The Fusemate Logic Programming System

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Fusemate - Language and Model Computation Overview

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Input language: Prolog-like rules

```
R(a,b)
R(X,Y) :- R(Y,X)
R(X,Z) :- R(X,Y), r(Y,Z)
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← Botton-up model generation
(Hyper tableau, Hyper resolution, SATCHMO, …)

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Disjunctions: possible model semantics [Sakama 90]

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Inclusive reading of "or"

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Belief revision

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What's special?

What's new?

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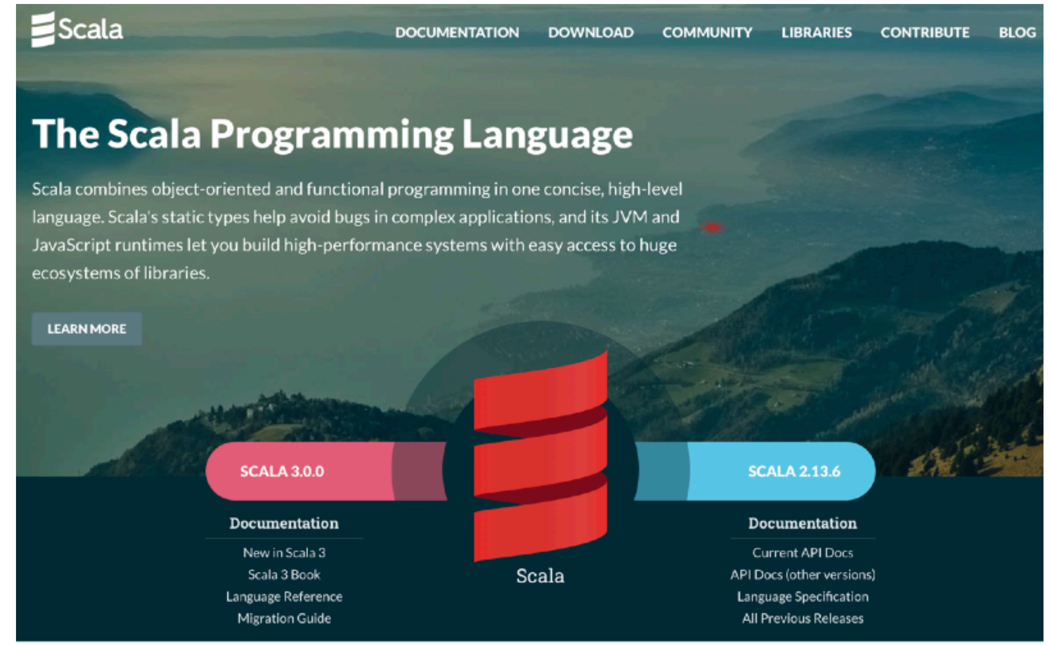

Implementation language: Scala

- Scala combines **object-oriented** and **functional programming**

```
def qsort(l: List[Int]): List[Int] =
  l match {
    case Nil            => Nil
    case pivot :: tail => qsort(tail filter {_ < pivot}) ::: pivot ::
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- Access to **huge ecosystem of libraries**
- Runs on JVM; compiled or in data-analysis style **interactive workbooks** (Jupyter)

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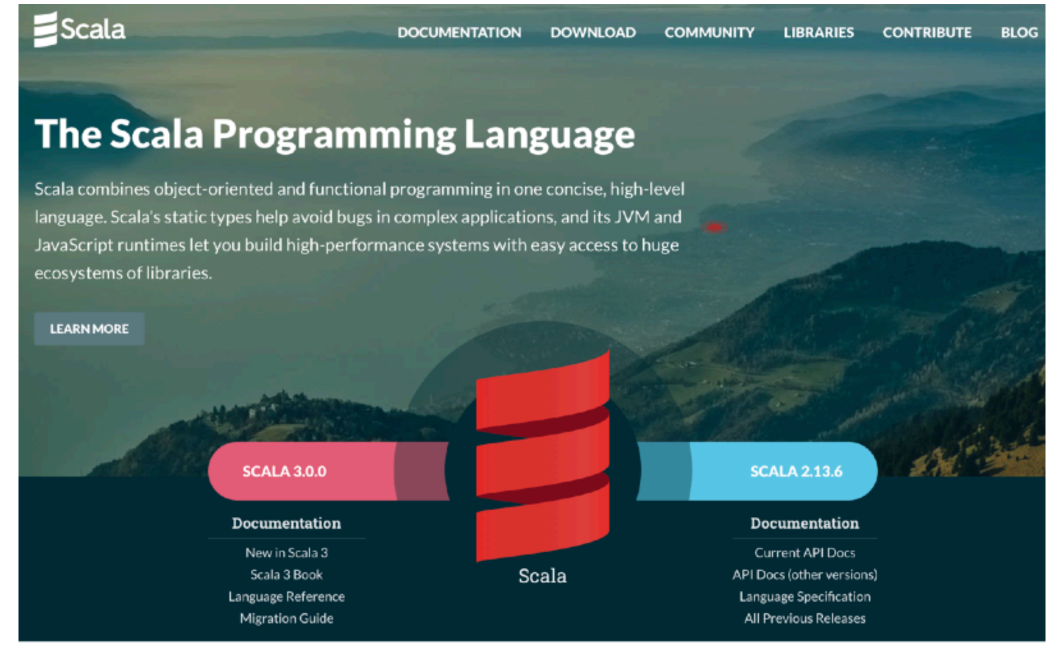

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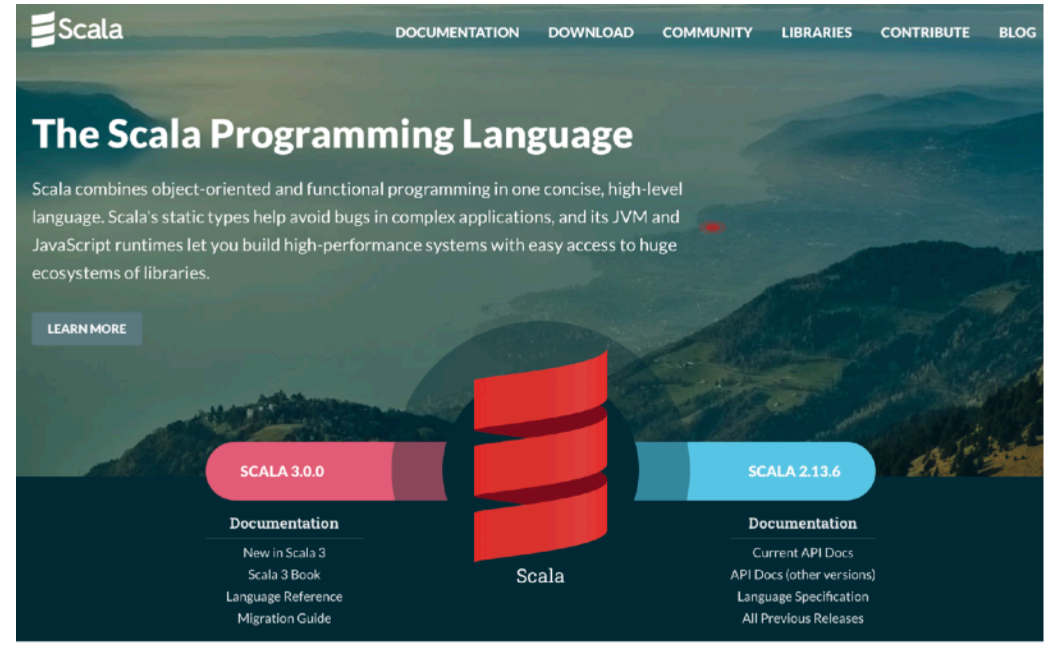

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Implementation technique: shallow embedding

- Logic program **translated into** Scala program that is executed for model computation
- AFAIK Fusemate is the only logic programming system implemented that way
- ***Q: what are the advantages/disadvantages of this approach?***

  E.g. in terms of capitalizing on / integrating the **above features** of Scala

Shallow Embedding Into Scala

- User writes Scala program with rules embedded into it

```scala
type Time = Int

case class GoodSleep(time: Time) extends Atom

@rules
    …
    GoodSleep(time) :-
        WakeUp(time),
        GoToBed(t), t <= time - 8,
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Rules

- The rules are macro expanded into Scala curried partial functions

```
(I: Interpretation) => {
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- Given-clause loop operating on rules-as-partial-functions and interpretations (tableaux)

Shallow Embedding Into Scala

Logic	Scala
Pred/Fun signature	Class declaration
Atom/Term	Class instance
Interpretation	Set of class instances
Variable	Variable
Rule	Partial function
Matching subst	Pattern matching

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Rules

All logic notions are Scala

- "Interpretation" available as term
- Trivial interface to/from Scala
- Type checking/inference for free

Every Scala term is a term of the logic

- The rules are macro expanded into Scala curried partial functions

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Comprehension operator

These operators are user-definable

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What's New? (2)

Stratification by predicates and by time (SBTP)

- Stratification disallows definitorial loop through "**not** *<body>*" literal
- Stratification renders "**not** *<body>*" evaluation monotonic

```
p(time) :- q(time), not r(time-1)
r(time) :- p(time)
```

✗ Stratified by predicates

✓ Stratified by time

✓ **SBTP**

```
q(time) :- p(time), not s(time)
```

✓ Stratified by predicates

✗ Stratified by time

✓ **SBTP**

SBTP = lexicographic combination of "by time" and "by predicates"

What's New (1) - (2) Showcase - Fusemate as Description Logic Reasoner

Description logic ALCIF

$$\begin{aligned} \mathsf{Person} &\sqsubseteq \mathsf{Rich} \sqcup \mathsf{Poor} \\ \mathsf{Person} &\sqsubseteq \exists \mathsf{father}.\mathsf{Person} \\ \mathsf{Rich} &\sqsubseteq \forall \mathsf{father}^{-1}.\mathsf{Rich} \\ \mathsf{Rich} \sqcap \mathsf{Poor} &\sqsubseteq \bot \end{aligned}$$

father is functional

$$\begin{aligned} \mathsf{Anne} &: \mathsf{Person} \sqcap \mathsf{Poor} \\ (\mathsf{Anne}, \mathsf{Fred}) &: \mathsf{father} \\ \mathsf{Bob} &: \mathsf{Person} \\ (\mathsf{Bob}, \mathsf{Fred}) &: \mathsf{father} \end{aligned}$$

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$$\mathsf{Anne} : \mathsf{Person} \sqcap \mathsf{Poor}$$
$$(\mathsf{Anne}, \mathsf{Fred}) : \mathsf{father}$$
$$\mathsf{Bob} : \mathsf{Person}$$
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Iterative algorithm

Uses SBTP

Uses aggregation

Paper has details

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$$\text{Rich} \sqsubseteq \forall \text{father}^{-1}.\text{Rich} \qquad \text{Bob} : \text{Person}$$
$$\text{Rich} \sqcap \text{Poor} \sqsubseteq \bot \qquad (\text{Bob}, \text{Fred}) : \text{father}$$

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As a logic program

```
IsA(x, Exists(RN("father"), CN("Person")), time) :-
  IsA(x, CN("Person"), time)
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ALCIF satisfiability = LP satisfiability"

- LP encodes standard tableau construction [Baader et al 2017]
  - "Time" is quantifier expansion depth
  - TBox -> rules, ABox -> facts
  - Some general library rules
- Requires model inspection for "double blocking"

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$$\begin{aligned} \mathsf{Anne} &: \mathsf{Person} \sqcap \mathsf{Poor} \\ (\mathsf{Anne}, \mathsf{Fred}) &: \mathsf{father} \\ \mathsf{Bob} &: \mathsf{Person} \\ (\mathsf{Bob}, \mathsf{Fred}) &: \mathsf{father} \end{aligned}$$

Iterative algorithm

Uses SBTP

Uses aggregation

Paper has details

As a logic program

```
IsA(x, Exists(RN("father"), CN("Person")), time) :-
  IsA(x, CN("Person"), time)
```

ALCIF satisfiability = LP satisfiability"

- LP encodes standard tableau construction [Baader et al 2017]
  - "Time" is quantifier expansion depth
  - TBox -> rules, ABox -> facts
  - Some general library rules
- Requires model inspection for "double blocking"

```
Label(x, cs, time) :-
  IsA(x, _, time),
  COLLECT(cs, c STH IsA(x, c, time))

// Pairwise blocking
// y is blocked by x if ...
Blocked(y, x, time) :-
  // ... x is an ancestor of y,
  Anc(x, y, time),
  // ... the labels of y and x are the same
  Label(y, yIsAs, time),
  Label(x, xIsAs, time),
  yIsAs ≡ xIsAs,
  // ... y and x are r-successors of some y1 and x1, for s
  HasA(y1, r, y, time),
  HasA(x1, r, x, time),
  // ... the labels of y1 and x1 are the same
  Label(y1, y1IsAs, time),
  Label(x1, x1IsAs, time),
  y1IsAs ≡ x1IsAs
```

What's New (1) - (2) Showcase - Fusemate as Description Logic Reasoner

Description logic ALCIF

$$\mathsf{Person} \sqsubseteq \mathsf{Rich} \sqcup \mathsf{Poor}$$
$$\mathsf{Person} \sqsubseteq \exists \mathsf{father}.\mathsf{Person}$$
$$\mathsf{Rich} \sqsubseteq \forall \mathsf{father}^{-1}.\mathsf{Rich}$$
$$\mathsf{Rich} \sqcap \mathsf{Poor} \sqsubseteq \bot$$

father is functional

$$\mathsf{Anne} : \mathsf{Person} \sqcap \mathsf{Poor}$$
$$(\mathsf{Anne}, \mathsf{Fred}) : \mathsf{father}$$
$$\mathsf{Bob} : \mathsf{Person}$$
$$(\mathsf{Bob}, \mathsf{Fred}) : \mathsf{father}$$

Iterative algorithm

Uses SBTP

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Textbook 1-to-1

What's New (3) - Usability and Workflow

Case study for combined Scala / logic programming workflow

2 Million taxi rides in New York City

`Ride(taxi,license,from,to,start,end,fare)`

Ride

Gap (between rides)

Pickup/dropoff clusters

(1) Rules for gaps, pickup/dropoff clustering and concave hull

(2) Rules for anomaly detection

```
=====
driver license-3568
=====
taxi-3568 license-3568 2013-01-01T22:10 2013-01-01T22:38        28m       5.7km
pickup anomaly from: hotspot-15
 hour:          0     1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    21    22    23
 pickups:      16    34    35    30    26    20     7    20     8     5     9    25    36    36    31    55    50    44    24    64    69    38  |109|   21
 dropoffs:  (  16    40    70    73    48    22    33    17    22    28    44    43   116    76    76    83    57    74    70    76    36    13  | 34|   18  )
```

What’s New (3) - Usability an Workflow

From Scala to logic program and back

Scala is both extension language and scripting language

```
val gaps42 = rides filter {
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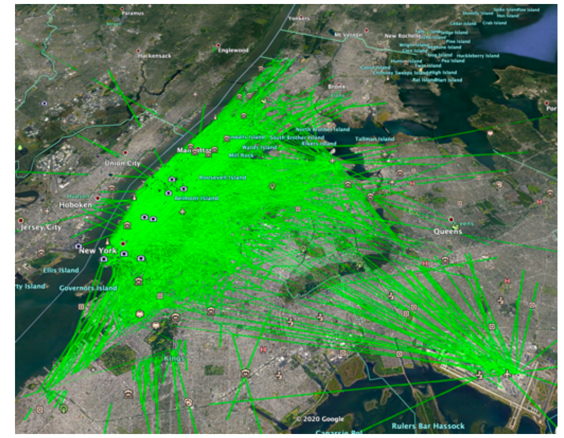
What's New (3) - Usability an Workflow



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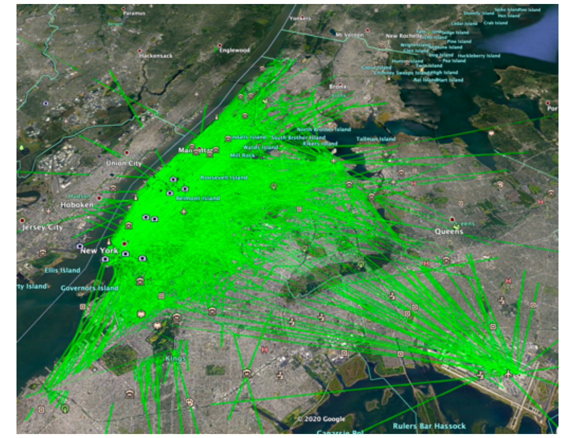

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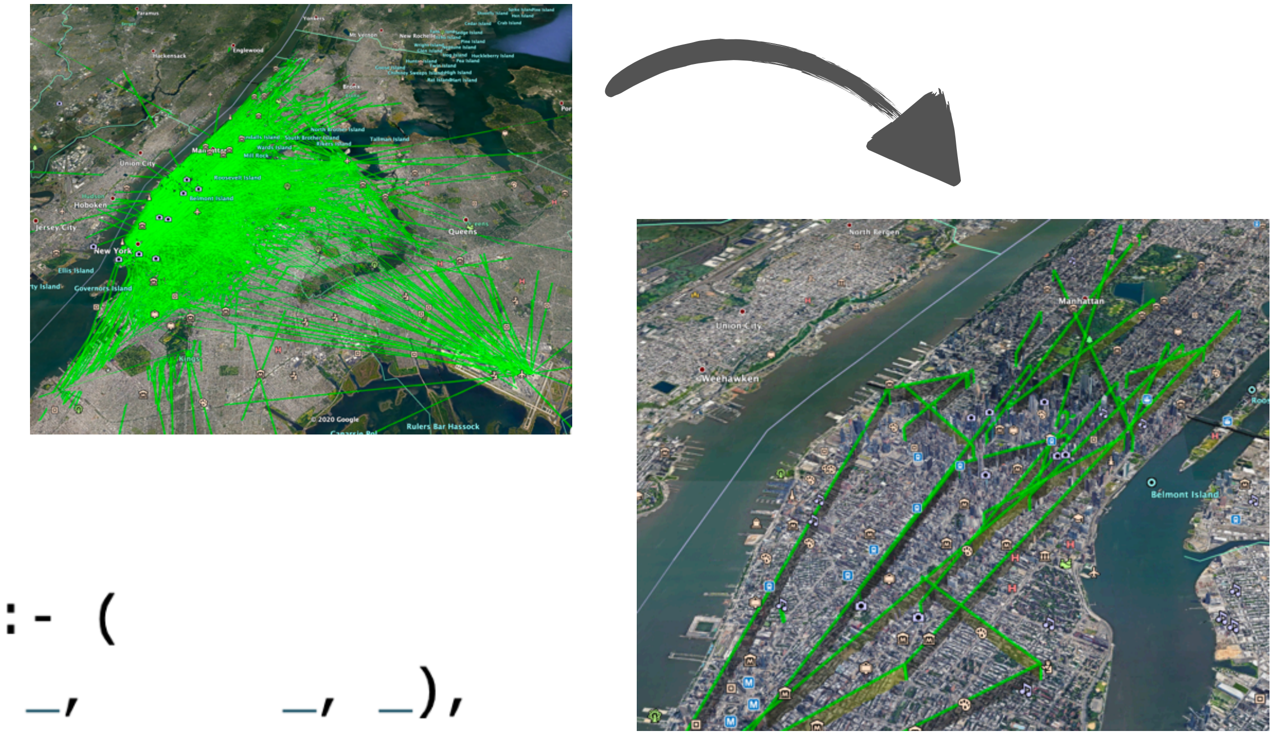

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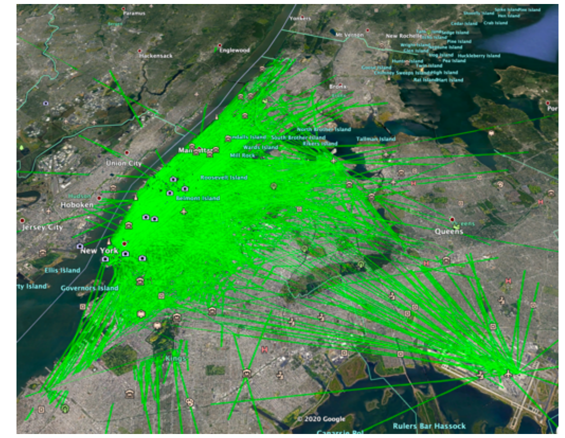

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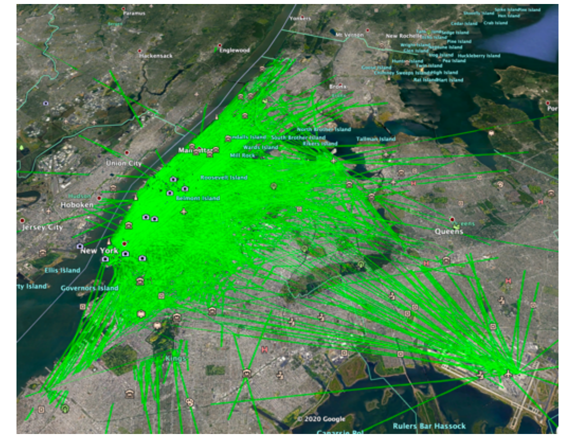

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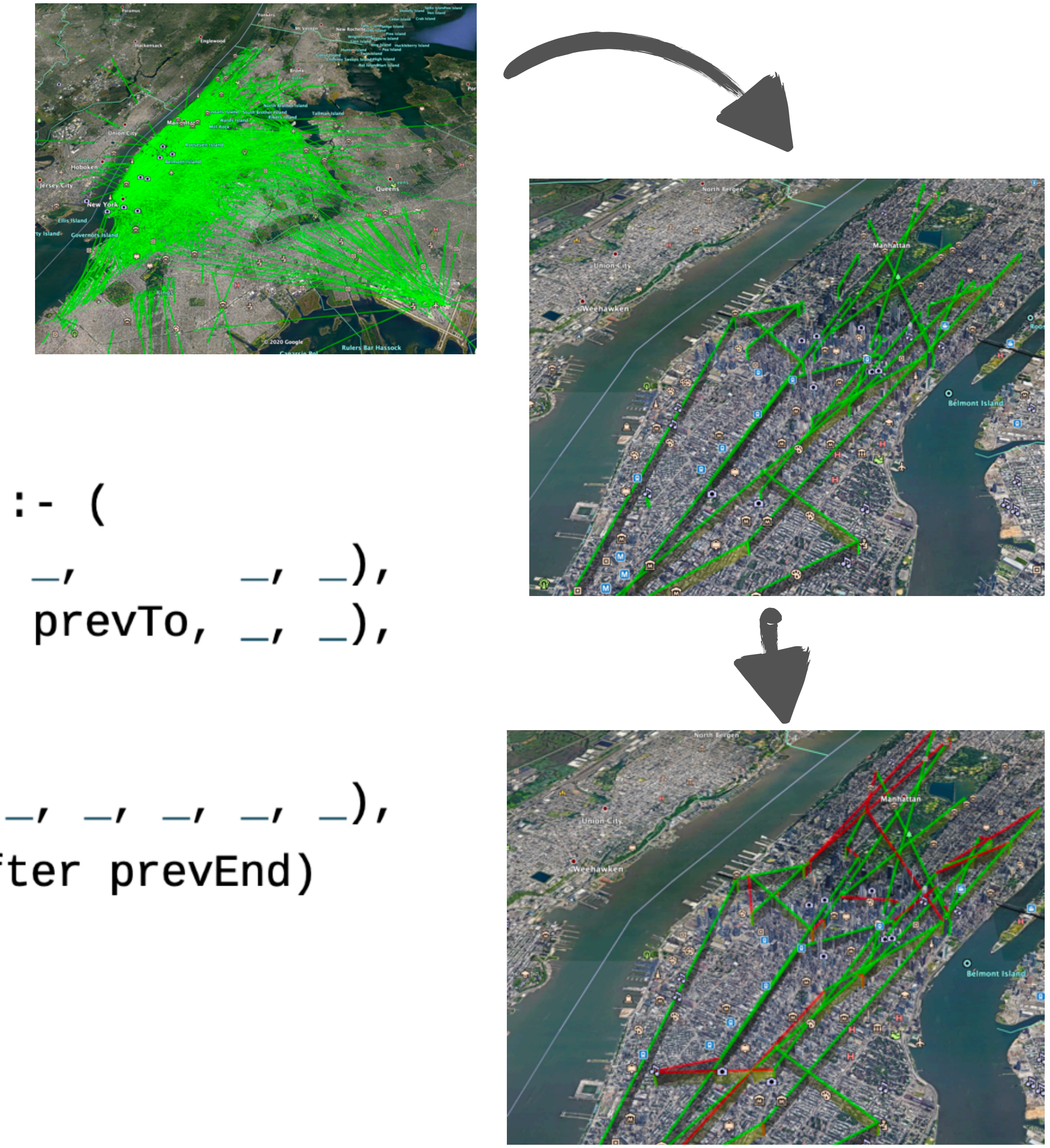
Fusemate invocation



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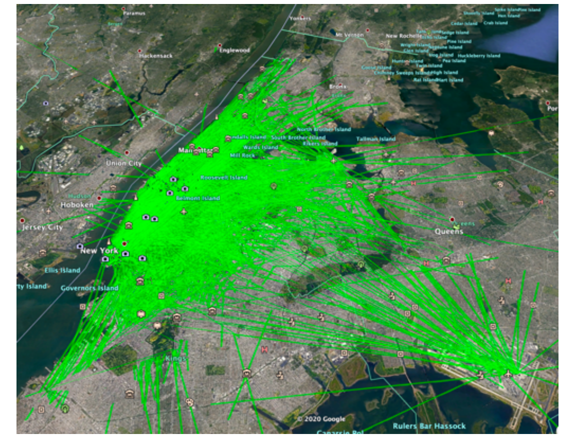

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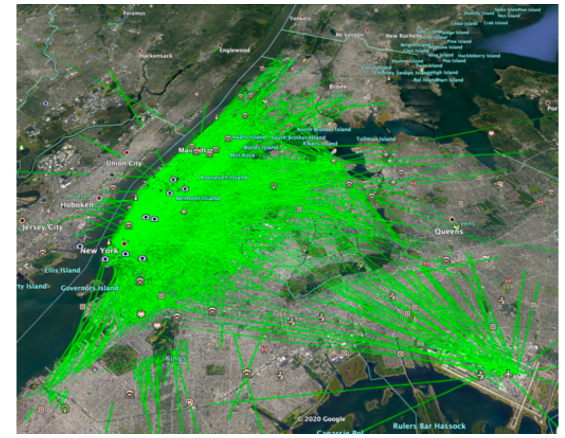

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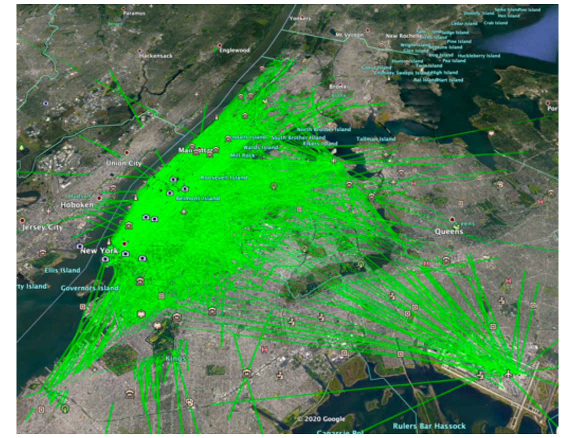
Fusemate invocation

Functional + Logic programming

(in a new way?)



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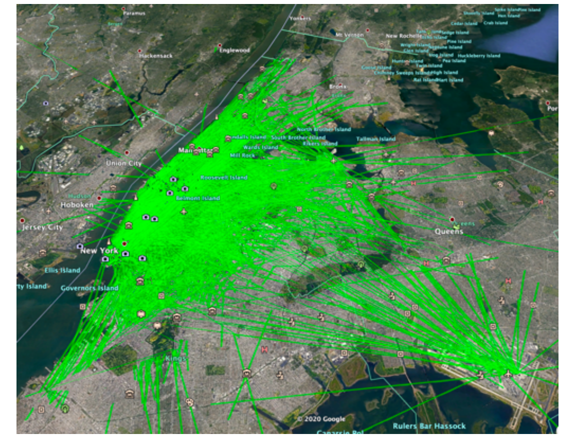

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```

Fusemate invocation

Defined as a Scala function

Functional + Logic programming
(in a new way?)

Conclusions

Fusemate is implemented by shallow embedding into Scala

- New operators for aggregation and comprehension
- Atoms and interpretations are first-class citizens
- Light-weight interface logic programming <-> Scala

  Workflow: logic programming = operator on collections of objects (case classes)

Efficiency

- SAT problem for propositional possible models of stratified DLPs is NP-complete
- Atoms indexed by time then indexed by predicate symbols

  Helps a lot, in particular “comprehension”
- OK for slow-running processes

  Bigger data sets currently need combined workflow (taxi example)

Availability

`https://bitbucket.csiro.au/users/bau050/repos/fusemate/`