49
  linkage specification, 147
  pointer to abstract, 203
  polymorphic, 198
  scope of enumerator, 131
  template, 648
  unnamed, 123
class-key, 175, 939
class-name, 175, 939
class-specifier, 175, 939
classes
  narrow-oriented iostream, 376
  wide-oriented iostream, 377
classic
  locale, 540
classic_table
  ctype<char>, 548
class base, see base class
class derived, see derived class
class local, see local class
class member, see also member
class name, 150
  elaborated, 127, 177
  point of declaration, 178
  scope of, 176
  typedef, 123, 178
class nested, see nested class
class object
  assignment to, 104
  const, 64
  member, 179
  operations on, 175
  sizeof, 89
class object copy, see also copy constructor
class object initialization, see also constructor
clear
  basic_ios, 819
  basic_string, 509
  unordered associative containers, 599
<climits>, 968
<clocale>, 960
<clocale>, 382
clog, 803
close
  basic_filebuf, 870, 878
  basic_ifstream, 875
  basic_ofstream, 877
  messages, 578
codecvt, 548
codecvt_bynname, 553
collate, 564
collate_bynname, 565
collating element, 881
combine
  locale, 538
comment, 14
  */ */, 15
  //, 15
collapse
  basic_string, 520
  collate, 565
  sub_match, 903
comparison
  pointer, 100, 101
  pointer to function, 100, 101
  undefined pointer, 98, 100
  unspecified pointer, 100
  void* pointer, 100
compilation
  separate, 11
compiler control line, see preprocessing directive
completely defined, 178
<ccomplex>, 735
complex, 737
complex, 739
<complex.h>, 745
component, 376
compound-statement, 108, 934
concatenation
  string, 22
  undefined string literal, 22
condition, 108, 935
  rules for, 108
conditional-expression
  throw-expression in, 102
conj, 744
  complex, 742
consistency
  linkage, 120
  linkage specification, 147
  type declaration, 51
const, 64
  constructor and, 184, 220
  destructor and, 184, 226
  linkage of, 48, 120
  overloading and, 249
const_local_iterator, 596
  unordered associative containers, 596
const_mem_fun1_ref_t, 463
const_mem_fun1_t, 463
const_mem_fun_ref_t, 463
const_mem_fun_t, 463
const_pointer_cast
  shared_ptr, 485
constant, 18, 75
  enumeration, 129
  null pointer, 71
constant-expression, 105, 934
constant_initializer, 178, 940
constructor, 219
  address of, 220
  array of class objects and, 232
  conversion by, 224
  copy, 220, 222, 240, 384
  exception handling, 352
  inheritance of, 220
  non-trivial, 220
  type of, 220
union, 186
unspecified argument to, 94
constructor call
  explicit, 220
constructor conversion by, see also user-defined conversion
constructor default, see default constructor
context
  non-deduced, 341
control line, see preprocessing directive
conevention, 380
conversion
  argument, 158
  array pointer, 68
  array-to-pointer, 68
  Boolean, 72
  class, 223
  derived-to-base, 262
  floating point, 70
  floating-integral, 71
  function-to-pointer, 68
  implementation-defined floating point, 70
  implementation defined pointer integer, 85
  implicit, 67, 223
  implicit user-defined, 223
  inheritance of user-defined, 226
  integer, 70
  lvalue-to-rvalue, 68, 950
  overload resolution and, 259
  overload resolution and pointer, 268
  pointer, 71
  pointer to function, 68
  pointer to member, 71
  void*, 72
  return type, 113
reverse_iterator, 681
signed unsigned integer, 70
standard, 67
static user-defined, 226
type of, 225
user-defined, 223–225
virtual user-defined, 226
conversion operator, see conversion function
conversion rank, 263
conversion-function-id, 225, 940
conversions
qualification, 68
usual arithmetic, 74
conversion explicit type, see casting
conversion function, see user-defined conversion
  copy
    class object, 240
copy, 711
    basic_string, 515
copy_backward, 711
copyfmt
    basic_ios, 818
copysign, 795
copy assignment operator
    implicitly-declared, 242
copy constructor
    implicitly-declared, 241
cos, 781, 795
    complex, 743
cosh, 781, 795
    complex, 743
count, 709
    bitset, 651
    unordered associative containers, 599
count_if, 709
cout, 803
cref
    reference_wrapper, 456
<cstdlib>, 388
cshift
    valarray, 778
<ctgmath>, 159
<cstdlib>, 388
<cstdlib>, 90, 98, 960, 961
<ctgmath>, 404
<cstdlib>, 803, 804, 868, 870, 960
<cstdlib>, 871
<ctgmath>, 51, 53, 386, 960, 964
<string>, 383, 960
<string>, 383, 968, 974
<string>
<ctgmath>
<ctime>, 960
<ctime>, 532
ctor-initializer, 232, 941
ctype, 541
ctype<
    ctype<char>, 547
ctype_byname, 545
cv-qualifier, 64
cv-qualifier, 150, 938
<cvchar>, 383, 388, 960
<cvctype>, 388
DAG
  multiple inheritance, 193, 194
  non-virtual base class, 194
  virtual base class, 193, 194
data
  basic_string, 516
  vector, 627
  array, 606
data member, see member
    static, 184
date_order
    time_get, 567
deallocation, see delete
dec, 822
dec, 852
decimal-literal, 18, 929
decimal_point
    numpunct, 563
decl-specifier, 118, 936
declaration, 25, 117
    extern reference, 172
typedef as type, 122
    access, 210
    array, 157
    asm, 145
    bit-field, 187
class member, 178, 940
class name, 26
    constant pointer, 153
default argument, 161
definition versus, 25
ellipsis in function, 78, 158
    enumerator point of, 30
    extern, 25
    forward, 121
    forward class, 177
    function, 25, 158
    member, 178
    multiple, 51
    name, 25
Draft
overloaded, 247
overloaded name and friend, 213
parameter, 158
parentheses in, 151, 153
pointer, 153
reference, 155
register, 119
static member, 26
storage class, 119
type, 152
typedef, 26
declaration, 117, 935
declaration-statement, 113, 935
declaration hiding, see name hiding
declaration matching
  overloaded function, 250
declarator, 118, 149
    meaning of, 152
    multidimensional array, 157
declarator, 149, 938
declarator-id, 150, 938
decrement operator
  overloaded, 271
default
  access control, 205
default-initialization, 166
defaultfloat, 823
default argument
  overload resolution and, 259
default constructor, 220
default initializers
  overloading and, 249
definition, 25, 375
  static member, 185
alternate, 388
class, 175, 178
class name as type, 176
constructor, 165
declaration as, 118
empty class, 175
enumerator point of, 130
function, 164
local class, 189
member function, 180
namespace, 131
nested class, 188
  pure virtual function, 202
  scope of class, 176
  virtual function, 200
delete, 54, 94, 95, 229
  operator, 490
destructor and, 95, 227
  operator, 389, 408, 409
  overloading and, 56
  type of, 230
  undefined, 95
delete-expression, 94, 933
deprecated features, 81, 89
<deque>, 602
deque, 607
derreferencing, see also indirection
derivation, see inheritance
derived class, 191
  most, 6
  overloading and, 250
derived object
  most, 6
destructor, 226, 384
  default, 226
  exception handling, 352
  non-trivial, 226
  program termination and, 227
  pure virtual, 227
  union, 186
  virtual, 227
destructor call
  explicit, 227
  implicit, 227
digit, 16, 929
digit-sequence, 22, 930
digraph, 15
direct-abstract-declarator, 150, 939
direct-declarator, 149, 938
direct-new-declarator, 90, 933
directed acyclic graph, see DAG
directive
  error, 371
  null, 372
  pragma, 371
  preprocessing, 361
discard_block, 758
  base, 759
discard_block, 758
operator(), 759
seed, 759
template parameters, 758
distance, 678
distribution
  variate_generator, 751, 752
div, 794
divides, 457
division
  implementation defined, 97
do_always_noconv
codecvt, 552
do_close
  messages, 579
do_compare
collate, 565
do_curr_symbol
  moneypunct, 577
do_date_order
  time_get, 568
do_decimal_point
  moneypunct, 576
  numpunct, 563
do_encoding
codecvt, 552
do_falsename
  numpunct, 564
do_frac_digits
  moneypunct, 577
do_get
  messages, 578, 579
  money_get, 572
  num_get, 555
do_get_date
  time_get, 568
do_get_monthname
  time_get, 568
do_get_time
  time_get, 568
do_get_weekday
  time_get, 568
do_get_year
  time_get, 568
do_grouping
  moneypunct, 576
  numpunct, 563
  do_hash
  collate, 565
do_in
  codecvt, 550
do_is
cctype, 543
do_length
  codecvt, 552
do_max_length
  codecvt, 552
do_narrow, 548
cctype, 544
do_neg_format
  moneypunct, 577
do_negative_sign
  moneypunct, 577
do_open
  messages, 578
do_out
  codecvt, 550
do_pos_format
  moneypunct, 577
do_positive_sign
  moneypunct, 577
do_put
  money_put, 574
  num_put, 559
  time_put, 570
do_scan_is
  cctype, 544
do_scan_not
  cctype, 544
do_thousands_sep
  moneypunct, 576
  numpunct, 563
do_tolower
  cctype, 544
do_toupper
  cctype, 544
do_transform
  collate, 565
do_truename
  numpunct, 564
do_unshift
  codecvt, 551
do_widen, 547
domain_error, 420
domain_error, 420
dominance
  virtual base class, 196
dot operator, see class member access operator
dynamic binding, see virtual function
dynamic_pointer_cast
  shared_ptr, 484
eback
  basic_streambuf, 828
ECMAScript, 891, 923
egptr
  basic_streambuf, 828
egrep, 891
elaborated-type-specifier, 127, 937
elaborated type specifier, see elaborated class name
elosion
copy constructor, 244
ellipsis
  overload resolution and, 259
dot operator, see class member access operator
dynamic binding, see virtual function
dynamic_pointer_cast
  shared_ptr, 484
encoding
  multibyte, 23
encoding
codecvt, 550
end
  basic_string, 508
  array, 605
  match_results, 911
  unordered associative containers, 600
end-of-file, 652
endl, 855
endl, 852
ends, 855
engine
  variate_generator, 751
  entity, 25
  entropy
    random_device, 762
  enum, 63
    overloading and, 248
    type of, 129, 130
  enumeration, 129
    linkage of, 49
  enumeration type
    conversion to, 84
    static_cast
      conversion to, 84
  enumerator
    definition, 27
    value of, 129
  enumerator, 129, 937
  enum name
    typedef, 123
  environment
    program, 51
eof
  basic_ios, 819
epptr
  basic_streambuf, 829
eq
  char_traits, 517–519
equal, 709
  istreambuf_iterator, 695
equal_range, 722
    unordered associative containers, 599
equal_to, 457
equality-expression, 100, 933
equivalence
  template type, 288
  type, 122, 176
equivalent parameter declarations, 248
  overloading and, 248
erase
  basic_string, 513
deque, 611
  list, 616
  vector, 627
    unordered associative containers, 599
erf, 795
erfc, 795
error_type, 893, 894
escape-sequence, 20, 930
escape character, see backslash
escape sequence
undefined, 20
evaluation
order of argument, 79
unspecified order of, 52, 73
unspecified order of argument, 79
unspecified order of function call, 79
example
*const, 153
static member, 185
array, 157
class definition, 179
const, 153
constant pointer, 153
constructor, 220
constructor and initialization, 231
declaration, 26, 160
declarator, 150
definition, 26
delete, 230
derived class, 191
destructor and delete, 230
ellipsis, 158
enumeration, 130 explicit destructor call, 228 explicit qualification, 195 friend, 177 friend function, 211 function declaration, 159 function definition, 164 linkage consistency, 120 local class, 189 member function, 182, 211 member name access, 210 nested type name, 190 nested class, 188 nested class definition, 188, 217 nested class forward declaration, 189 pointer to member, 156 pure virtual function, 202 scope of delete, 230 scope resolution operator, 195 subscripting, 157
typedef, 122
type name, 150
unnamed parameter, 165
variable parameter list, 158
virtual function, 199, 200
exception
allowing an, 356
arithmetic, 73
bad_function_call, 464
bad_weak_ptr, 478
handling, 349
object, 351
undefined arithmetic, 73
<exception>, 414
exception
exception, 414
exception-declaration, 349, 942
exception-specification, 355, 942
exceptions
basic_ios, 820
exit, 51, 53, 112, 386, 405, 411
exp, 781, 795
complex, 743
exp2, 795
expired
weak_ptr, 487
explanation
subscripting, 157
explicit-specialization, 324
explicit type conversion, see casting
expm1, 795
exponent-part, 21, 930
exponential_distribution, 767
lambda, 767
export, 277
expression, 73
arithmetic constant, 105
constant, 105
order of evaluation of, 8
parenthesized, 75
pointer to member constant, 88
postfix, 76
primary, 74
reference, 73
unary, 88, 932
INDEX

expression, 104, 934
expression-list, 77, 932
expression-statement, 107, 934
extern, 119
  linkage of, 120
extern "C", 386, 388
extern "C++", 386, 388

fabs
  complex, 742
facet
  locale, 535
fail
  basic_ios, 819
failed
  ostreambuf_iterator, 696
failure
  ios_base::failure, 808
false
  numpunct, 563
fclose, 871
fclose, 871
fdim, 795
FE_ALL_EXCEPT, 735
FE_DFL_ENV, 735
FE_DIVBYZERO, 735
FE_DOWNWARDZERO, 735
FE_INEXACT, 735
FE_INVALID, 735
FE_OVERFLOW, 735
FE_TONEAREST, 735
FE_TOWARDZERO, 735
FE_UNDERFLOW, 735
FE_UPWARD, 735
fexclexception, 735
fegetenv, 735
fegetexceptflag, 735
fegetround, 735
fholdexcept, 735
<fenv.h>, 735
fenv_t, 735
fraisexception, 735
fesetenv, 735
fesetexceptflag, 735
fesetround, 735
fetestexcept, 735
feupdateenv, 735
fexcept_t, 735
file, 11
  source, 11, 386, 388
filebuf, 799, 867
  implementation-defined, 873
fill, 713
  basic_ios, 818
gslice_array, 787
  indirect_array, 790
mask_array, 788
  slice_array, 783
fill_n, 713
find, 707
  basic_string, 516
  unordered associative containers, 599
find_end, 707
find_first_not_of
  basic_string, 519
find_first_of
  basic_string, 517
find_if, 707
find_last_not_of
  basic_string, 519
find_last_of
  basic_string, 518
finite state machine, 881
fixed, 822
flags
  ios_base, 541, 811
flip
  bitset, 650
float_round_style, 400
  floating-literal, 21, 930
  floating-suffix, 22, 930
floating point type, 63
  implementation-defined, 63
floor, 795
flush, 811, 837, 850, 855
  basic_ostream, 855
fma, 795
fmax, 795
fmin, 795
fmtflags
  ios_base, 808
  ios, 856

Draft
fopen, 870
for
    scope of declaration in, 112
for_each, 707
formal argument, see parameter
format
    match_results, 911
format specifier, 881
format_default, 892, 893
format_first_only, 892, 893, 916
format_no_copy, 892, 893, 916
forward_iterator_tag, 677
forwarding call wrapper, 452
fpclassify, 797
fpos, 805, 814, 815
fractional-constant, 21, 930
free, 490
freeze
    ostrstream, 974
    strstreambuf, 969
    strstream, 976
free store, see also new, delete
frexp, 795
friend
    virtual and, 200
    access specifier and, 214
class access and, 212
inheritance and, 214
local class and, 214
template and, 293
friend function
    access and, 211
    inline, 214
    linkage of, 213
    member function and, 211
front_insert_iterator, 686
    front_insert_iterator, 687
front_inserter, 687
fseek, 870
<fstream>, 867
fstream, 799
full-expression, 8
function, see also friend function, member function, in-line function, virtual function, 159
function, see also function argument, parameter, parameter list, parameter type, formal argument, virtual function, 159
allocation, 55, 91
comparison, 376
conversion, 225
deallocation, 56, 95, 229
definition, 27
global, 388, 391
handler, 376
linkage specification overloaded, 147
modifier, 376
observer, 377
operator, 269
plain old, 418
pointer to member, 97
replacement, 377
reserved, 377
viable, 251
virtual member, 388, 391
function, 465
    ~function, 467
    bool conversion, 468
    function, 466
    invocation, 468
operator!=, 468
operator(), 468
operator=, 467
operator==, 468
swap, 467, 469
target, 468
target_type, 468
function objects
    binders, 459–461
    mem_fn, 464
    reference_wrapper, 454
    return type, 453–454
    wrapper, 464–469
    function-body, 164, 939
    function-definition, 164, 939
    function-specifier, 121, 936
    function-try-block, 349, 942
    <functional>, 448
functions
    candidate, 316
    function argument, see argument
function call, 78
    recursive, 79
    undefined, 85
INDEX

function call operator
  overloaded, 271
function overloaded, see overloading
function parameter, see parameter
function prototype, 32
function return, see return
function return type, see return type
function virtual, see virtual function
fundamental type
destructor and, 229
fundamental type conversion, see conversion, user-defined conversion

gamma_distribution, 768
  alpha, 769
  gamma_distribution, 769
gbump
  basic_streambuf, 828
gcount
  basic_istream, 841
generate, 714
generate_n, 714
generated destructor, see default destructor
geometric_distribution
  geometric_distribution, 764
  p, 764
get
  auto_ptr, 477
  basic_istream, 841
  money_get, 571
  num_get, 554
  array, 607
  pair, 431
  reference_wrapper, 455
  shared_ptr, 482
tuple, 436
get_date
  time_get, 567
get_deleter
  shared_ptr, 485
get_monthname
  time_get, 567
get_temporary_buffer, 474
get_time
  time_get, 567
get_weekday
  time_get, 567
g_year
  time_get, 567
getline
  basic_istream, 842, 843
  basic_string, 524
getloc
  basic_streambuf, 826
  ios_base, 812
global
  locale, 539
good
  basic_ios, 819
goto
  initialization and, 113
gptr
  basic_ios, 819
  ios_base, 812
  has_facet
  locale, 540
  has_facet
  locale, 540
  has_facet
  locale, 540
  has_facet
  locale, 540
  has_facet
  locale, 540
  handler
  exception, 353, 392
  incomplete type in exception, 353
  handler, 349, 942
  handler-seq, 349, 942
  has_facet
  locale, 540
  hash, 469
collate, 540
  instantiation restrictions, 469
  operator(), 469
  hash code, 596
  hash function, 595
  hash tables, see unordered associative containers
  hash_function
Draft
unordered associative containers, 598
hasher
unordered associative containers, 596
header
C, 386, 388, 391, 963
header-name, 15, 928
headers
C++, 385
hex, 822
hex-quad, 13, 927
hexadecimal-digit, 18, 929
hexadecimal-escape-sequence, 20, 930
hexadecimal-literal, 18, 929
hexfloat, 822
hiding; see name hiding, 34
hypot, 795
id
qualified, 76
id
locale, 537
id-expression, 75
id-expression, 75, 931
identifier, 17, 75, 118
identifier, 16, 928
identifier-nondigit, 16, 928
ifstream, 799, 867
ignore
basic_istream, 843
ilogb, 795
imag, 744
complex, 742
imbue
basic_filebuf, 873
basic_ios, 818
basic_streambuf, 829
ios_base, 812
immolation
self, 326
implementation
freestanding, 385
hosted, 385
implementation-defined, 70, 385, 388, 392, 394, 406,
410, 413–415, 812, 863, 872, 960
implementation-dependent, 837, 850
implementation-generated, 26
implicitly-declared default constructor, 220, see also default constructor
implicit object argument, 252
implied object parameter, 252
implicit conversion sequences, 252
in
codecvt, 550
in_avail
basic_streambuf, 827
includes, 724
inclusion
conditional, 363
source file, 364
incomplete, 98
increment
bool, 81, 89
increment operator
overloaded, 271
indirect_array, 789
indirect_array, 789
indirection, 88
inheritance, 191, see also multiple inheritance
Init
ios_base::Init, 811
init
basic_ios, 836, 849
init-declarator, 149, 938
init-declarator-list, 149, 938
initialization, 165
static member, 185
static object, 166
array, 168
array of class objects, 171, 232
auto, 114
auto object, 165
automatic, 113, 114
base class, 232, 233
character array, 171
class member, 167
class object, 168, 231
const, 125, 168
const member, 234
constant, 52
constructor and, 231
copy, 167
default, 166
Draft
default constructor and, 231
definition and, 118
direct, 167
dynamic, 52
jump past, 110, 113
local static, 114
member, 232
member object, 233
order of, 52, 192
order of base class, 234
order of member, 234
order of virtual base class, 234
overloaded assignment and, 232
parameter, 78
reference, 155, 172
reference member, 234
run-time, 52
static object, 52, 165
struct, 168
union, 171, 186
virtual base class, 235, 242
initialization class object, see also constructor
initializer
  base class, 165
  constant, 178, 940
  member, 165
  scope of member, 235
  temporary and declarator, 222
initializer, 165, 939
initializer-clause, 165, 939
initializer-list, 165, 939
injected-class-name, 175
inline, 391
inline
  linkage of, 48
inline function, 121
inner_product, 792
inplace_merge, 723
input_iterator_tag, 677
insert
  basic_string, 512
deque, 611
list, 615
vector, 627
unordered associative containers, 598
insert_iterator, 687
inserter, 689
instantiation
  explicit, 321
  point of, 315
  template implicit, 318
int
  bool promotion to, 70
int16_t, 404
int32_t, 404
int64_t, 404
int8_t, 404
int_fast16_t, 404
int_fast32_t, 404
int_fast64_t, 404
int_fast8_t, 404
int_least16_t, 404
int_least32_t, 404
int_least64_t, 404
int_least8_t, 404
integer-literal, 18, 929
integer-suffix, 19, 929
integer type, 63
integral type, 63
  sizeof, 62
internal, 821
intmax_t, 404
intptr_t, 404
invalid_argument, 420, 648, 649
  invalid_argument, 420
invocation
  macro, 366
INVOKE, 452
<iomanip>, 834
<ioc>, 804
ios, 799, 805
ios_base, 805
  ios_base, 814
  ios_base::failure, 808
  ios_base::Init, 810
<iows>, 799
iostate
  ios_base, 808
<iostream>, 802
is
cctype<char>, 547
ctype, 543
is_bind_expression, 459
   value, 459
is_open
   basic_filebuf, 869, 878
   basic_ifstream, 875
   basic_ofstream, 876
is_placeholder, 459
   value, 460
isalnum, 540
isalpha, 540
iscntrl, 540
isctype
   regex_traits, 896
   Regular Expression Traits, 883, 924
isdigit, 540
isfinite, 797
isgraph, 540
isgreater, 797
isgreaterequal, 797
isinf, 797
isless, 797
islessequal, 797
islessgreater, 797
islower, 540
isnan, 797
isnormal, 797
<iso646.h>, 960
isprint, 540
ispunct, 540
isspace, 540
<istream>, 833
istream, 799, 833
istream_iterator, 689
   operator!», 691
   operator==, 691
istreambuf_iterator, 692
   istreambuf_iterator, 694
istringstream, 799, 858
istrstream, 972
   istrstream, 973
isunordered, 797
isupper, 540
isxdigit, 540
iter_swap, 712
iteration-statement, 110, 112, 935
<iterator>, 672
iword
   ios_base, 813
Jessie, 224
jump-statement, 112, 935
key_eq
   unordered associative containers, 598
key_equal
   unordered associative containers, 596
key_type
   unordered associative containers, 596
keyword, 927
label, 113
   case, 107, 109
default, 107, 109
scope of, 32, 107
lambda
   exponential_distribution, 767
lattice; see DAG
   subobject, 192
layout
   access specifier and object, 207
   bit-field, 187
class object, 179, 192
layout-compatible type, 62
left, 821
left shift
   undefined, 99
left shift operator, 99, 933
length
   char_traits, 507, 508, 510–512, 514, 517–523
codecvt, 550
   sub_match, 902
   valarray, 777
length_error, 421, 501
   length_error, 421
less, 457
less_equal, 458
lexical conventions, 11
lexicographical_compare, 729
lgamma, 795
library
   C++ Standard, 375, 388, 390, 392

Draft
modifiable, 65

macro
  function-like, 365
  masking, 391
  object-like, 365
main(), 51
  implementation-defined linkage of, 51
  implementation-defined parameters to, 51
  parameters to, 51
  return from, 51, 53
make_heap, 728
make_pair, 431
make_tuple, 435
malloc, 490, 961
<string>, 630
map, 632
  operator<, 635
  operator==, 635
mask_array, 787
  mask_array, 788
match_any, 892
match_continuous, 892, 918
match_default, 892
match_flag_type, 892, 924
match_not_bol, 892
match_not_bow, 892
match_not_eol, 892
match_not_eow, 892
match_not_null, 892, 918
match_prev_avail, 892, 919
match_results, 908, 916, 919
  as Sequence, 908
  begin, 911
  empty, 910
  end, 911
  format, 911
  match_results, 909, 910
  matched, 910
max, 728
  random_device, 762
  uniform_int, 763
  uniform_real, 767
  valarray, 777
  variate_generator, 752
max_bucket_count
  unordered associative containers, 599
max_element, 729
max_length
  codecvt, 550
max_load_factor
  unordered associative containers, 600
max_size
  basic_string, 508
  array, 605
  match_results, 910
mean
  normal_distribution, 768
  poisson_distribution, 765
mem-initializer, 233, 941
mem-initializer-id, 232, 941
mem_fn, 464
mem_fun, 462, 463
mem_fn1_ref_t, 462
mem_fn1_t, 462
mem_fun_ref, 463, 464
mem_fun_ref_t, 462
mem_fun_t, 462
member, see also base class member
  class static, 54
  enumerator, 131
  static, 184
  template and static, 291
  static, 88
member-declaration, 178, 940
member-declarator, 178, 940
member-specification, 178, 940
member access operator
  overloaded, 271
member function
  class, 180
  const, 183
  constructor and, 221
destructor and, 227
friend, 213
inline, 180
local class, 190
nested class, 217
overload resolution and, 252
static, 184, 185
union, 186
volatile, 183
member function call
undefined, 182
member pointer to; see pointer to member, 63
member use
static, 184
memchr, 528
<memory>, 469
memory model, 5
memory management, see also new, delete
merge, 723
list, 617
mersenne_twister, 753
algorithm, 753
mersenne_twister, 754
operator==, 755
seed, 754
template parameters, 754
message
diagnostic, 2
messages, 577
messages_byname, 579
min, 728
random_device, 762
uniform_int, 763
uniform_real, 767
valarray, 777
variate_generator, 752
min_element, 729
minmax, 728
minmax_element, 729
minstd_rand, 761
minstd_rand0, 761
minus, 456
mismatch, 709
mod, 795
modf, 795
modulus
implementation defined, 97
modulus, 457
money_get, 571
money_put, 573
moneypunct, 574
moneypunct_byname, 577
mt19937, 761
multimap, 636
operator<, 639
operator==, 639
multiple inheritance, 191, 192
virtual and, 200
multiplicative-expression, 97, 933
multiplies, 457
multiset, 643
operator<, 645
operator==, 645
mutable, 119
name, 17, 25, 75
address of cv-qualified, 88
dependent, 310, 315
elaborated enum, 127
global, 33
length of, 17
macro, 366
overloaded function, 247
overloaded member, 179
point of declaration, 30
predefined macro, 372
qualified, 40
reserved, 387
scope of, 29
unqualified, 35
name
locale, 539
type_info, 412
namespace, 384, 963
global, 388
unnamed, 133
namespaces, 131
placeholders, 461
regex_constants, 890
name class, see class name
name hiding, 30, 34, 75, 76, 113, 931
class definition, 176
function, 250
overloading versus, 250
user-defined conversion and, 224
name space
label, 107
nan, 795
narrow
basic_ios, 818
ctype<char>, 548
ctype, 543
NDEBUG, 386
nearbyint, 795
negate, 457
nested-name-specifier, 76, 931
nested class
local class, 190
scope of, 188
new, 389, 406
operator, 407, 410, 490
array of class objects and, 93
constructor and, 93
default constructor and, 93
exception and, 93
initialization and, 93
operator, 407–410
scoping and, 90
storage allocation, 90
type of, 229
unspecified constructor and, 94
unspecified order of evaluation, 94
new-declarator, 90, 932
new-expression, 90, 932
new-initializer, 90, 933
new-placement, 90, 932
new-type-id, 90, 932
new_handler, 55, 411
next_permutation, 730
nextafter, 795
nexttoward, 795
noboolalpha, 820
nondigit, 16, 929
none
bitset, 651
nonzero-digit, 18, 929
norm, 744

Draft
object class, see also class object
object lifetime, 56
object temporary, see temporary
object type, 62
oct, 822
octal-digit, 18, 929
octal-escape-sequence, 20, 930
octal-literal, 18, 929
offsetof, 961
ofstream, 799, 867
open
  basic_filebuf, 870, 878
  basic_ifstream, 875
  basic_ofstream, 877
  messages, 578
openmode
  ios_base, 810
operator, 270, 778, 779
  **, 104
  +=, 89, 104
  -=, 104
  /=, 104
  %=, 104
  &=, 104
  ^=, 104
  <<=, 104
  >>=, 104
  |, 104
  additive, 97
address-of, 88, 932
assignment, 104, 384
bitwise, 101
bitwise AND, 101
bitwise exclusive OR, 101
bitwise inclusive OR, 101
cast, 88, 95, 150, 932
class member access, 79
comma, 104
conditional expression, 102
copy assignment, 240
decrement, 81, 88, 89, 932
division, 97, 933
equality, 100, 933
function call, 77, 269
greater than, 99, 933
greater than or equal to, 99, 933
increment, 81, 88, 89, 932
indirection, 88, 932
inequality, 100, 933
less than, 99, 933
less than or equal to, 99, 933
logical AND, 102
logical negation, 88, 89, 932
logical OR, 102
modulus, 97, 933
multiplication, 97, 933
multiplicative, 97
one’s complement, 88, 89, 932
overloaded, 73
pointer to member, 96
pragma, 373
precedence of, 8
relational, 99
scope resolution, 75, 76, 92, 181, 191, 202, 931
side effects and comma, 104
side effects and logical AND, 102
side effects and logical OR, 102
sizeof, 88, 89, 932
subscripting, 77, 269
unary, 88, 932
unary minus, 88, 89, 932
unary plus, 88, 89, 932
operator
  overloaded, 269
operator!, 430
operator delete, 92, see also delete, 95, 229
operator new, see also new, 92
operator!=
  basic_ios, 819
  valarray, 776
operator!=, 430
basic_string, 522
complex, 741
istreambuf_iterator, 695
locale, 539
reverse_iterator, 683
type_info, 412
bitset, 651
function, 468
queue, 619
regex_iterator, 918
regex_token_iterator, 922
shared_ptr, 483
stack, 622
sub_match, 903–907
tuple, 437
valarray, 779
operator()
locale, 539
discard_block, 759
function, 468
hash, 469
random_device, 762
reference_wrapper, 456
uniform_int, 763
variate_generator, 751
xor_combine, 760
operator*
auto_ptr, 477
back_insert_iterator, 686
complex, 741
front_insert_iterator, 687
insert_iterator, 688
istreambuf_iterator, 694
ostreambuf_iterator, 696
reverse_iterator, 682
regex_iterator, 918, 919
regex_token_iterator, 922
operator+=
basic_string, 510
complex, 739, 740
gslice_array, 787
indirect_array, 790
mask_array, 788
reverse_iterator, 682
slice_array, 783
valarray, 776
operator-
complex, 740
reverse_iterator, 683, 684
valarray, 776
valarray, 778
operator-=
complex, 739, 740
gslice_array, 787
indirect_array, 790
mask_array, 788
reverse_iterator, 683
slice_array, 783
valarray, 776
operator->
auto_ptr, 477
reverse_iterator, 681
shared_ptr, 482
operator-function-id, 269, 941
operator/
valarray, 778
operator/= 
complex, 740
gslice_array, 787
indirect_array, 790
mask_array, 788
slice_array, 783
valarray, 776
operator<
basic_string, 523
pair, 431
reverse_iterator, 683
queue, 619
shared_ptr, 483
stack, 622  
sub_match, 903–907  
tuple, 437  
valarray, 779  
weak_ptr, 488  
operator<<  
    basic_ostream, 851, 852  
    basic_string, 524  
    complex, 742  
    bitset, 652, 653  
    valarray, 778  
operator<<  
    shared_ptr, 484  
    sub_match, 908  
operator<=  
    gslace_array, 787  
    indirect_array, 790  
    mask_array, 788  
    slice_array, 783  
    bitset, 649  
    valarray, 776  
operator<=. 430  
    basic_string, 523  
    reverse_iterator, 684  
    queue, 619  
    stack, 623  
    sub_match, 903, 904, 906–908  
    tuple, 437  
    valarray, 779  
operator=  
    auto_ptr, 476  
    back_insert_iterator, 686  
    bad_alloc, 410  
    bad_cast, 413  
    bad_exception, 415  
    bad_typeid, 413  
    basic_string, 507  
    exception, 414  
    front_insert_iterator, 687  
    gslace_array, 786  
    indirect_array, 789  
    insert_iterator, 688  
    mask_array, 788  
    ostreambuf_iterator, 696  
    reverse_iterator, 681  
    slice_array, 783  
type_info, 412  
valarray, 775  
basic_regex, 900  
enable_shared_from_this, 489  
function, 467  
match_results, 910  
shared_ptr, 481  
tuple, 434  
weak_ptr, 487  
operator==  
    basic_string, 522  
    complex, 741  
    istreambuf_iterator, 695  
    locale, 539  
    pair, 431  
    reverse_iterator, 683  
    type_info, 412  
    bitset, 651  
    function, 468  
    mersenne_twister, 755  
    queue, 619  
    regex_iterator, 918  
    regex_token_iterator, 920, 922  
    shared_ptr, 483  
    stack, 622  
    sub_match, 903, 905–907  
    subtract_with_carry, 756  
    subtract_with_carry_01, 757  
    tuple, 436  
    valarray, 779  
operator>  430  
    basic_string, 523  
    reverse_iterator, 684  
    queue, 620  
    stack, 623  
    sub_match, 903–907  
    tuple, 437  
    valarray, 779  
operator>=. 430  
    basic_string, 524  
    reverse_iterator, 684  
    queue, 620  
    stack, 623  
    sub_match, 903–907  
    tuple, 437  
    valarray, 779
operator>>
  basic_istream, 839
  basic_string, 524
  complex, 741
  istream, 838
  bitset, 652
  valarray, 778
operator>>=
  gslcite_array, 787
  indirect_array, 790
  mask_array, 788
  slice_array, 783
  bitset, 649
  valarray, 776
operator--
  reverse_iterator, 682
operator~
  valarray, 776
  bitset, 650
operator|
  bitset, 652
  valarray, 778
operator|=  
gslcite_array, 787
  indirect_array, 790
  mask_array, 788
  slice_array, 783
  bitset, 649
  valarray, 776
operator left shift, see left shift operator
operator overloading, see also overloaded operator
operator right shift; right shift operator, 99
operator shift, see left shift operator, right shift operator
operator use
  scope resolution, 185
optimization of temporary, see elimination of temporary
ordering
  function template partial, 302
order of execution
  base class constructor, 220
  base class destructor, 227
  constructor and static objects, 232
  constructor and array, 231
destructor, 227
destructor and array, 227
  member constructor, 220
  member destructor, 227
<ostream>, 833
ostream, 799, 834
ostream_iterator, 691
ostreambuf_iterator, 695
  ostreambuf_iterator, 696
ostringstream, 799, 858
ostrstream, 973
Draft
ostrstream, 974
out
codecv, 549
out_of_range, 421, 501, 648, 650, 651
out_of_range, 421
output_iterator_tag, 677
overflow, 73
undefined, 73
overflow
basic_filebuf, 872
basic_stringbuf, 861
strstreambuf, 970
overflow_error, 422, 648, 651
overflow_error, 422
overloaded function
address of, 89, 267
overloaded operator, 269
inheritance of, 270
overloading, 159, 176, 247, 300
example of, 247
overloads
floating point, 744
overload resolution contexts, 251
overrider
final, 198

P
bernoulli_distribution, 764
binomial_distribution, 766
gaussian_distribution, 764
pair, 430, 434
get, 431
tuple interface to, 430
parameter, 3
reference, 155
scope of, 31
void, 158
parameter-declaration, 158, 939
parameterized type, see template parameters
macro, 366
parameter list
variable, 78, 158
parameter type list, 159
partial_sort, 720
partial_sort_copy, 720
partial_sum, 792
partition, 717
pbackfail
basic_filebuf, 871
basic_stringbuf, 832
basic_stringbuf, 860
strstreambuf, 970
pbase
basic_streambuf, 829
pbump
basic_stringbuf, 829
pcount
ostrstream, 974
strstreambuf, 969
strstream, 976
peek
basic_istream, 844
period, 382
phases
translation, 11
placeholders, 461
placement syntax
new, 92
plus, 456
pm-expression, 96, 933
POD-struct, 175
POD class type, 93
POD type, 93
POF, 418
pointer
zero, 71
void*, 64
pointer_to_binary_function, 461
pointer_to_unary_function, 461
pointer to member, 63, 96
poisson_distribution, 765
mean, 765
poisson_distribution, 765
polar, 744
complex, 742
pop
priority_queue, 621
pop_heap, 727
POSIX
extended regular expressions, 891

Draft
regular expressions, 891
postfix ++ and -, 271
postfix ++ and -, 81
pow, 744, 781, 795
complex, 743
pp-number, 16, 928
pptr
  basic_streambuf, 829
precision
  ios_base, 541, 811
prefix
  L, 20, 22
prefix
  match_results, 911
prefix ++ and -
  overloading, 271
prefix ++ and -, 89
preprocessing, 361
preprocessing-op-or-punc, 18
preprocessing-token, 14, 928
preprocessor
  macro, 361
prev_permutation, 730
primary equivalence class, 881
priority_queue, 620
  priority_queue, 621
private, 205
program, 48
  ill-formed, 2
  well-formed, 4
promotion
  floating point, 70
  integral, 70
protected, 205
protection, see access control, 392
proxy
  istreambuf_iterator, 693
pseudo-destructor-name, 79
pseudo-destructor-name, 77, 932
Pseudo-random number engine requirements, 745
ptr-operator, 150, 938
ptr_fun, 461
ptrdiff_t, 98
  implementation defined type of, 98
pubimbue
  basic_streambuf, 826
public, 205
pubseekoff
  basic_streambuf, 827
pubseekpos
  basic_streambuf, 827
pubsetbuf
  basic_streambuf, 827
pubsync
  basic_streambuf, 827
punctuators, 17
pure-specifier, 178, 940
pure specifier, 178, 940
push
  priority_queue, 621
push_heap, 727
put
  basic_ostream, 854
  money_put, 573
  num_put, 558
  time_put, 569
putback
  basic_istream, 844
pword
  ios_base, 813
qualification
  explicit, 40
qualified-id, 75, 931
<queue>, 603
queue, 618

<random>, 749
Random distribution requirements, 747
random number generators, 745–769
random_access_iterator_tag, 677
random_device, 761
  entropy, 762
  max, 762
  min, 762
  operator(), 762
  random_device, 762
random_device using pseudo-random engine, 761
random_shuffle, 717
range_error, 422
  range_error, 422

Draft
ranlux3, 761
ranlux3_01, 761
ranlux4, 761
ranlux4_01, 761
ranlux64_base_01, 761
ranlux_base_01, 761
rbegin
  basic_string, 508
rdbuf
  basic_filebuf, 878
  basic_ifstream, 875
  basic_ios, 818
  basic_iostream, 864
  basicofstream, 876
  basic_ostringstream, 865
  basic_stringstream, 867
  istream, 973
  ostrstream, 974
  stream, 975
rdstate
  basic_ios, 819
read
  basic_istream, 844
  readsome
    basic_istream, 844
real, 744
  complex, 742
realloc, 490
redefinition
  enumerator, 130
  typedef, 122
reentrancy, 392
ref
  reference_wrapper, 456
reference, 63
  assignment to, 104
  call by, 78
  const, 173
  direct binding of, 173
  null, 155
  sizeof, 89
reference-compatible, 172
reference-related, 172
reference_wrapper, 454
  cref, 456
  get, 455
operator(), 456
  ref, 456
  reference_wrapper, 455
<regex>, 883
regex, 883
regex_constants, 890
  error_type, 893, 894
  match_flag_type, 892
  syntax_option_type, 890
regex_error, 894, 897, 924
regex_iterator, 916
  end-of-sequence, 917
  increment, 918
  operator!=, 918
  operator*, 918
  operator++, 918, 919
  operator==, 918
  regex_iterator, 918
regex_match, 912–914
regex_replace, 916
regex_search, 914, 915
regex_token_iterator, 919
  end-of-sequence, 919
  operator!=, 922
  operator*, 922
  operator++, 922
  operator==, 920, 922
  regex_token_iterator, 921
regex_traits, 894
  char_class_type, 895
  isctype, 896
  lookup_classname, 896
  lookup_collatename, 896
  specializations, 895
  transform, 895
  transform_primary, 895
  translate, 895
  translate_nocase, 895
region
  declarative, 25, 29
register, 119
register_callback
  ios_base, 814
regular expression, 881–925
  grammar, 923
  matched, 881
Draft
requirements, 881
Regular Expression Traits, 923
  char_class_type, 882
  isctype, 883, 924
  lookup_classname, 883, 924, 925
  lookup_collatename, 882, 924
requirements, 881, 895
transform, 882, 924
transform_primary, 882, 924, 925
translate, 882, 924
translate_nocase, 882, 924
rehash
  unordered associative containers, 600
rel_ops, 429
relational-expression, 99, 933
release
  auto_ptr, 477
remainder, 795
remainder operator, see modulus operator
remove, 714
  list, 617
remove_copy, 714
remove_copy_if, 714
remove_if, 714
remquo, 795
rend
  basic_string, 508
replace, 713
  basic_string, 514
replace_copy, 713
replace_copy_if, 713
replace_if, 713
replacement
  macro, 365
representation
  object, 60
  value, 60
requirements, 379
  Allocator, 426
Container, 596, 605, 606, 908
    not required for unordered associated containers, 595
    not supported by unordered associated containers, 600
container, 585
CopyConstructible, 425
EqualityComparable, 425
iterator, 667
LessThanComparable, 425
numeric type, 733
Pseudo-random number engine, 745
Random distribution, 747
Regular Expression Traits, 881, 895
Sequence, 908
Swappable, 426
uniform random number generator, 745
Unordered Associative Container, 596
reraise, 352
rescanning and replacement, 368
reserve
  basic_string, 509
  vector, 626
reserved identifier, 17
reset
  auto_ptr, 477
  bitset, 650
  shared_ptr, 482
  weak_ptr, 487
resetiosflags, 855
resize
  basic_string, 509
  deque, 610
  list, 615
  vector, 627
  valarray, 778
resolution
  argument matching, see overload
  function template overload, 346
overload, 251
overloaded function call resolution, see also argument matching, overload
resolution overloading, see overload
scoping ambiguity, 195
template name, 303
template overload, 302
restriction, 390–392
  static member local class, 185
address of bit-field, 187
anonymous union, 186
bit-field, 187
constructor, 220
copy assignment operator, 243
Draft
copy constructor, 242
destructor, 226, 227
enumerator, 130
extern, 120
local class, 190
overloading, 270
pointer to bit-field, 187
reference, 155
register, 119
static, 120
union, 186, 220
restrictions
  operator overloading, 269
result_of, 453
type, 453
result_type
  xor_combine, 760
rethrow, 352
return, 112, 113, 935
  constructor and, 113
  reference and, 172
return statement, see also return
return type, 159
  overloading and, 247
reverse, 716
  list, 617
reverse_copy, 716
reverse_iterator, 678
  reverse_iterator, 680
rfind
  basic_string, 517
right, 822
right shift
  implementation defined, 99
  right shift operator, 99, 933
rint, 795
rotate, 716
rotate_copy, 717
round, 795
rounding, 71
rule
  as-if, 6
  one-definition, 27
runtime_error, 421
  runtime_error, 421
rvalue, 65
lvalue conversion to, 68
lvalue conversion to, 950
s-char, 22, 931
s-char-sequence, 22, 931
sbumpc
  basic_streambuf, 827
scalar type, 62
scalbln, 795
scalbn, 795
scan_is
  ctype<char>, 547
ctype, 543
scan_not
  ctype<char>, 547
ctype, 543
scientific, 822
scope, 25, 29
  anonymous union at namespace, 186
class, 33
destructor and exit from, 112
exception declaration, 31
function, 32
global, 33
global namespace, 33
iteration-statement, 110
  local, 31
macro definition, 368
namespace, 32
overloading and, 250
potential, 29
selection-statement, 108
scope resolution operator, 41
search, 710
seed
  discard_block, 759
  linear_congruential, 753
  mersenne_twister, 754
  subtract_with_carry, 756
  subtract_with_carry_01, 757
  xor_combine, 760
seekdir
  ios_base, 810
seekg
  basic_istream, 845
seekoff
Draft
basic_filebuf, 872
basic_streambuf, 829
basic_stringbuf, 861
strstreambuf, 970
seekp
  basic_ostream, 850
seekpos
  basic_filebuf, 873
  basic_streambuf, 830
  basic_stringbuf, 863
  strstreambuf, 972
selection-statement, 108, 935
semantics
  class member, 79
sentry
  basic_istream, 836
  basic_ostream, 849
sequence
  ambiguous conversion, 262
  implicit conversion, 261
  standard conversion, 67
  statement, 107
sequence point, 7
sequence point, 73
sequencing operator, see comma operator
<set>, 631
set, 640
  operator<, 642
  operator==, 642
  bitset, 650
set_difference, 725
set_intersection, 725
set_new_handler, 389, 411
set_symmetric_difference, 726
set_terminate, 389, 416
set_unexpected, 389, 416
set_union, 724
setbase, 856
setbuf
  basic_filebuf, 872
  basic_streambuf, 829
  streambuf, 972
  strstreambuf, 972
setf
  ios_base, 811
setfill, 857
setg
  basic_streambuf, 828
setiosflags, 856
setjmp, 388
setlocale, 382
setp
  basic_streambuf, 829
setprecision, 857
setstate
  basic_ios, 819
setw, 857
sgetc
  basic_streambuf, 827
sgetn
  basic_streambuf, 827
shared_from_this
  enable_shared_from_this, 489
shared_ptr, 478, 489
  ~shared_ptr, 481
  const_pointer_cast, 485
  dynamic_pointer_cast, 484
get, 482
get_deleter, 485
operator! =, 483
operator*, 482
operator->, 482
operator<, 483
operator<<, 484
operator==, 481
operator==, 483
reset, 482
shared_ptr, 480
static_pointer_cast, 484
swap, 482, 484
unique, 483
use_count, 483
shift
  valarray, 778
shift-expression, 99, 933
shift operator, see left shift operator, right shift operator
short
typedef and, 119
showbase, 820
showmanyc
  basic_filebuf, 871
  basic_streambuf, 830, 871
showpoint, 820
showpos, 820
side, 7
side effects, 73
sigma
  normal_distribution, 768
sign, 21, 930
signature, 3
signbit, 797
signed
  typedef and, 119
simple call wrapper, 452
simple-escape-sequence, 20, 930
simple-type-specifier, 126, 936, 937
sin, 781, 795
  complex, 744
sinh, 781, 795
  complex, 744
size
  basic_string, 508
gslice, 785
slice, 782
array, 605, 606
bitset, 651
match_results, 910
size_t, 90
sizeof
  empty class, 175
skipws, 821
slice, 781
  slice, 782
slice_array, 782
  slice_array, 783
smanip
  implementation-defined, 855
smart pointers, 478–490
snextrc
  basic_streambuf, 827
sort, 719
  list, 618
sort_heap, 728
space
  white, 14
specialization
  class template, 283
  class template partial, 295
template, 317
template explicit, 324
special member function, see constructor, destructor,
  inline function, user-defined conversion, virtual function
specification
  template argument, 330
specifications
  C++ Standard Library exception, 392
  implementation-defined exception, 392
  Standard C library exception, 392
specifier
  declaration, 118
  explicit, 122
  friend, 392
  friend, 124
  function, 121
  inline, 121
  missing storage class, 120
  static, 119
  storage class, 119
  typedef, 122
  virtual, 122
specifier access, see access specifier
specifier type, see type specifier
splice
  list, 616
sputbackc
  basic_streambuf, 828
sputc
  basic_streambuf, 828
sputn
  basic_streambuf, 828
sqrt, 781, 795
  complex, 744
<iostream>, 858
stable algorithm, 377
stable_partition, 718
stable_sort, 719
<stack>, 603
stack, 621
standard
  structure of, 5
start
  program, 51, 52
start

Draft
gslice, 785
slice, 782
startup
  program, 387, 389
state
  object, 376
state
  fpos, 814
statement, 107
  continue in for, 111
  break, 112, 935
  compound, 107
  continue, 112, 935
  declaration, 113
  declaration in for, 112
  declaration in switch, 110
  do, 110, 111, 935
  empty, 107
  expression, 107
  for, 110, 111, 935
  goto, 107, 112, 113, 935
  if, 108, 109, 935
  iteration, 110
  jump, 112
  labeled, 107
  null, 107
  selection, 108
  switch, 108, 109, 112, 935
  while, 110, 935
statement, 107, 934
static, 119
  destruction of local, 114
  linkage of, 48, 120
  overloading and, 247
static_assert, 117, 118, 936
static_pointer_cast
  shared_ptr, 484
<string>, 20, 22
<stringexcept>, 419
<st dint.h>, 405
<stdl ib.h>, 964
storage class, 25
storage duration, 54
  auto, 54
  class member, 56
  dynamic, 54, 90
local object, 54
storage management, see new, delete
str
  basic_istream, 864
  basic_ostream, 865
  basic_stringbuf, 860
  basic_stringstream, 867
  istringstream, 973
  ostringstream, 974
  streambuf, 969
  stringstream, 976
  match_results, 910
  sub_match, 902
strchr, 526
stream
  arbitrary-positional, 375
  repositiona l, 377
<stringbuf>, 823
streambuf, 799, 823
  implementation-defined, 799
streamoff, 805, 815, 964
  implementation-defined, 805, 964
streampos
  implementation-defined, 964
streamsize, 805
strftime, 570
stride
  gslice, 785
  slice, 782
string
  distinct, 22
  null-terminated byte, 383
  null-terminated character type, 377
  null-terminated multibyte, 383
  null-terminated wide-character, 383
  sizeof, 23
  type of, 22
<string>, 498
<string_literal>, 22, 930
stringbuf, 799, 858
stringstream, 799
string literal, 22
  implementation-defined, 22
  narrow, 22
  type of, 22
  undefined change to, 22
Draft
wide, 22
strlen, 968
strlen, 968, 974
strpbrk, 528
strrchr, 528
strstr, 528
strstream, 974
strstream, 975
strstreambuf, 965
strstreambuf, 967
struct
class versus, 175
structure, 175
structure tag, see class name
sub-expression, 881
sub_match, 902
  compare, 903
  length, 902
  operator! =, 903–907
  operator<, 903–907
  operator<<, 908
  operator<=, 903, 904, 906–908
  operator==, 903, 905–907
  operator>, 903–907
  operator>>, 903–907
str, 902
subobject, 6
subscripting operator
  overloaded, 271
subsequence rule
  overloading, 265
substr
  basic_string, 520
substrct_with_carry, 755
    algorithm, 755
    operator==, 756
    seed, 756
    subtract_with_carry, 756
    template parameters, 755
subtract_with_carry_01, 756
    algorithm, 756
    operator==, 757
    seed, 757
    subtract_with_carry_01, 757
subtraction
  implementation defined pointer, 98
subtraction operator, 98, 933
suffix
  E, 22
  F, 22
  f, 22
  L, 19, 22
  l, 19, 22
  U, 19
  u, 19
suffix
  match_results, 911
sum
  valarray, 777
summary
  compatibility with ISO C, 947
  scope rules, 34
summary, syntax, 927
sungetc
  basic_streambuf, 828
swap, 711
  basic_string, 516, 524
  vector, 626
  array, 606
  basic_regex, 901, 902
  function, 467, 469
  match_results, 912
  shared_ptr, 482, 484
  unordered_map, 657
  unordered_multimap, 660
  unordered_multiset, 666
  unordered_set, 663
  weak_ptr, 487, 488
swap_ranges, 711
call
  basic_filebuf, 873
  basic_istream, 845
  basic_streambuf, 830
  sync
  with_stdio
  ios_base, 812
synonym, 135
  type name as, 122
syntax
  class member, 79
  syntax_option_type, 890
  awk, 890, 891
  basic, 890, 891
Draft
collate, 890, 891, 924
ECMAScript, 890, 891
egrep, 890, 891
extended, 890, 891
grep, 890, 891
icase, 890, 891
nosubs, 890, 891
optimize, 890, 891

\begin{itemize}
\item \texttt{binomial\_distribution}, 766
\item \texttt{table}
\item \texttt{ttan}, 781, 795
\item \texttt{complex}, 744
\item \texttt{tanh}, 781, 795
\item \texttt{complex}, 744
\item \texttt{target}
\item \texttt{function}, 468
\item \texttt{target\_object}, 452
\item \texttt{target\_type}
\item \texttt{function}, 468
\item \texttt{tellg}
\item \texttt{basic\_istream}, 845
\item \texttt{tellp}
\item \texttt{basic\_ostream}, 850
\item \texttt{template}, 277
\item \texttt{definition of}, 277
\item \texttt{function}, 330
\item \texttt{member function}, 290
\item \texttt{primary}, 295
\item \texttt{template}, 277, 941
\item \texttt{template-argument}, 282, 941
\item \texttt{template-argument-list}, 282, 941
\item \texttt{template-declaration}, 277, 941
\item \texttt{template-id}, 282, 941
\item \texttt{template-name}, 282, 941
\item \texttt{template-parameter}, 278, 941
\item \texttt{template-parameter-list}, 277, 941
\item \texttt{template name}
\item \texttt{linkage of}, 277
\item \texttt{temporary}, 221
\item \texttt{constructor for}, 222
\item \texttt{destruction of}, 222
\item \texttt{destructor for}, 222
\item \texttt{elimination of}, 221, 244
\texttt{implementation-defined generation of}, 221
\item \texttt{order of destruction of}, 222
\item \texttt{terminate}, 53, 405, 415, 416
\item \texttt{terminate()}, 358
\item \texttt{terminate\_handler}, 389, 416
\item \texttt{termination}
\item \texttt{program}, 51, 53
\item \texttt{terminology}
\item \texttt{pointer}, 64
\item \texttt{test}
\item \texttt{bitset}, 651
\item \texttt{tgamma}, 795
\item \texttt{<tgmath.h>}, 793
\item \texttt{this}, 75
\item \texttt{type of}, 183
\item \texttt{this\ pointer, see this}
\item \texttt{thousands\_sep}
\item \texttt{numpunct}, 563
\item \texttt{throw}, 349, 942
\item \texttt{throw\_expression}, 349, 942
\item \texttt{throwing}
\item \texttt{exception}, 350
\item \texttt{tie}, 435
\item \texttt{basic\_ios}, 817
\item \texttt{time\_get}, 566
\item \texttt{time\_get\_byname}, 569
\item \texttt{time\_put}, 569
\item \texttt{time\_put\_byname}, 570
\item \texttt{to\_string}
\item \texttt{bitset}, 651
\item \texttt{to\_ulong}
\item \texttt{bitset}, 650
\item \texttt{token}, 15, 18
\item \texttt{token}, 15, 928
\item \texttt{tolower}, 541
\item \texttt{ctype\<char>}, 547
\item \texttt{ctype}, 543
\item \texttt{toupper}, 541
\item \texttt{ctype\<char>}, 547
\item \texttt{ctype}, 543
\item \texttt{traits}, 377
\item \texttt{transform}, 712
\item \texttt{collate}, 565
\item \texttt{regex\_traits}, 895
\item \texttt{Regular\ Expression\ Traits}, 882, 924
\item \texttt{transform\_primaryl}
\end{itemize}
Regular Expression Traits, 882, 924, 925
transform_primary
  regex_traits, 895
translate
  regex_traits, 895
  Regular Expression Traits, 882, 924
translate_nocase
  regex_traits, 895
  Regular Expression Traits, 882, 924
translation
  separate, 11
translation unit, 11, 48
  name and, 25
trigraph, 11
truename
  numpunct, 563
trunc, 795
truncation, 71
try, 349, 942
try-block, 349, 942
<tuple>, 432
tuple, 432, 433, 607
  and array, 607
  and pair, 430
  get, 436
  make_tuple, 435
  operator!=, 437
  operator<, 437
  operator<=, 437
  operator==, 434
  operator==, 436
  operator>, 437
  operator>=, 437
tie, 435
tuple, 433, 434
tuple_element, 431, 436, 607
tuple_size, 431, 436, 607
type, 25
  arithmetic, 63
  array, 63, 159
  bitmask, 381, 382
  Boolean, 62
  char, 62
  character, 62
  character container, 376
  class and, 175
  compound, 63
  const, 124, 936
  destination, 167
  double, 63
  dynamic, 2
  enumerated, 63, 381
  enumeration underlying, 130
  example of incomplete, 61
  float, 63
  floating point, 62
  function, 63, 158, 159
  fundamental, 62
  sizeof, 62
  incomplete, 27, 31, 61, 68, 77–81, 83, 88–90, 95, 104, 191
  int, 62
  integral, 62
  long, 62
  long double, 63
  multi-level mixed pointer and pointer to member, 69
  multi-level pointer to member, 69
  object, 6
  POD, 62
  pointer, 63
  polymorphic, 198
  short, 62
  signed char, 62
  static, 3
  underlying wchar_t, 62
  unsigned, 62
  unsigned char, 62
  unsigned int, 62
  unsigned long, 62
  unsigned short, 62
  void, 63
  volatile, 124, 936
  wchar_t, 62
  type
    result_of, 453
  type-id, 150, 938
  type-id-list, 355, 942
  type-name, 126
  type-parameter, 278, 941
  type-specifier
    bool, 126
wchar_t, 126

typedef, 124, 936
type_info, 82, 411
type_info::name
  implementation-defined, 412
typedef
  function, 160
typedef
  overloading and, 248
typedef-name, 122, 936
typeid, 82
<typename>, 411
typename, 127, 937
types
  implementation-defined, 381
  implementation-defined exception, 392
type checking
  argument, 78
type conversion, explicit, see casting
type generator, see template
type name, 150
  nested, 190
  scope of nested, 190
type pun, 86
type specifier
  char, 126
class, 175, 939
double, 126
enum, 127, 937
float, 126
int, 126
long, 126
short, 126
struct, 175, 939
union, 175, 939
unsigned, 126
void, 126
volatile, 126

uflow
  basic_filebuf, 871
  basic_streambuf, 831
uint16_t, 404
uint32_t, 404
uint64_t, 404

uint8_t, 404
uint_fast16_t, 404
uint_fast32_t, 404
uint_fast64_t, 404
uint_fast8_t, 404
uint_least16_t, 404
uint_least32_t, 404
uint_least64_t, 404
uint_least8_t, 404
uintmax_t, 404
uintptr_t, 404
unary function, 454, 464
unary-expression, 88, 932
unary-operator, 88, 932
unary_function, 453, 469
unary_negate, 458
unary operator
  interpretation of, 270
  overloaded, 270
uncaught_exception, 417
undefined, 70, 377, 387, 388, 390, 510, 774, 776, 777, 779, 780, 785, 790, 815
undefined behavior, 693
underflow
  basic_filebuf, 871
  basic_streambuf, 830
  basic_stringbuf, 860
  strstreambuf, 970
underflow_error
  underflow_error, 422
unexpected, 416
unexpected(), 358
unexpected_handler, 389, 415
unget
  basic_istream, 845
Uniform number generator requirements, 745
uniform_int, 762
  max, 763
  min, 763
  operator(), 763
  uniform_int, 763
uniform_real, 766
  max, 767
  min, 767
  uniform_real, 766
uninitialized_copy, 474

Draft
uninitialized_fill, 475
uninitialized_fill_n, 475
union, 63, 186
class versus, 175
anonymous, 186
global anonymous, 186
unique, 715
list, 617
shared_ptr, 483
unique_copy, 715
unit
instantiation, 12
translation, 386, 387
unitbuf, 821
universal-character-name, 13, 928
unordered associative containers, 595–666
begin, 600
bucket, 600
bucket_count, 599
bucket_size, 600
clear, 599
complexity, 595
const_local_iterator, 596
count, 599
end, 600
equal_range, 599
equality function, 595
equivalent keys, 595, 596, 657, 663
erase, 599
exception safety, 601
find, 599
hash function, 595
hash_function, 598
hasher, 596
insert, 598
iterator invalidation, 600, 601
iterators, 600
key_eq, 598
key_equal, 596
key_type, 596
lack of comparison operators, 595, 600
load_factor, 600
local_iterator, 596
max_bucket_count, 599
max_load_factor, 600
rehash, 600
requirements, 595, 596, 600, 601
unique keys, 595, 596, 654, 660
<unordered_map>, 653
unordered_map, 653, 654
element access, 657
operator[], 657
swap, 657
unique keys, 654
unordered_map, 656
unordered_multimap, 653, 657
equivalent keys, 657
swap, 660
unordered_multimap, 659, 660
unordered_multiset, 653, 663
equivalent keys, 663
swap, 666
unordered_multiset, 665, 666
<unordered_set>, 653
unordered_set, 653, 660
swap, 663
unique keys, 660
unordered_set, 662, 663
unqualified-id, 75, 931
unsetf
ios_base, 811
unshift
codecvt, 550
unsigned
typedef and, 119
unsigned-suffix, 19, 929
unspecified, 407, 408, 412, 505, 720, 861, 967, 969, 970
unspecified behavior, 777
unwinding
stack, 353
upper_bound, 721
uppercase, 382, 387
uppercase, 821
use_count
shared_ptr, 483
weak_ptr, 487
use_facet
locale, 540
using-declaration, 135
using-directive, 142
<utility>, 429
wostream, 799, 834
wostringstream, 799, 858
wregex, 883
write
    basic_ostream, 854
ws, 846
ws, 839
wstreambuf, 799, 823
wstringbuf, 799, 858
wstringstream, 799
X(X&), see copy constructor
xalloc
    ios_base, 813
xor_combine, 759
    base1, 760
    base2, 760
    operator(), 760
    result_type, 760
    seed, 760
    template parameters, 760
    xor_combine, 760
xsgetn
    basic_streambuf, 830
xsputn
    basic_streambuf, 832
zero
    undefined division by, 73, 97
    undefined modulus, 73
zero-initialization, 166