Geospatial Information with Description Logics, OWL, and Rules

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TELEIOS

Outline

- Geospatial information with description logics and OWL
- OWL reasoners with geospatial capabilities
- Geospatial information with SWRL rules

Geospatial information with DLs and OWL

Three main approaches:

1. Use a DL as it is

2. Define a spatial DL (concrete domain approach)

3. Hybrid: OWL + Spatial ABox

Use a DL as it is

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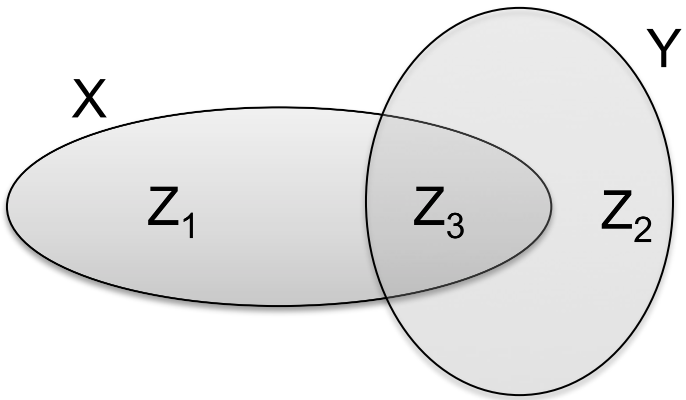
Use OWL-DL

[Katz et al., OWLED'05]

- **Regions** are represented by **concepts**
- **Points** are represented by **individuals**
- RCC-8 relations among regions expressed by DL axioms

Translation of `PO(X, Y)` as



$$
\left\{
\begin{array}{l}
Z_1 \equiv X \sqcap \neg Y \\
Z_2 \equiv \neg X \sqcap Y \\
Z_3 \equiv \forall R.X \sqcap \forall R.Y \\
\quad + \\
\mathrm{Z}_1(\mathrm{z}_1) \;\; \mathrm{Z}_2(\mathrm{z}_2) \;\; \mathrm{Z}_3(\mathrm{z}_3)
\end{array}
\right.
$$

TBox

ABox

Use a DL as it is

[Katz et al., OWLED'05]

Use OWL-DL

Discussion

- Impractical when implemented in a reasoner [Stocker-Sirin, OWLED'09]
- Unnatural modeling?
- Can we generalize the approach?
  - For example, can we define the concept of a dream house as one that is located inside a forest?
- How do we express disjunctions of RCC-8 relations (indefinite information)?

Define a spatial DL

(concrete domain approach)

Concrete domains

- Reason about specific domains
(real numbers, time intervals, spatial regions)

- Formalization of a concrete domain using a first-order theory

- From **roles** to **features**: associate an individual to a value from a concrete domain

- Notation: $\mathcal{DL}(\mathcal{D})$

Concrete domains

Examples:

- Reals with order ($\mathcal{R}$)
  Domain: the set of real numbers $\mathbb{R}$
  Predicates: $<$ interpreted by the "less-than" relation

- Allen's Interval Calculus
  Domain: the set of time intervals
  Predicates: Allen's basic interval relations (`before`, `starts`, etc.) and Boolean combinations of them

- RCC-8 Calculus
  Domain: the set of non-empty, regular closed subsets of $\mathbb{R}^2$
  Predicates: basic RCC-8 relations (`EQ`, `PO`, etc.) and Boolean combinations of them

Concrete domains

TBox

Concept equivalences/inclusions can include features and concrete domain predicates

ABox

Assertions can associate an individual to values from a concrete domain

Concrete domains

Two state of the art approaches

- $\mathcal{ALC}(\mathrm{RCC8})$: $\mathcal{ALC}$ with RCC-8 calculus as the concrete domain
  - extension of model-theoretic semantics of $\mathcal{ALC}$
  - ω-admissibility property
  - tableau-based technique

[Lutz-Milicic, JAR'07]

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[Lutz-Milicic, JAR'07]

- $\text{DL-Lite}^{\sqcap}_{\mathcal{F},\mathcal{R}}(\mathrm{RCC8})$: DL-Lite with RCC-8 calculus as the concrete domain
  - extension of model-theoretic semantics of DL-Lite
  - FOL-rewritability for unions of conjunctive queries

[Özçep-Möller, DL'12]

An Example

- **DreamHouse**
  One that is located inside a pine forest and borders a lake

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$$\mathrm{DreamHouse} \sqsubseteq \forall hasForest.\mathrm{PineForest} \sqcap \forall hasLake.\mathrm{Lake}$$

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An Example (classification)

- **ABox**

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- **Answer**: Yes.

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- **Why?**

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Hybrid: OWL + Spatial ABox

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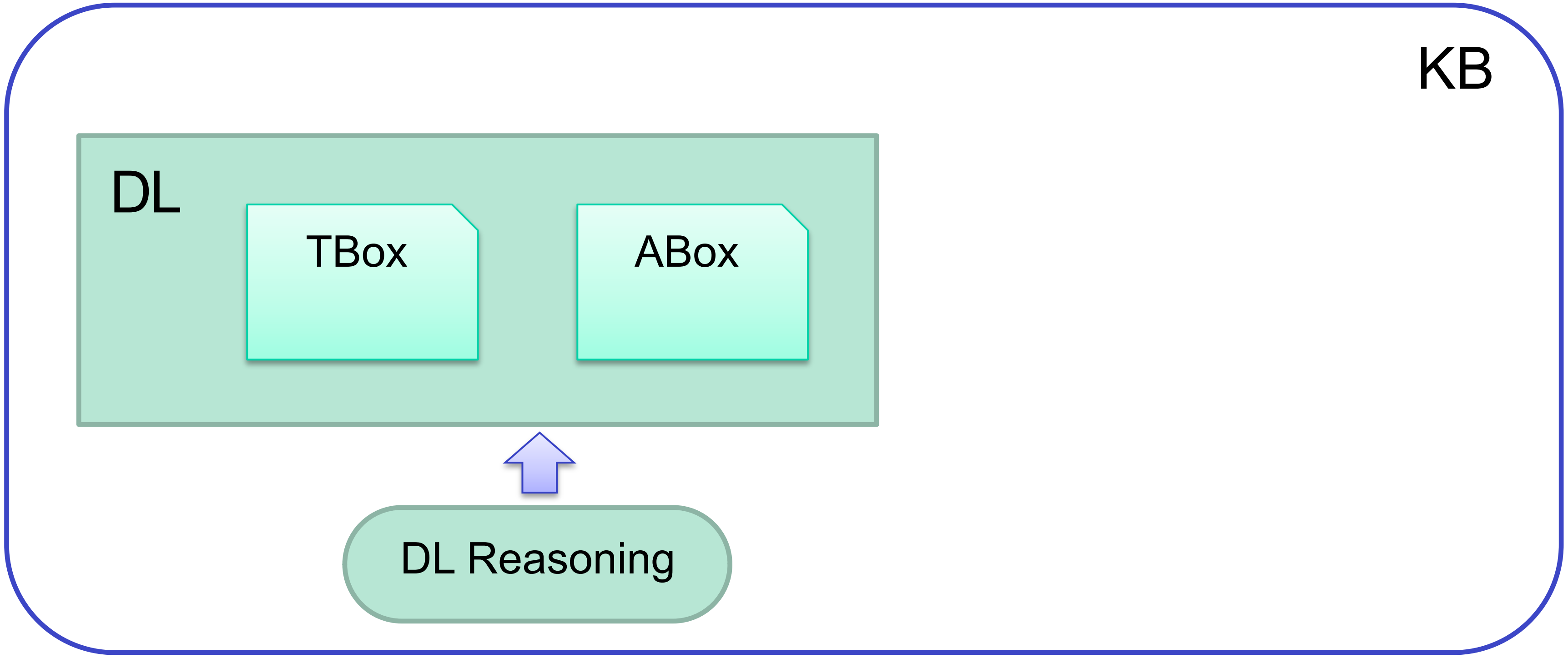
General architecture



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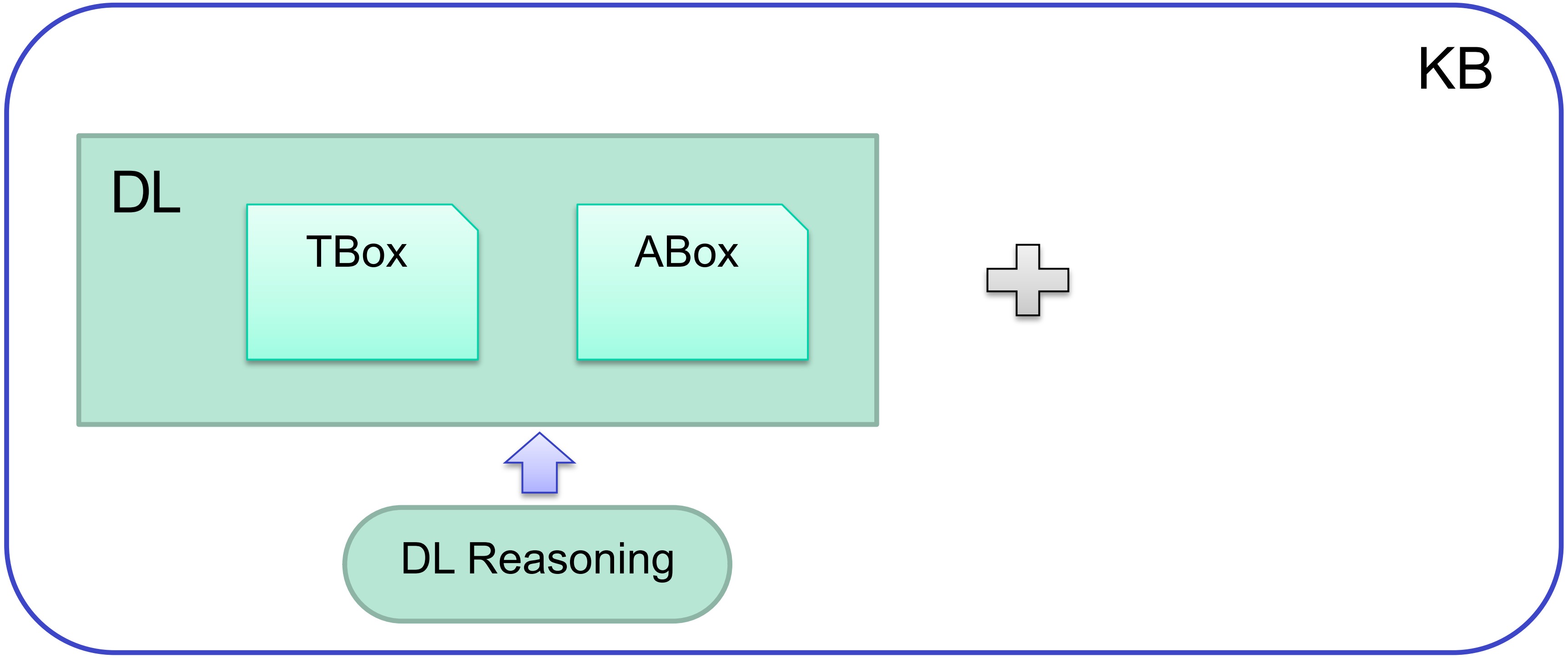

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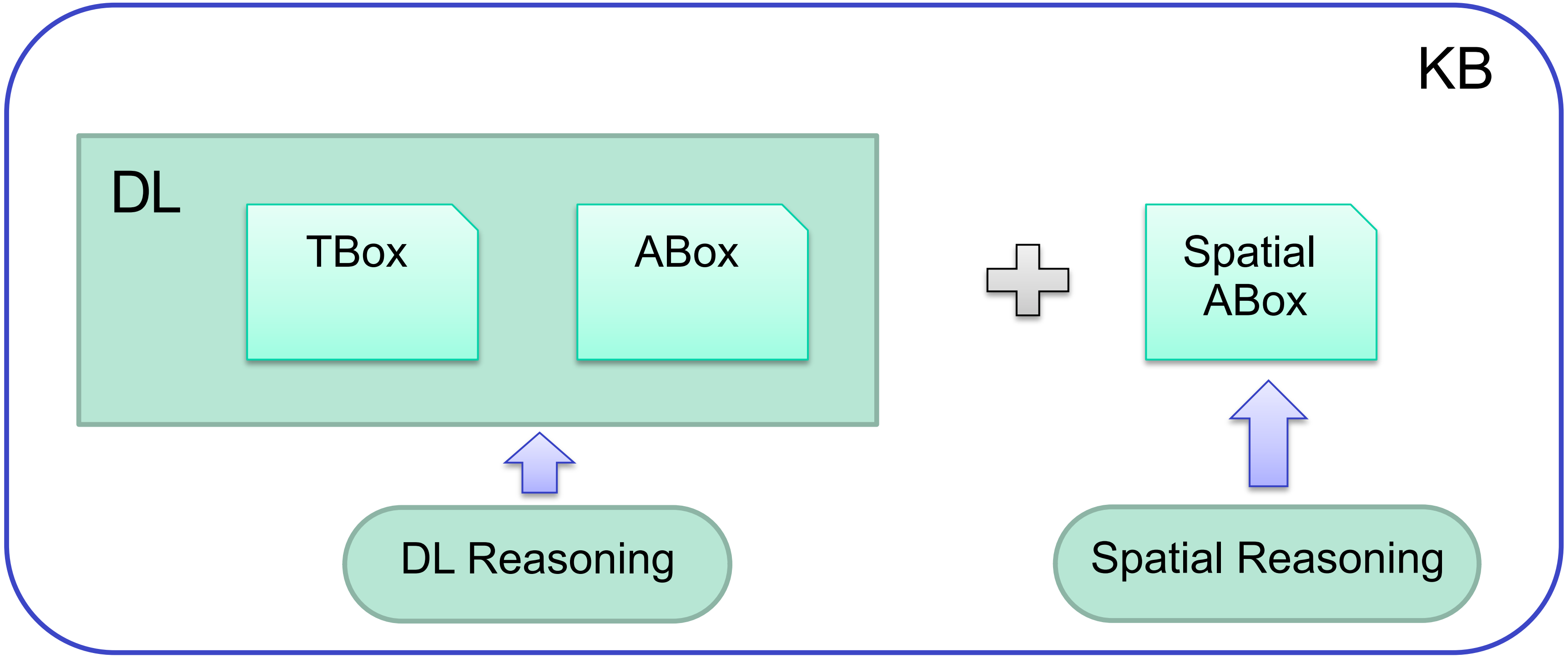


Hybrid: OWL + Spatial ABox

1. Grutter et al.

2. Reasoner RacerPro (DL/OWL + Spatial ABox)

3. Reasoner PelletSpatial (DL/OWL + Spatial ABox)

Hybrid: OWL + Spatial ABox

[Grütter et al., ISWC'08]

Domain Knowledge (TBox)

- Introduction of roles (e.g., `partiallyOverlaps`) for RCC relations (e.g., `PO`)
- `spatiallyRelated`: top role for topological relations
- Role inclusion axioms for RCC relations

$$\mathrm{partiallyOverlaps} \sqsubseteq \mathrm{spatiallyRelated}$$

Assertions (ABox)

- Assertion of the "connectsWith" relation, `connectsWith(a, b)`, between two regions (individuals)

Hybrid: OWL + Spatial ABox

[Grütter et al., ISWC'08]

RCCBox

- Definition of RCC relations based on the "connectsWith" relation

$$\mathrm{P(x,y)} \equiv_{\mathrm{def}} \forall \mathrm{z}(\mathrm{C(z,x)} \rightarrow \mathrm{C(z,y)}) \qquad \mathrm{DC(x,y)} \equiv_{\mathrm{def}} \neg \mathrm{C(x,y)}$$

- Axioms for composition tables of RCC

Predicate `C(x, y)` corresponds to **role** `connectsWith(x, y)` in ABox

Hybrid: OWL + Spatial ABox

[Grütter et al., ISWC'08]

Application

1. Input: a set of geometries (polygons in $\mathbb{Z}^2$)

2. Compute assertions of the form `connectsWith(a, b)`

3. Update ABox with new spatial relations according to definitions in RCCBox
    1. Should `DC(a, b)` be inferred in RCCBox, then
    2. the role assertion `disconnectedWith(a, b)` is inserted in ABox

4. Check spatial consistency of ABox using path consistency on the RCC network constructed from the spatial role assertions of the ABox

The reasoner RacerPro

[Möller et al.]
[Wessel-Möller, JAPLL'09]

- **Description Logic**: $\mathcal{SHIQ}$
- **Spatial Extension**: the ABox is associated to a spatial representation layer (RCC substrate)
- **RCC substrate**: offers representation and querying facilities for RCC networks

Available from
http://www.racer-systems.com/products/racerpro/

Features

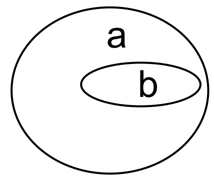
- Representation of indefinite information: disjunctions of RCC relations can be used between two individuals
- Consistency checking of RCC networks
- Querying of **asserted** and **entailed** RCC relations using the query language nRQL

RacerPro: ABox Reasoning

- Spatial regions: `a`, `b`, and `c`

- Region `a` contains `b`

```
(rcc-related a b ((:ntppi :tppi)))
```



- Region `a` is disjoint with `c`

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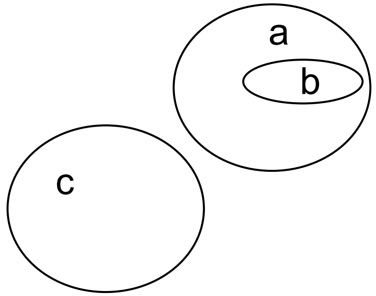

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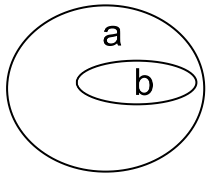

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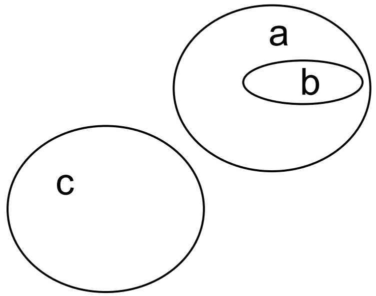

(?) Which regions are disjoint?

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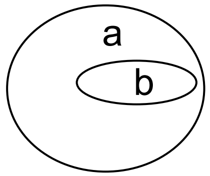

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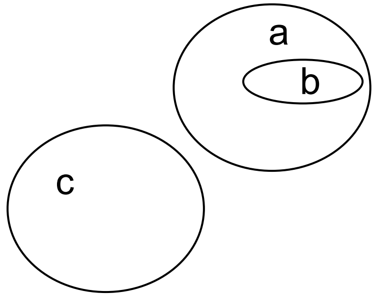

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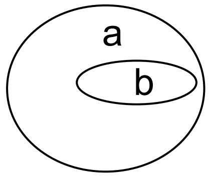

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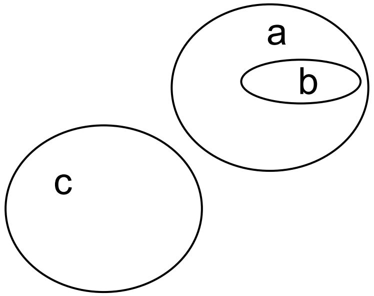


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`(a, c)` and `(c, b)`

Dream House (definition)

- **DreamHouse**
  One that is located inside a pine forest and borders a lake

$$\mathrm{DreamHouse} \equiv \mathrm{House} \sqcap \exists (loc), (hasLake\ loc).\mathrm{EC}$$
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Dream House (ABox reasoning)

- **ABox**

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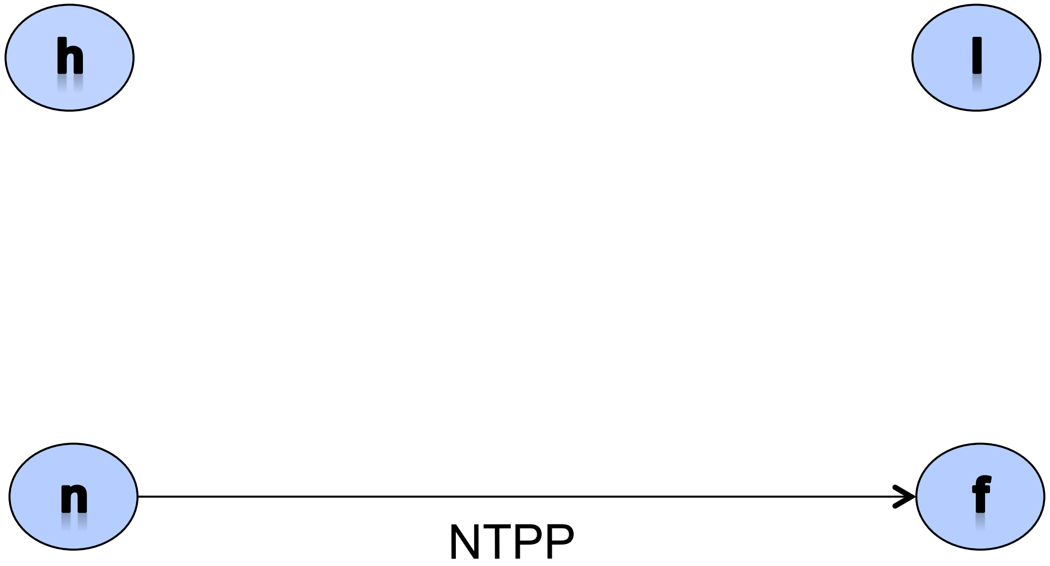

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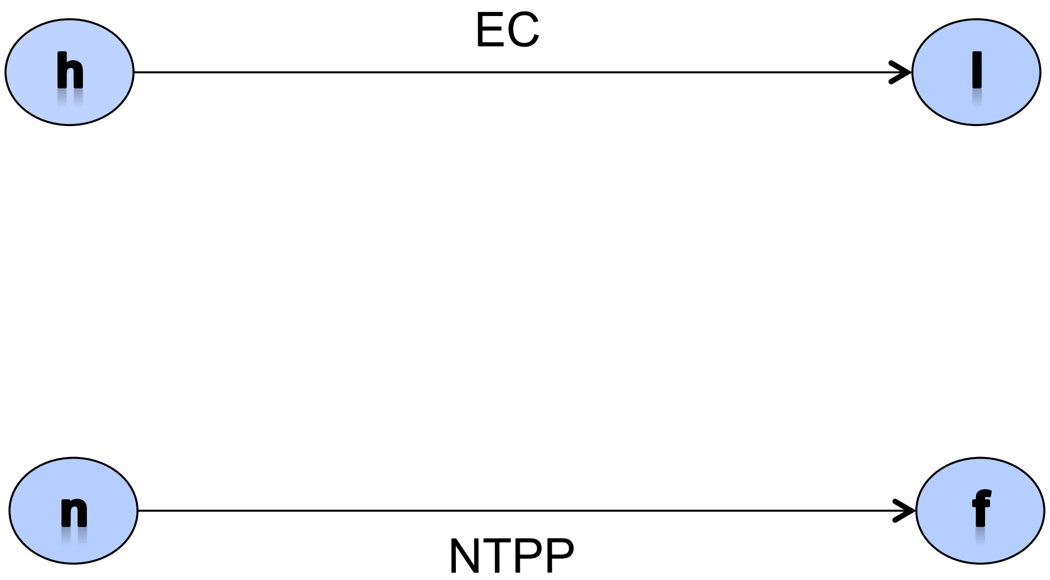

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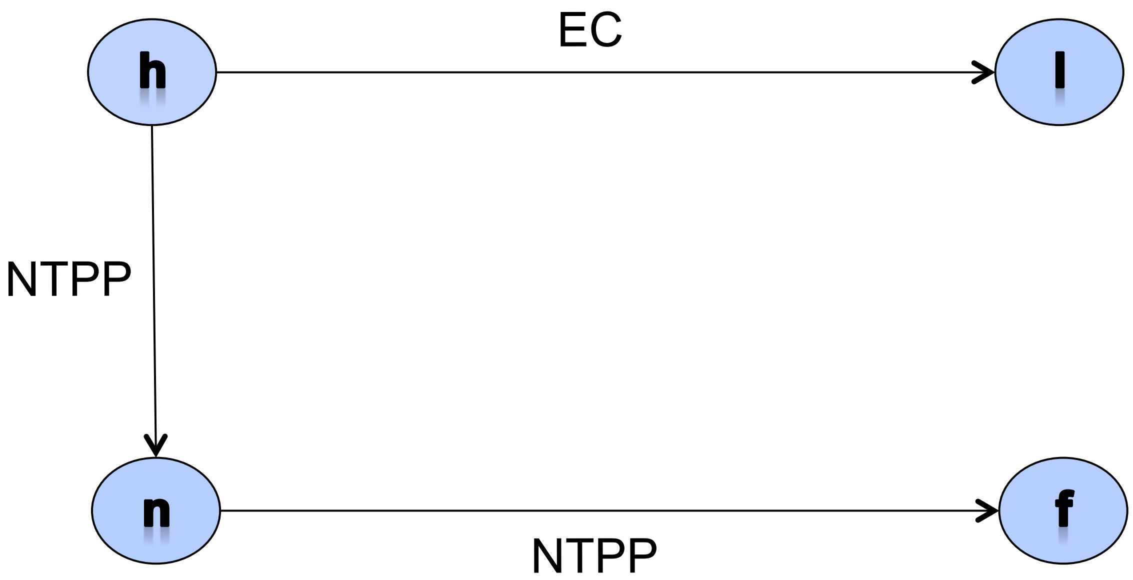

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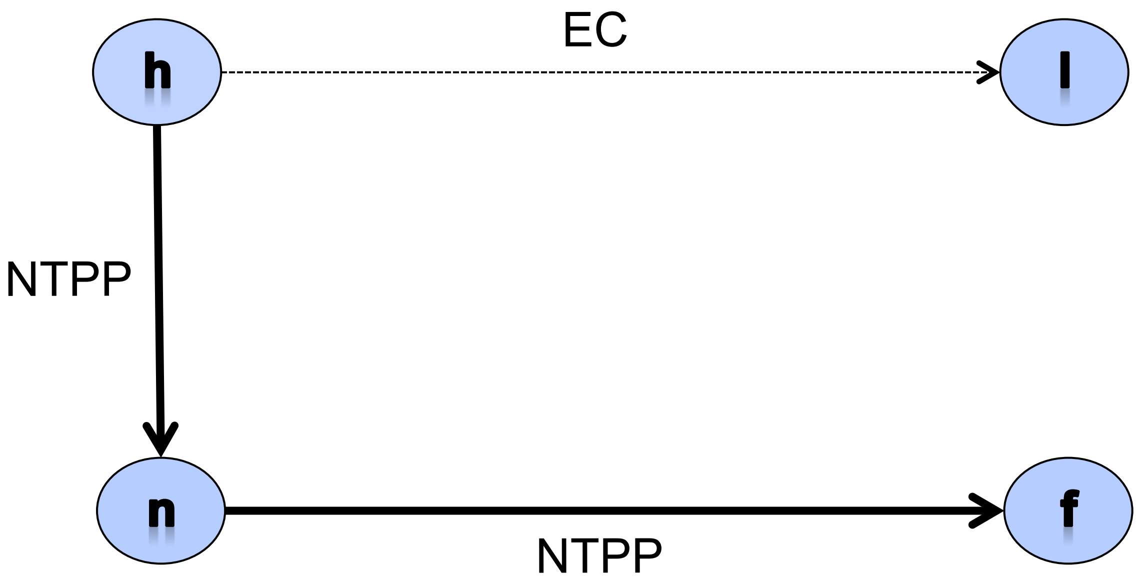
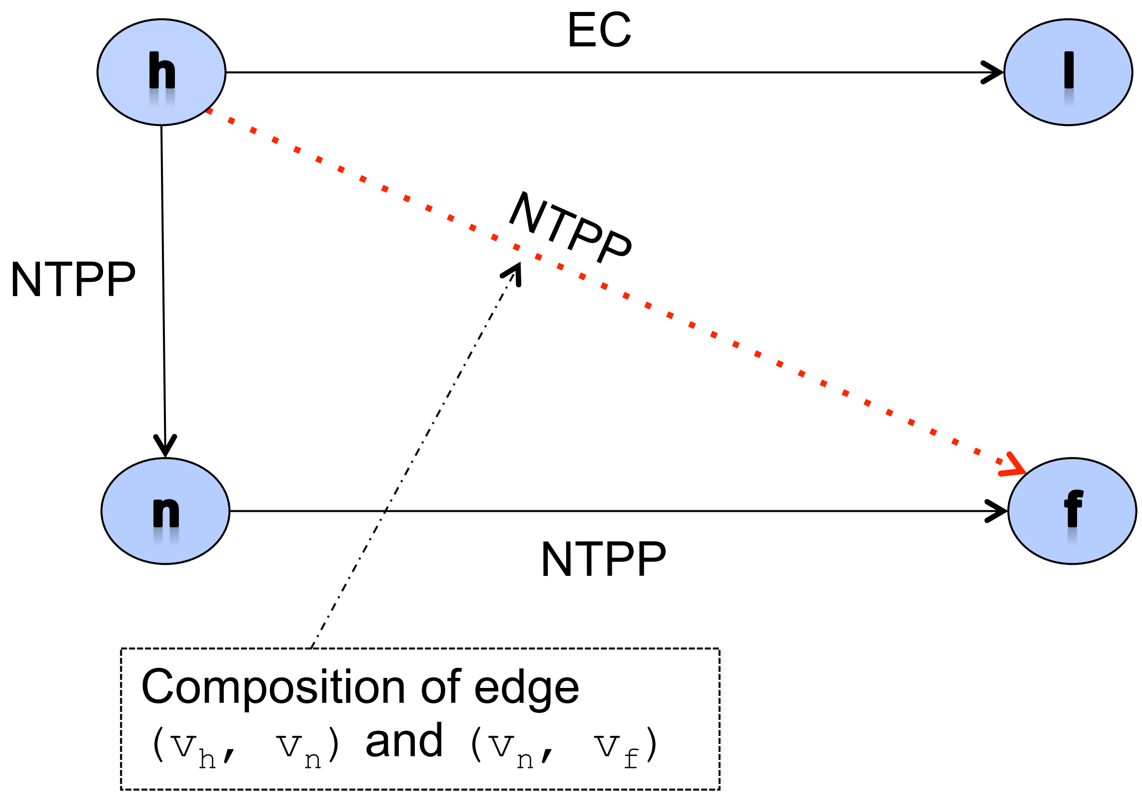


Composition of edge (v_h, v_n) and (v_n, v_f)

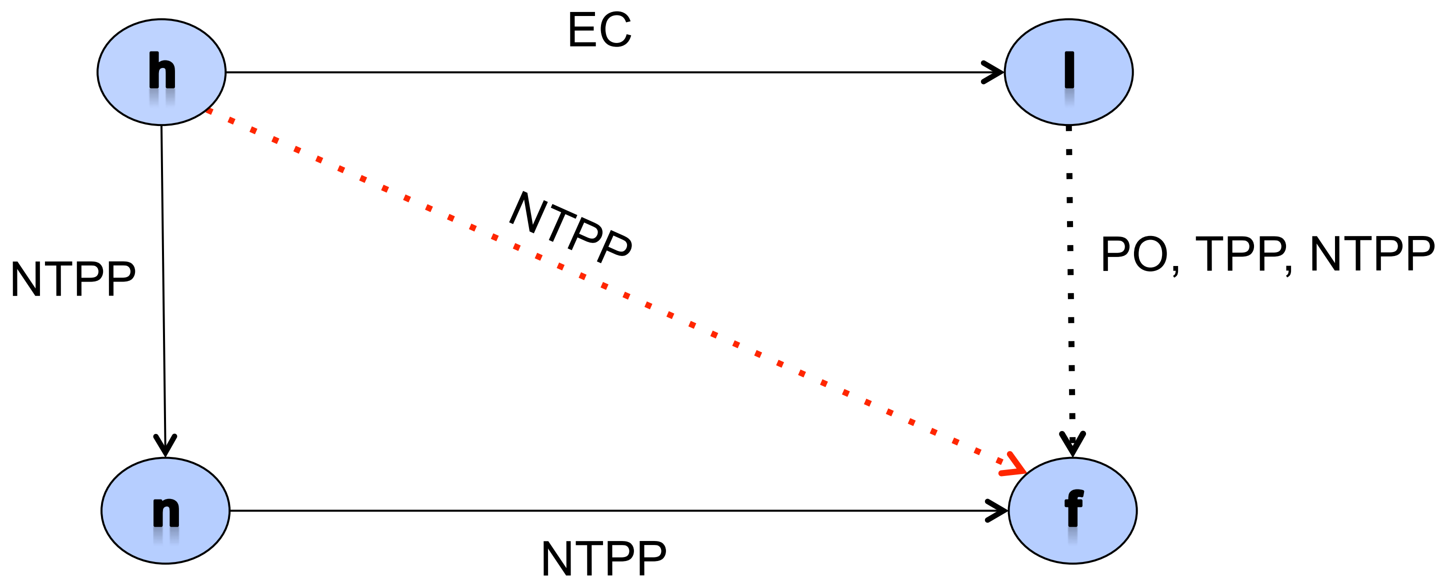
Dream House (ABox reasoning)

$\mathrm{Fire}(f)$	$\mathrm{House}(h)$	$\mathrm{NTPP}(h,n)$
$\mathrm{PineForest}(n)$	$\mathrm{hasForest}(h,n)$	$\mathrm{NTPP}(n,f)$
$\mathrm{Lake}(l)$	$\mathrm{hasLake}(h,l)$	$\mathrm{EC}(h,l)$



Dream House (ABox reasoning)

$$\begin{array}{lll} \mathrm{Fire}(f) & \mathrm{House}(h) & \mathrm{NTPP}(h,n) \\ \mathrm{PineForest}(n) & \mathrm{hasForest}(h,n) & \mathrm{NTPP}(n,f) \\ \mathrm{Lake}(l) & \mathrm{hasLake}(h,l) & \mathrm{EC}(h,l) \end{array}$$



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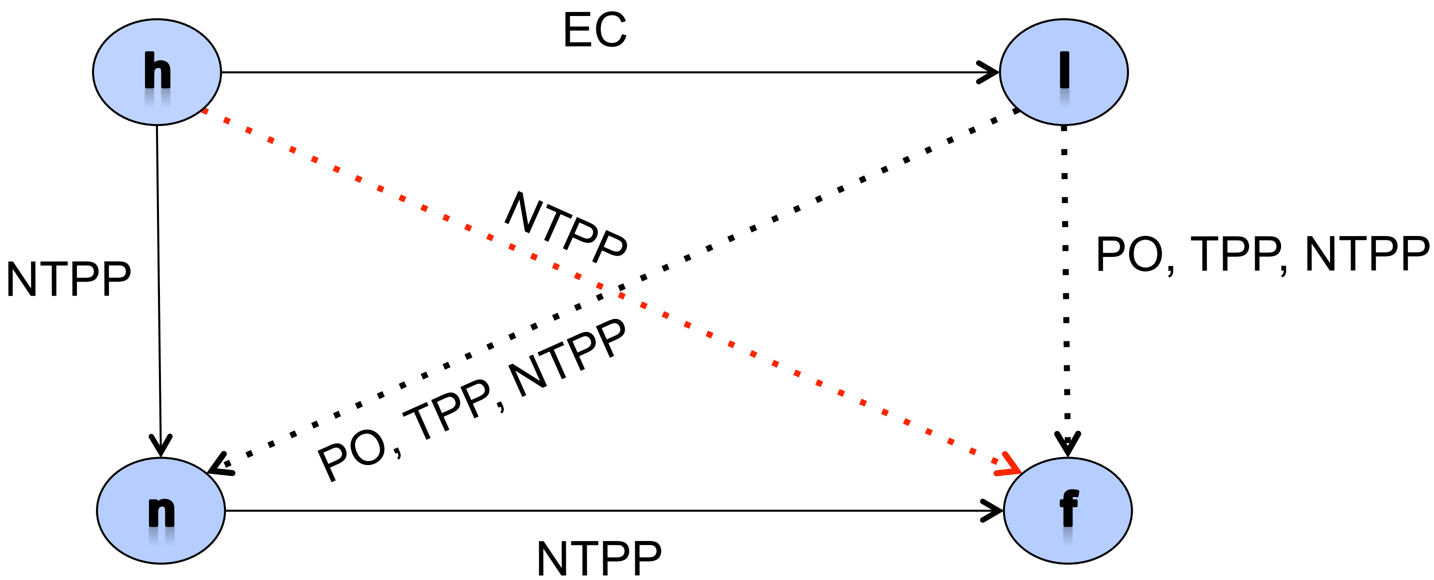


The reasoner PelletSpatial

[Stocker-Sirin, OWLED'09]

- **Description Logic**: OWL 2 ($\mathcal{SROIQ}(\mathcal{D})$)
- **Spatial Extension**: Separate ABox for spatial data
- **Spatial ABox**: Topological relations are managed as a **basic** RCC-8 network (a single relation between two nodes)

Features

- Representation of definite information only
- Consistency checking of basic RCC-8 networks (path consistency)
- Querying of **asserted** and **entailed** basic RCC-8 relations using a subset of SPARQL (BGPs and operator AND)

Available from http://clarkparsia.com/pellet/spatial

SWRL Rules

Geospatial information with SWRL rules

[Batsakis et al., RuleML'11]

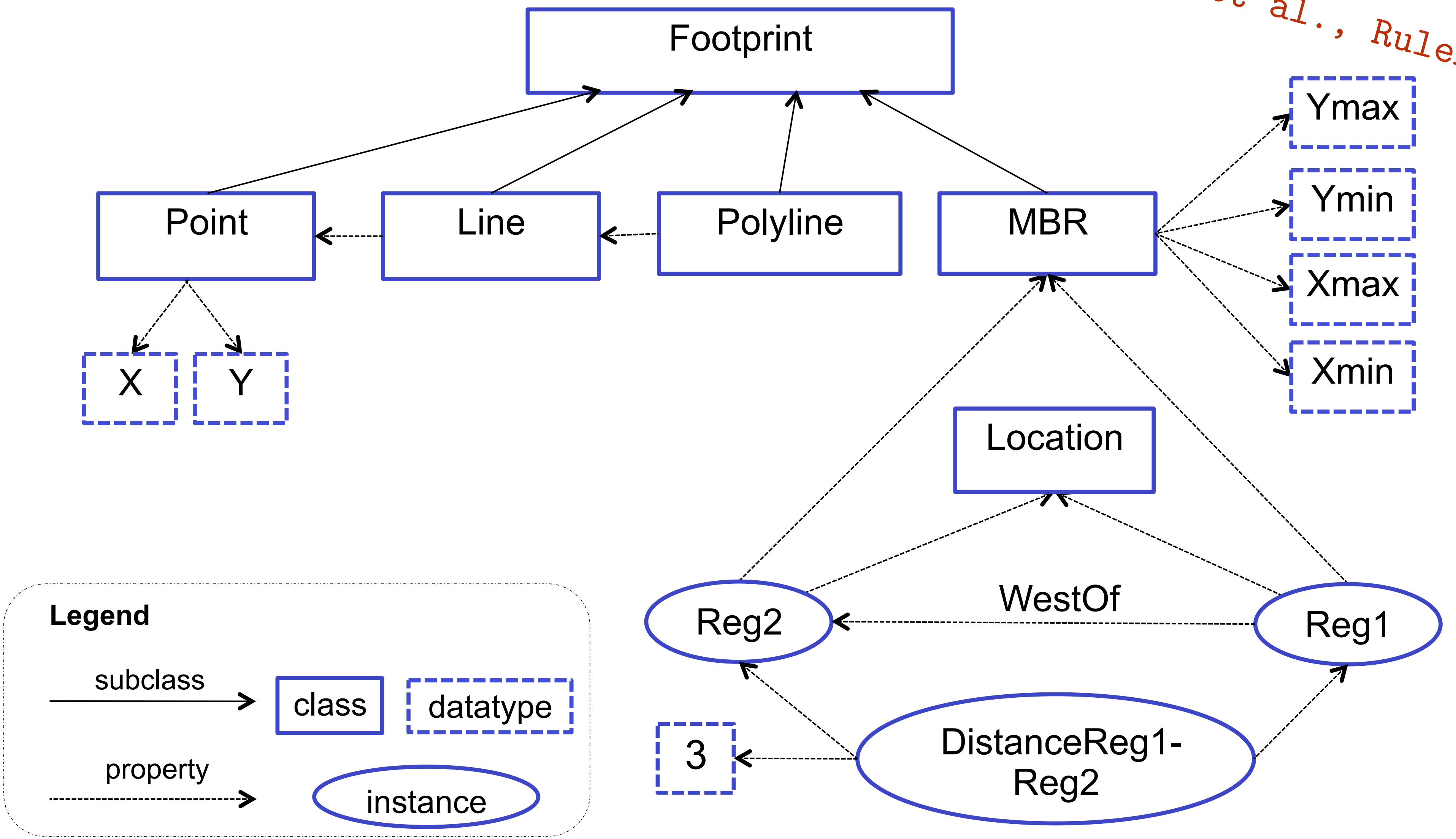
Extension of OWL for the representation of qualitative and quantitative spatial information (SOWL)

- RCC-8
- Directional relations (e.g., East, North-West), and
- Distance relations (e.g., "3Km away from Vienna")

Geospatial information with SWRL rules

Modeling

[Batsakis et al., RuleML'11]



Geospatial information with SWRL rules

[Batsakis et al., RuleML'11]

Spatial assertions

- RCC-8 relations between two regions
- Directional relations between two regions
- Distance relations between two regions
- Geometry of regions (in subclasses of `Footprint`)

Geospatial information with SWRL rules

Implementation of the previous framework using OWL

1. OWL 2 property axioms for expressing inverse, symmetry, and transitivity for spatial relations

[Batsakis et al., RuleML'11]

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2. SWRL rules to
   - encode composition of spatial relations
   - compute the intersection of two sets of spatial relations
   - check spatial consistency (using Pellet)

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$$\mathrm{DC}(\mathrm{X},\mathrm{Z}) \leftarrow \mathrm{NTPP}(\mathrm{X},\mathrm{Y}) \wedge \mathrm{EC}(\mathrm{Y},\mathrm{Z})$$

$$\mathrm{DC\_EC}(\mathrm{X},\mathrm{Z}) \leftarrow \mathrm{EC}(\mathrm{X},\mathrm{Y}) \wedge \mathrm{TPPi}(\mathrm{Y},\mathrm{Z})$$

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   - compute the intersection of two sets of spatial relations

$$\mathrm{NTPP(X, Y)} \leftarrow \mathrm{NTPP\_PO(X, Y)} \wedge \mathrm{DC\_EC\_NTPP(X, Y)}$$

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$$R_s(x,y) \leftarrow R_i(x,y) \cap (R_j(x,k) \circ R_k(k,y))$$

Geospatial information with SWRL rules

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$$R_s(x,y) \leftarrow \boxed{R_i(x,y)} \cap (R_j(x,k) \circ R_k(k,y))$$

Current relation between regions x and y

Geospatial information with SWRL rules

Implementation of the previous framework using OWL

[Batsakis et al., RuleML'11]

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$$R_s(x,y) \leftarrow \boxed{R_i(x,y)} \cap \boxed{(R_j(x,k) \circ R_k(k,y))}$$

Composition of R_j with R_k

Current relation between regions x and y

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   - check spatial consistency (using Pellet)

$$\boxed{R_s(x,y)} \leftarrow \boxed{R_i(x,y)} \cap \boxed{(R_j(x,k) \circ R_k(k,y))}$$

New relation between x and y

Current relation between regions x and y

Composition of R_j with R_k

Geospatial information with SWRL rules

[Batsakis et al., RuleML'11]

- Implementation of SOWL is available at http://www.intelligence.tuc.gr/prototypes.php

Conclusions

- We talked about
  - Geospatial information with description logics and OWL
  - OWL reasoners with geospatial capabilities
  - Geospatial information with SWRL rules
- **Next topic**: conclusions, questions, discussion

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