Planning with Time and Scheduling
– Three Examples

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Summary

- 1st Example: TP4
  - Makespan-optimal planning.
  - Temporal regression.

- 2nd Example: LPGP & Crikey
  - Separating planning and plan scheduling (almost).
  - “Expressive” temporal planning (PDDL2.1).

- 3rd Example: HSTS/Europa
  - Constraint-Based Scheduling.
  - Planning with an activity/constraint model.
Simple temporal planning ("TGP semantics"):
- Actions have *duration*, \( \text{dur}(a) > 0 \).
- For action \( a \) to execute over \([s, t]\):
  - preconditions hold at \( s \);
  - preconditions and effects *not interfered with* (not added/deleted by any other action) over \([s, t]\);
  - effects can be relied on only at \( t \).
- Temporal regression.
  - The "regression cut" property.
- \( h^2 \) heuristic for makespan.
Temporal Constraint Network (TCN):
- Variables representing *time points*
- Disjunctive interval constraints on differences:
  \[(t_j - t_i \in [l_1, u_1]) \lor \ldots \lor (t_j - t_i \in [l_n, u_n])\]
- Consistency checking is NP-hard
- Reasonably efficient meta-CSP approach.

Simple Temporal Network (STN):
- Single interval constraint between any two variables:
  \[d_{i,j}^{\text{min}} \leq t_j - t_i \leq d_{i,j}^{\text{max}}\]
- Constraint are *linear* – consistency checking is tractable.
- More efficient: all-pairs shortest path on *distance graph*.

PDDL2.1 temporal planning:

- Actions have conditions at start, at end and over all (interior of execution interval).
- Actions have instantaneous effects at start and at end.
- Compatibility constraints at a time point are the same as in simple temporal planning.
- States have duration > 0: conditions must be separated from establishing effects by a positive amount of time.

Separating planning and scheduling:

- Sequential plan in the space of events: sets of actions starting and ending.
- Maintain temporal constraints as STN/LP to ensure schedulability.
- Makespan optimality only in the limit – not in practice.
Variables:

- \( start(A) \), \( end(A) \), \( \forall A \) – absolute or relative.

Constraints:

- Duration: \( d_{\text{min}}(A) \leq end(A) - start(A) \leq d_{\text{max}}(A) \)
- Precedence ("A before B"): \( end(A) < start(B) \).
- Unary resource:
  \[(end(A) < start(B)) \lor (end(B) < start(A)).\]
- Cumulative: \( \forall t, \left( \sum_{start(A) \leq t \leq end(A)} req(A) \right) \leq cap(R) \).

Alternative resources and (optional) set-up activities cause disjunctions – hard to deal with efficiently.

Specialised propagators for certain classes of resource constraints more efficient than general (disjunctive) formulation.
Activity/constraint model:
- Timelines – state variables.
- Tokens – variable value over time interval \([s, t](v = x)\).
- Compatibility constraints
  \([s, t](v = x) \rightarrow ([u_1, v_1](v_1' = y)) \lor \ldots \lor ([u_n, v_n](v_n' = z))\)
- No distinction between states and actions!

Search:
- Branch on disjunctive compatibilities/token placement.
- Maintain consistency by STN.
- Solution – consistent and all compatibilities satisfied.

Requires (domain-specific) search control for efficiency.

Recent work on domain-independent heuristics.