Probabilistic Logical Networks

Spatio-Temporal Inference

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Outline

Spatio-temporal PLN inference overview

1. Extract Spatio-temporal predicates from the scene
   - Spatial: `inside(ball, box)`
   - Temporal: `atTime(11pm, ring(bell))`
   - Spatio-temporal: `atTime(11pm, near(Jill, John))`

Spatio-temporal PLN inference overview

1. Extract Spatio-temporal predicates from the scene
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   - Temporal: `atTime(11pm, ring(bell))`
   - Spatio-temporal: `atTime(11pm, near(Jill, John))`
2. Based on Spatio-temporal laws and background knowledge infer new predicates
   - `inside(X,Y) AND inside(Y,Z)` $\Rightarrow$ `inside(X,Z)`

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   - Temporal: `atTime(11pm, ring(bell))`
   - Spatio-temporal: `atTime(11pm, near(Jill, John))`
2. Based on Spatio-temporal laws and background knowledge infer new predicates
   - `inside(X,Y) AND inside(Y,Z)` $\Rightarrow$ `inside(X,Z)`
3. Laws and background knowledge are expressed in PLN
   - hand-coded
   - learned based on past experience
   - infered

Extract Spatio-temporal predicates

- EvaluationLink <0.99>
  near
  ListLink
  yellow_cube
  green_cube
- EvaluationLink <0.85>
  externally_connected
  ListLink
  floor
  green_cube
- EvaluationLink <0.95>
  externally_connected
  ListLink
  floor
  yellow_cube

Extract Spatio-temporal predicates

- EvaluationLink <0.99>
  near
  ListLink
  yellow_cube
  green_cube
- EvaluationLink <0.85>
  externally_connected
  ListLink
  floor
  green_cube
- EvaluationLink <0.95>
  externally_connected
  ListLink
  floor
  yellow_cube

- Can be pre-processed independently (Computer Vision)

Extract Spatio-temporal predicates

- EvaluationLink <0.99>
  near
  ListLink
  yellow_cube
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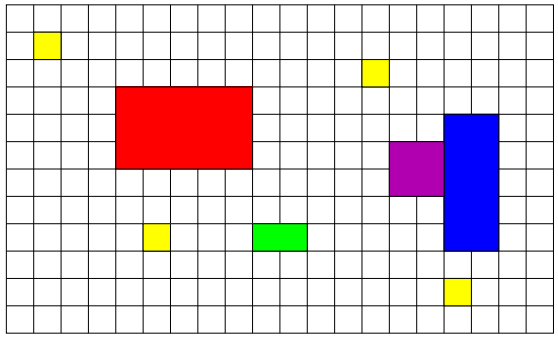
- EvaluationLink <0.85>
  externally_connected
  ListLink
  floor
  green_cube
- EvaluationLink <0.95>
  externally_connected
  ListLink
  floor
  yellow_cube

- Can be pre-processed independently (Computer Vision)
- or in tight interaction with PLN/OpenCog (feedback to correct predicate extraction)

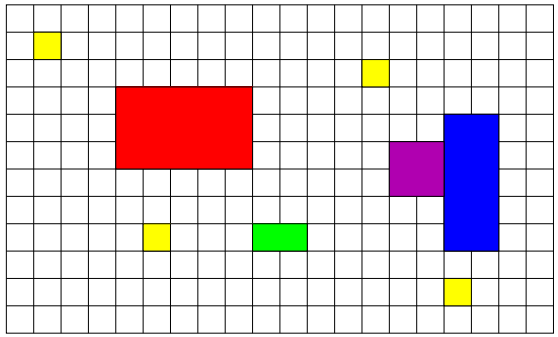
Extract Spatio-temporal predicates, OpenCog (for now)



2D or 3D SpaceMap

- Grid, objects placed on the grid

Extract Spatio-temporal predicates, OpenCog (for now)

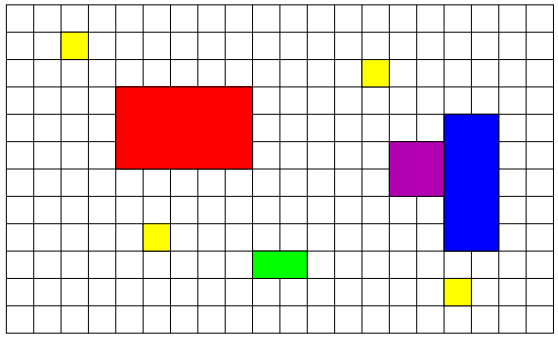


t=1

2D or 3D SpaceMap

- Grid, objects placed on the grid
- recorded over time

Extract Spatio-temporal predicates, OpenCog (for now)

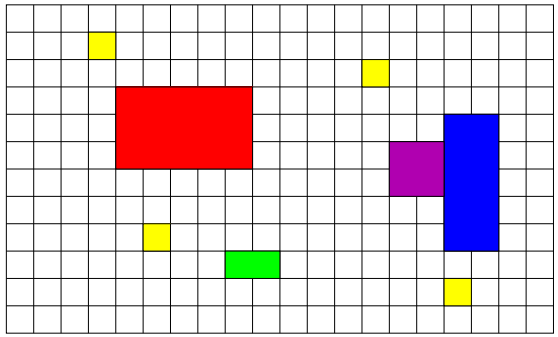


t=2

2D or 3D SpaceMap

- Grid, objects placed on the grid
- recorded over time

Extract Spatio-temporal predicates, OpenCog (for now)

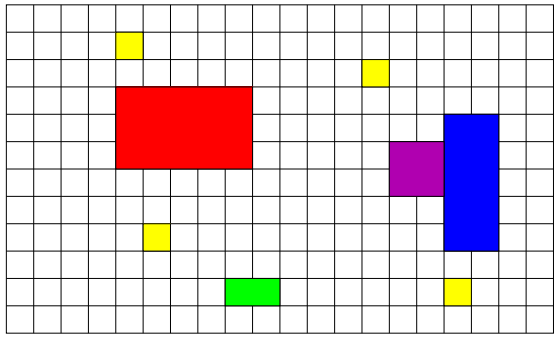


t=3

2D or 3D SpaceMap

- Grid, objects placed on the grid
- recorded over time

Extract Spatio-temporal predicates, OpenCog (for now)

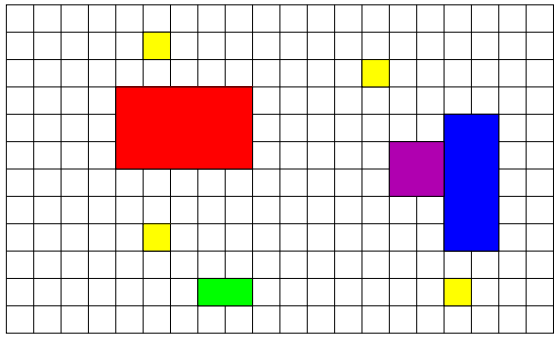


t=4

2D or 3D SpaceMap

- Grid, objects placed on the grid
- recorded over time

Extract Spatio-temporal predicates, OpenCog (for now)

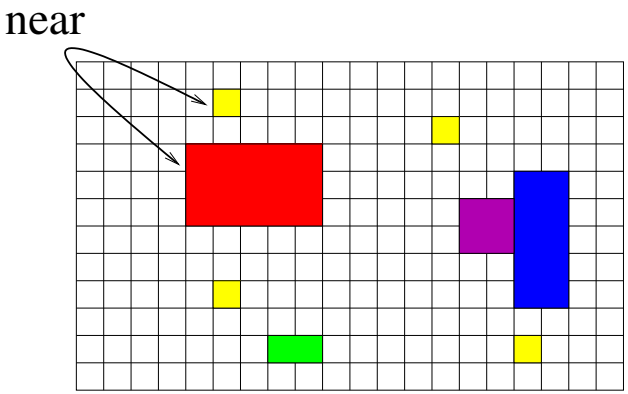


t=5

2D or 3D SpaceMap

- Grid, objects placed on the grid
- recorded over time

Extract Spatio-temporal predicates, OpenCog (for now)



t=5

```
AtTime
     5
     EvaluationLink
          near
          ListLink
               yellow_obj1
               red_obj
```

2D or 3D SpaceMap

- Grid, objects placed on the grid
- recorded over time
- Fixed set of spatial predicates (near, inside, above, etc) computed and timestamped

Spatio-temporal Inference

Spatio-temporal PLN inference is not much different than other kind of PLN inference.

Spatio-temporal Inference

Spatio-temporal PLN inference is not much different than other kind of PLN inference.

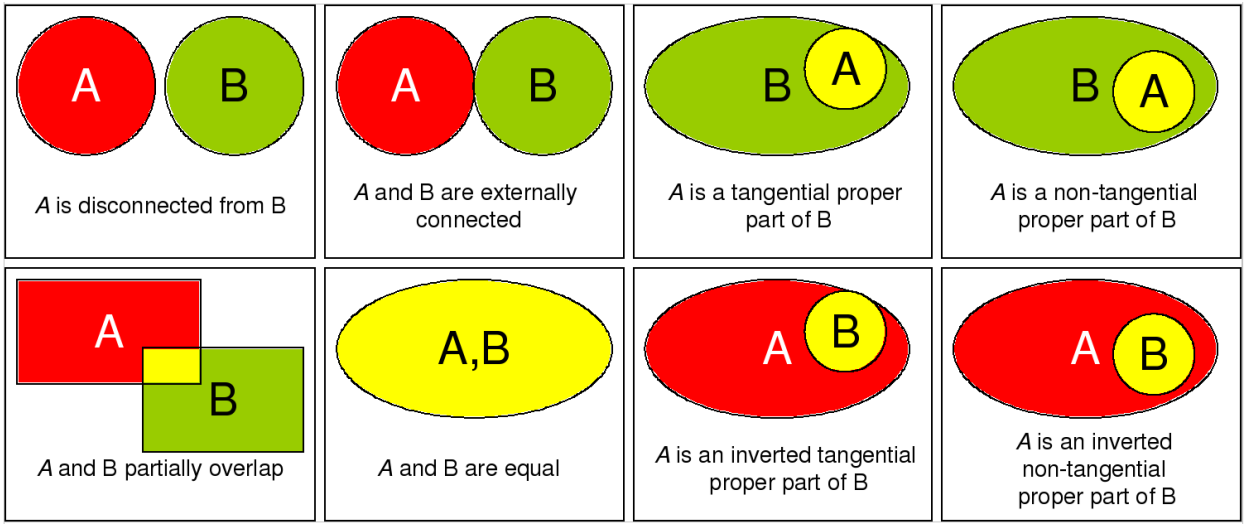
In practice

- hand-coded Spatio-temporal inference rules in PLN (ImplicationLink)
- Dedicated inference control mechanism

Outline

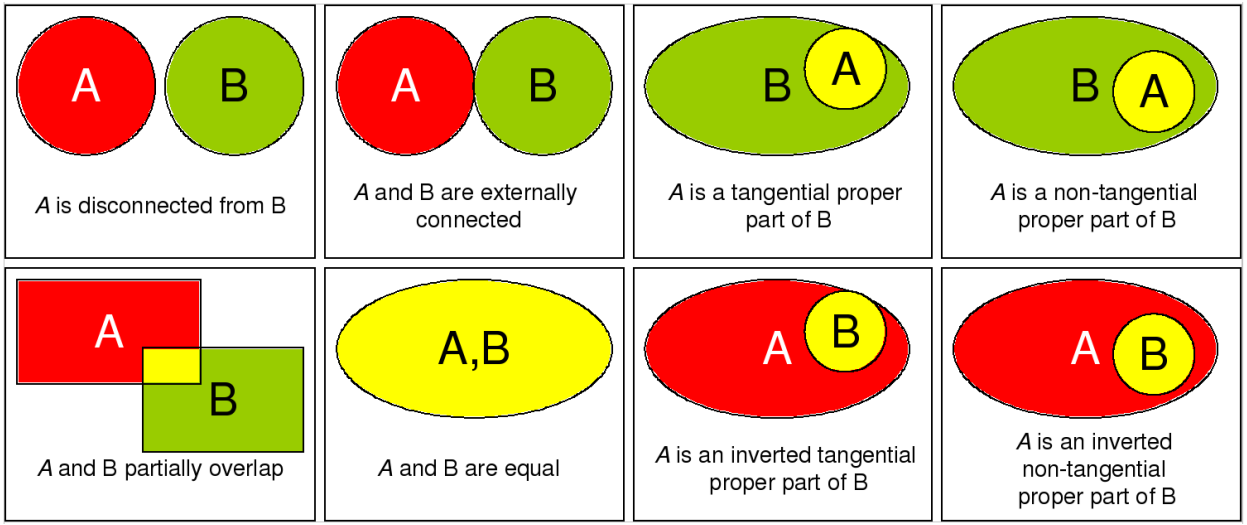
Spatial inference: Region Connection Calculus

1. Predefined set of topological spatial relationships

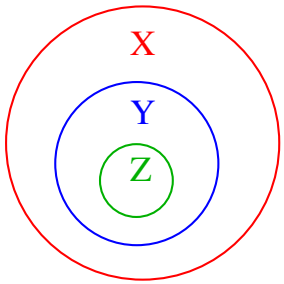


Spatial inference: Region Connection Calculus

1. Predefined set of topological spatial relationships



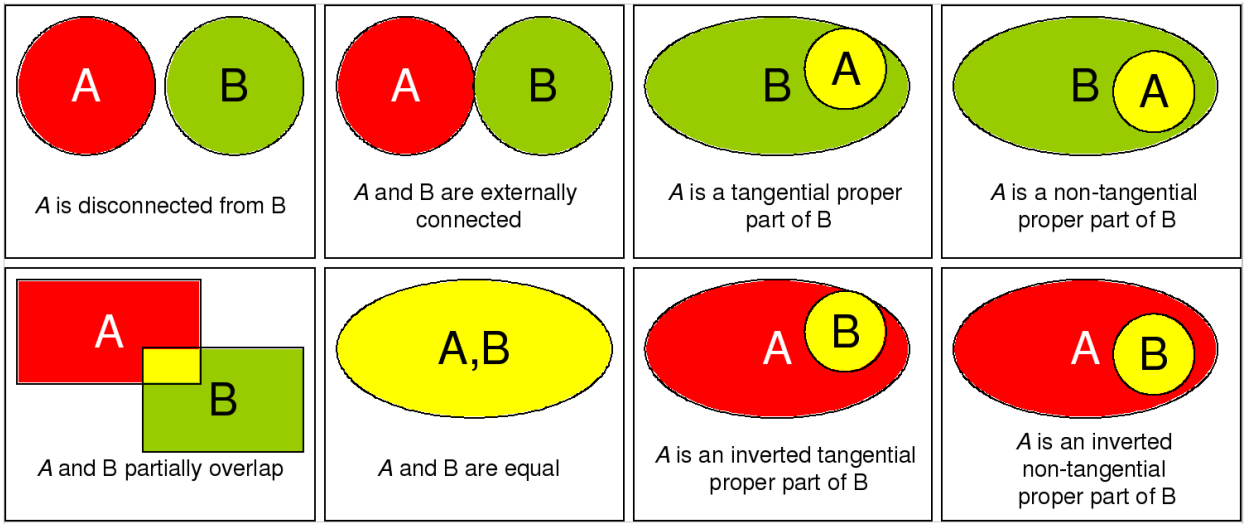
2. Rules to infer new relationships



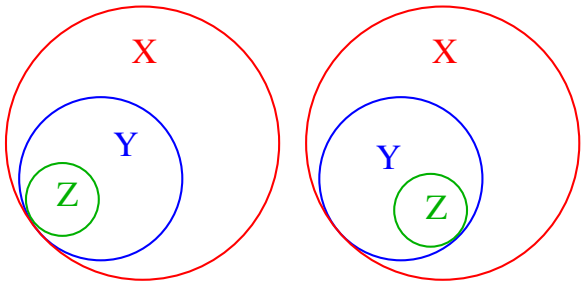

```
ImplicationLink
    AND
        nonTangentialProperPart($X,$Y)
        nonTangentialProperPart($Y,$Z)
    nonTangentialProperPart($X,$Z)
```

Spatial inference: Region Connection Calculus

1. Predefined set of topological spatial relationships



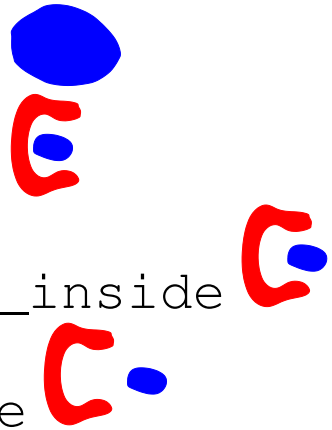
2. Rules to infer new relationships




```
ImplicationLink
    AND
        tangentialProperPart($X,$Y)
        tangentialProperPart($Y,$Z)
    XOR
        tangentialProperPart($X,$Z)
        nonTangentialProperPart($X,$Z)
```

Spatial inference: extending Region Connection Calculus

1. Adding more topological predicates
   - `convex`
   - `inside`
   - `partly_inside`
   - `outside`
   - `...`



Spatial inference: extending Region Connection Calculus

1. Adding more topological predicates
   - `convex`
   - `inside`
   - `partly_inside`
   - `outside`
   - ...
2. Adding metrical predicates
   - `near`
   - `next`
   - ...

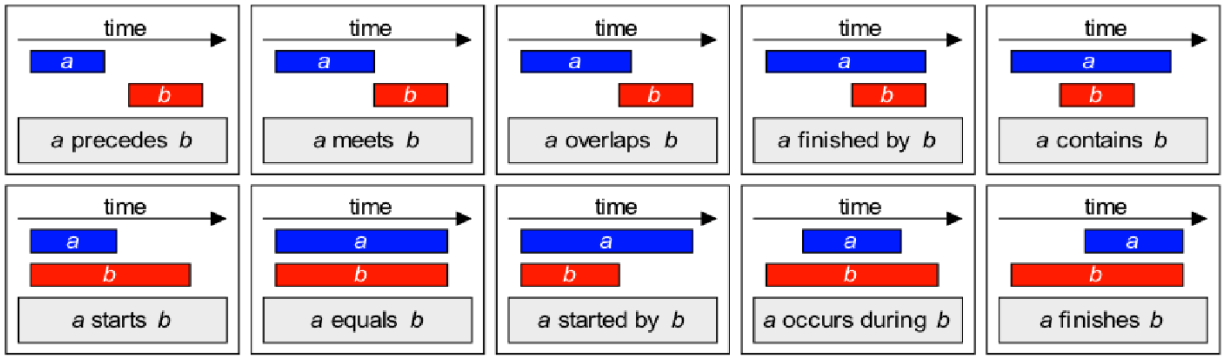
Spatial inference: extending Region Connection Calculus

1. Adding more topological predicates
   - `convex`
   - `inside`
   - `partly_inside`
   - `outside`
   - ...
2. Adding metrical predicates
   - `near`
   - `next`
   - ...
3. Probabilistic or Fuzzy extension (natural in PLN)

Outline

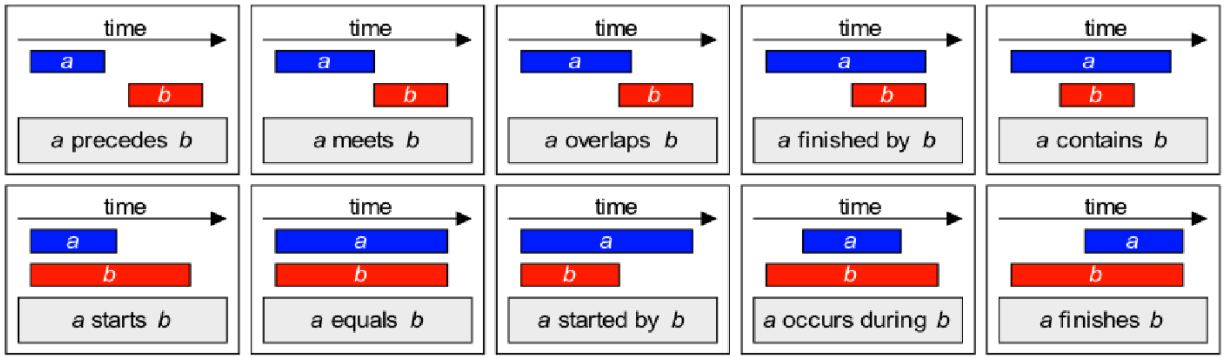
Temporal Inference: Allen's Interval Algebra

1. Predefined set of topological temporal relationships

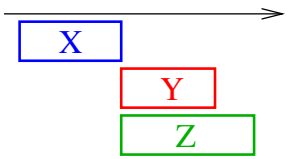


Temporal Inference: Allen's Interval Algebra

1. Predefined set of topological temporal relationships



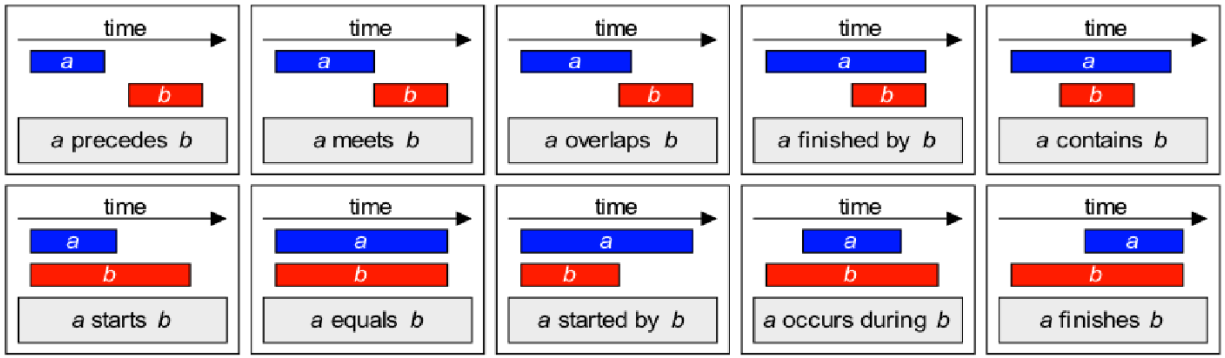
2. Rules to infer new relationships



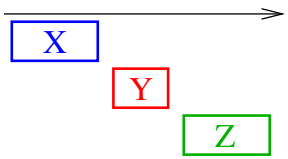

```
ImplicationLink
    AND
        meet($X,$Y)
        start($Y,$Z)
    meet($X,$Z)
```

Temporal Inference: Allen's Interval Algebra

1. Predefined set of topological temporal relationships



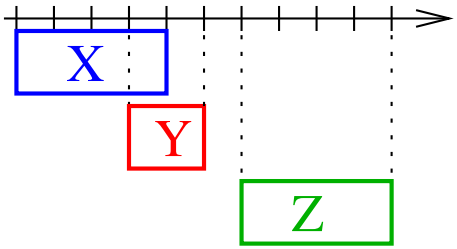
2. Rules to infer new relationships




```
ImplicationLink
    AND
        precede($X,$Y)
        precede($Y,$Z)
    precede($X,$Z)
```

Spatial inference: extending Allen's Interval Algebra

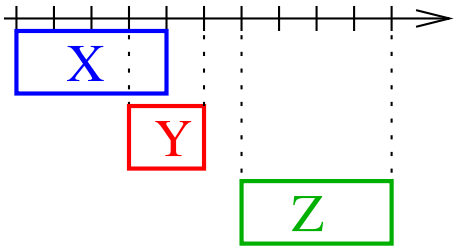
1. Quantitatif time




```
initiatedAt(0,$X), terminatedAt(5,$X),
initatedAt(4,$Y), terminatedAt(6,$Y),
initatedAt(7,$Z), terminatedAt(11,$Z)
```

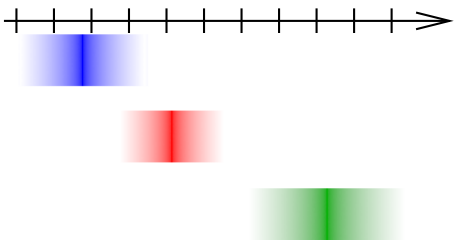
Spatial inference: extending Allen's Interval Algebra

1. Quantitatif time




```
initiatedAt(0,$X), terminatedAt(5,$X),
initatedAt(4,$Y), terminatedAt(6,$Y),
initatedAt(7,$Z), terminatedAt(11,$Z)
```

2. Probabilistic and Fuzzy extension



Spatial inference: extending Allen's Interval Algebra

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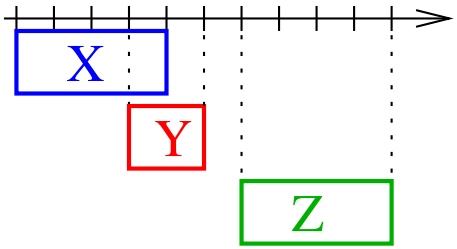
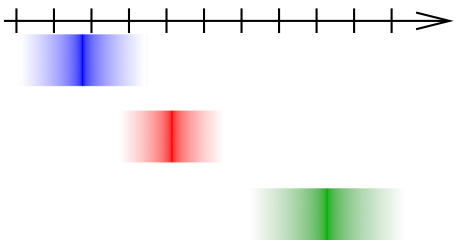



```
initiatedAt(0,$X), terminatedAt(5,$X),
initatedAt(4,$Y), terminatedAt(6,$Y),
initatedAt(7,$Z), terminatedAt(11,$Z)
```

2. Probabilistic and Fuzzy extension



3. Temporal logic, etc

Example of Spatio-temporal Inference

Assessing the probability of being in the airport an hour before my flight considering I set my alarm clock at 5am.

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Axioms

1. `atTime(5am, alarm_clock) <1>`

Example of Spatio-temporal Inference

Assessing the probability of being in the airport an hour before my flight considering I set my alarm clock at 5am.

Axioms

1. `atTime(5am, alarm_clock) <1>`
2.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, alarm_clock)
        atTime($T+5mn, waking_up)
```

Example of Spatio-temporal Inference

Assessing the probability of being in the airport an hour before my flight considering I set my alarm clock at 5am.

Axioms

1. `atTime(5am, alarm_clock) <1>`
2.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, alarm_clock)
        atTime($T+5mn, waking_up)
```
3.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, waking_up)
        atTime($T+25mn, grab_a_cab)
```

Example of Spatio-temporal Inference

Assessing the probability of being in the airport an hour before my flight considering I set my alarm clock at 5am.

Axioms

1. `atTime(5am, alarm_clock) <1>`
2.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, alarm_clock)
        atTime($T+5mn, waking_up)
```
3.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, waking_up)
        atTime($T+25mn, grab_a_cab)
```
4.
```
ForAll $T
    ImplicationLink <0.8>
        atTime($T, grab_a_cab)
        atTime($T+30mn, inside(self, airport_parking))
```

Example of Spatio-temporal Inference

Assessing the probability of being in the airport an hour before my flight considering I set my alarm clock at 5am.

Axioms

1. `atTime(5am, alarm_clock) <1>`
2.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, alarm_clock)
        atTime($T+5mn, waking_up)
```
3.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, waking_up)
        atTime($T+25mn, grab_a_cab)
```
4.
```
ForAll $T
    ImplicationLink <0.8>
        atTime($T, grab_a_cab)
        atTime($T+30mn, inside(self, airport_parking))
```
5.
```
ForAll $T
    atTime($T, inside(airport_parking, airport)) <1>
```

Example of Spatio-temporal Inference

Assessing the probability of being in the airport an hour before my flight considering I set my alarm clock at 5am.

Axioms

1. `atTime(5am, alarm_clock) <1>`
2.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, alarm_clock)
        atTime($T+5mn, waking_up)
```
3.
```
ForAll $T
    ImplicationLink <0.9>
        atTime($T, waking_up)
        atTime($T+25mn, grab_a_cab)
```
4.
```
ForAll $T
    ImplicationLink <0.8>
        atTime($T, grab_a_cab)
        atTime($T+30mn, inside(self, airport_parking))
```
5.
```
ForAll $T
    atTime($T, inside(airport_parking, airport)) <1>
```
6. `atTime(7am, flight) <1>`

Example of Spatio-temporal Inference

Spatio-temporal rule

1. At T, if X is inside Y and Y is inside Z then X is inside Z

```
ForAll $T, $X, $Y, $Z
    ImplicationLink
        AND
            atTime($T, inside($X,$Y))
            atTime($T, inside($Y,$Z))
        atTime($T, inside($X,$Z))
```

Example of Spatio-temporal Inference

Target theorem

```
atTime(6am, inside(self, airport)) <?>
```

Example of Spatio-temporal Inference

Target theorem

```
atTime(6am, inside(self, airport)) <?>
```

Sub-target theorem

```
atTime(6am, inside(self, airport_parking)) <?>
```

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

```
atTime(6am, inside(self, airport_parking)) <?>
```

1. Instantiate axiom 2 with `$T=5am`

```
ImplicationLink <0.9>
    atTime(5am, alarm_clock)
    atTime(5:05am, waking_up)
```

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

`atTime(6am, inside(self, airport_parking)) <?>`

1. Instantiate axiom 2 with `$T=5am`
   ```
   ImplicationLink <0.9>
       atTime(5am, alarm_clock)
       atTime(5:05am, waking_up)
   ```
2. Apply axiom 1 as premise of previous inference step
   `atTime(5:05am, waking_up) <0.9>`

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

```
atTime(6am, inside(self, airport_parking)) <?>
```

1. Instantiate axiom 2 with `$T=5am`
```
ImplicationLink <0.9>
    atTime(5am, alarm_clock)
    atTime(5:05am, waking_up)
```
2. Apply axiom 1 as premise of previous inference step
```
atTime(5:05am, waking_up) <0.9>
```
3. Instantiate axiom 3 with `$T=5:05am`
```
ImplicationLink <0.9>
    atTime(5:05am, waking_up)
    atTime(5:30am, grab_a_cab)
```

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

```
atTime(6am, inside(self, airport_parking)) <?>
```

1. Instantiate axiom 2 with `$T=5am`
```
ImplicationLink <0.9>
    atTime(5am, alarm_clock)
    atTime(5:05am, waking_up)
```
2. Apply axiom 1 as premise of previous inference step
```
atTime(5:05am, waking_up) <0.9>
```
3. Instantiate axiom 3 with `$T=5:05am`
```
ImplicationLink <0.9>
    atTime(5:05am, waking_up)
    atTime(5:30am, grab_a_cab)
```
4. Apply the result of step 2 as premise of the previous step
```
atTime(5:30am, grab_a_cab) <0.81>
```

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

`atTime(6am, inside(self, airport_parking)) <?>`

1. Instantiate axiom 2 with `$T=5am`
```
ImplicationLink <0.9>
    atTime(5am, alarm_clock)
    atTime(5:05am, waking_up)
```
2. Apply axiom 1 as premise of previous inference step
```
atTime(5:05am, waking_up) <0.9>
```
3. Instantiate axiom 3 with `$T=5:05am`
```
ImplicationLink <0.9>
    atTime(5:05am, waking_up)
    atTime(5:30am, grab_a_cab)
```
4. Apply the result of step 2 as premise of the previous step
```
atTime(5:30am, grab_a_cab) <0.81>
```
5. Instantiate axiom 4 with `$T=5:30am`
```
ImplicationLink <0.8>
    atTime(5:30am, grab_a_cab)
    atTime(6am, inside(self, airport_parking))
```

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

`atTime(6am, inside(self, airport_parking)) <?>`

1. Instantiate axiom 2 with `$T=5am`
```
ImplicationLink <0.9>
    atTime(5am, alarm_clock)
    atTime(5:05am, waking_up)
```
2. Apply axiom 1 as premise of previous inference step
```
atTime(5:05am, waking_up) <0.9>
```
3. Instantiate axiom 3 with `$T=5:05am`
```
ImplicationLink <0.9>
    atTime(5:05am, waking_up)
    atTime(5:30am, grab_a_cab)
```
4. Apply the result of step 2 as premise of the previous step
```
atTime(5:30am, grab_a_cab) <0.81>
```
5. Instantiate axiom 4 with `$T=5:30am`
```
ImplicationLink <0.8>
    atTime(5:30am, grab_a_cab)
    atTime(6am, inside(self, airport_parking))
```
6. Apply the result of step 4 as premise of the previous step
```
atTime(6am, inside(self, airport_parking)) <0.73>
```

Example of Spatio-temporal Inference

Inference Steps for the sub-target theorem

```
atTime(6am, inside(self, airport_parking)) <0.73>
```

1. Instantiate axiom 2 with `$T=5am`
```
ImplicationLink <0.9>
    atTime(5am, alarm_clock)
    atTime(5:05am, waking_up)
```
2. Apply axiom 1 as premise of previous inference step
```
atTime(5:05am, waking_up) <0.9>
```
3. Instantiate axiom 3 with `$T=5:05am`
```
ImplicationLink <0.9>
    atTime(5:05am, waking_up)
    atTime(5:30am, grab_a_cab)
```
4. Apply the result of step 2 as premise of the previous step
```
atTime(5:30am, grab_a_cab) <0.81>
```
5. Instantiate axiom 4 with `$T=5:30am`
```
ImplicationLink <0.8>
    atTime(5:30am, grab_a_cab)
    atTime(6am, inside(self, airport_parking))
```
6. Apply the result of step 4 as premise of the previous step
```
atTime(6am, inside(self, airport_parking)) <0.73>
```

Example of Spatio-temporal Inference

Inference steps for the target theorem

`atTime(6am, inside(self, airport)) <?>`

1. Instantiate axiom 5 with `$T=6am`
   `atTime(6am, inside(airport_parking, airport)) <1>`

Example of Spatio-temporal Inference

Inference steps for the target theorem

`atTime(6am, inside(self, airport)) <?>`

1. Instantiate axiom 5 with `$T=6am`
   `atTime(6am, inside(airport_parking, airport)) <1>`
2. Apply sub-target theorem and previous step (standard probability theory)
   `AND <0.73>`
   `atTime(6am, inside(self,airport_parking))`
   `atTime(6am, inside(airport_parking,airport))`

Example of Spatio-temporal Inference

Inference steps for the target theorem

`atTime(6am, inside(self, airport)) <?>`

1. Instantiate axiom 5 with `$T=6am`
   ```
   atTime(6am, inside(airport_parking, airport)) <1>
   ```
2. Apply sub-target theorem and previous step (standard probability theory)
   ```
   AND <0.73>
       atTime(6am, inside(self,airport_parking))
       atTime(6am, inside(airport_parking,airport))
   ```
3. Instantiate spatio-temporal rule 1, with `$T=6am`, `$X=self`, `$Y=airport_parking` and `$Z=parking`
   ```
   ImplicationLink <1>
       AND
           atTime(6am, inside(self,airport_parking))
           atTime(6am, inside(airport_parking,airport))
       atTime(6am, inside(self,airport))
   ```

Example of Spatio-temporal Inference

Inference steps for the target theorem

`atTime(6am, inside(self, airport)) <?>`

1. Instantiate axiom 5 with `$T=6am`
   `atTime(6am, inside(airport_parking, airport)) <1>`
2. Apply sub-target theorem and previous step (standard probability theory)
   ```
   AND <0.73>
       atTime(6am, inside(self,airport_parking))
       atTime(6am, inside(airport_parking,airport))
   ```
3. Instantiate spatio-temporal rule 1, with `$T=6am`, `$X=self`, `$Y=airport_parking` and `$Z=parking`
   ```
   ImplicationLink <1>
       AND
           atTime(6am, inside(self,airport_parking))
           atTime(6am, inside(airport_parking,airport))
       atTime(6am, inside(self,airport))
   ```
4. Apply step 2 as premise of previous step
   `atTime(6am, inside(self, airport)) <0.73>`

Example of Spatio-temporal Inference

Inference steps for the target theorem

```
atTime(6am, inside(self, airport)) <0.73>
```

1. Instantiate axiom 5 with `$T=6am`
   ```
   atTime(6am, inside(airport_parking, airport)) <1>
   ```
2. Apply sub-target theorem and previous step (standard probability theory)
   ```
   AND <0.73>
       atTime(6am, inside(self,airport_parking))
       atTime(6am, inside(airport_parking,airport))
   ```
3. Instantiate spatio-temporal rule 1, with `$T=6am`, `$X=self`, `$Y=airport_parking` and `$Z=parking`
   ```
   ImplicationLink <1>
       AND
           atTime(6am, inside(self,airport_parking))
           atTime(6am, inside(airport_parking,airport))
       atTime(6am, inside(self,airport))
   ```
4. Apply step 2 as premise of previous step
   ```
   atTime(6am, inside(self, airport)) <0.73>
   ```

Outline

Conclusion

- Coding Spatio-temporal laws in the atomSpace
- Getting spatio-temporal knowledge (computer vision)
- In practice, inference control will play a great role to lead to efficient inference