GeospatialRules: A Datalog^{+} RuleML Rulebase for Geospatial Reasoning

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Outline

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1. Background
2. Development of GeospatialRules
3. Conclusion and Future Work

Datalog$^+$

- Datalog$^+$ extends Datalog with rule heads allowing
    - Existential quantifiers
    - Equality
    - Falsity (for integrity rules)
- A family of decidable sublanguages of Datalog$^+$, Datalog$^\pm$, restricts rule bodies for ontological querying
- Deliberation RuleML 1.01 introduces Relax NG and XSD schemas for Datalog$^+$

Region Connection Calculus (RCC)

- RCC axiomatizes spatial relations between 'regions' in first-order logic
- Primitive binary relation $C(x, y)$: x connects with y
  - Reflexivity and symmetry of $C(x, y)$

$$
\begin{array}{ll}
(1) & \forall x : C(x, x) \\
(2) & \forall x, y : C(y, x) \rightarrow C(x, y)
\end{array}
$$

Defining Axioms of RCC Relations

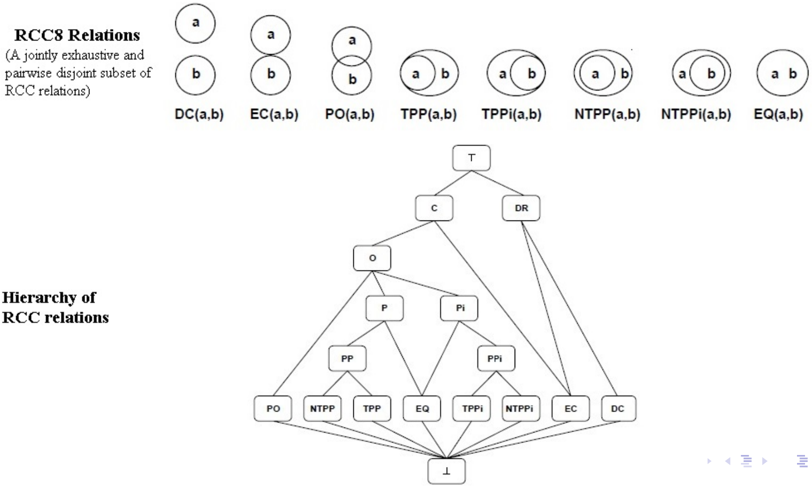
Relation Definition	Meaning
$C(x, y)$ (primitive)	x connects with y
(3) $DC(x, y) \equiv_{def} \neg C(x, y)$	x is disconnected from y
(4) $P(x, y) \equiv_{def} \forall z[C(z, x) \rightarrow C(z, y)]$	x is part of y
(5) $O(x, y) \equiv_{def} \exists z[P(z, x) \wedge P(z, y)]$	x overlaps with y
(6) $DR(x, y) \equiv_{def} \neg O(x, y)$	x is discrete from y
(7) $EC(x, y) \equiv_{def} C(x, y) \wedge DR(x, y)$	x is externally connected to y
(8) $PO(x, y) \equiv_{def} O(x, y) \wedge \neg P(x, y) \wedge \neg P(y, x)$	x partially overlaps with y
(9) $EQ(x, y) \equiv_{def} P(x, y) \wedge P(y, x)$	x is equal to y
(10) $PP(x, y) \equiv_{def} P(x, y) \wedge \neg P(y, x)$	x is a proper part of y
(11) $TPP(x, y) \equiv_{def} PP(x, y) \wedge \exists z[EC(z, x) \wedge EC(z, y)]$	x is a tangential proper part of y
(12) $NTPP(x, y) \equiv_{def} PP(x, y) \wedge \neg\exists z[EC(z, x) \wedge EC(z, y)]$	x is a nontangential proper part of y

Inverses of non-symmetric RCC relations:

$$\Phi i(x, y) \equiv_{def} \Phi(y, x), \Phi \in \{P, PP, TPP, NTPP\}$$

Graphical View of RCC Relations

Figures borrowed from Cohn, A., Bennett, B., Gooday, J., Gotts, N.: Qualitative spatial representation and reasoning with the Region Connection Calculus. GeoInformatica 1(3) (October 1997) 275–316.



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Kinds of GeospatialRules

- Rules
  a) Datalog^{+} fragment of the first-order RCC defining axioms
  b) Additional rules which express part of the RCC knowledge that is not captured by a)
- Facts and Queries (special cases of Rules)

Mapping: RCC Relations $\longleftrightarrow$ GeospatialRules Relations

RCC Relation	GeospatialRules Relation
C	RCCConnected
DC	RCCDisconnected
P	RCCPartOf
O	RCCOverlapped
DR	RCCDiscrete
EC	RCCExternallyConnected
PO	RCCPartiallyOverlapped
EQ	RCCEqual
PP	RCCProperPartOf
TPP	RCCTangentialProperPartOf
NTPP	RCCNonTangentialProperPartOf
Pi	RCCInversePartOf
PPi	RCCInverseProperPartOf
TPPi	RCCInverseTangentialProperPartOf
NTPPi	RCCInverseNonTangentialProperPartOf

Identifying Datalog$^+$ Fragment of RCC Axioms

- Reflexivity and symmetry axioms of C(x, y) are kept unchanged

```
Forall ?X ( RCCConnected(?X ?X) )
Forall ?X ?Y (
  RCCConnected(?Y ?X) :- RCCConnected(?X ?Y)
)
```

- Datalog$^+$ fragment of other axioms is exposed using first-order transformations
  - Split "iff" definitions into two rules expressing "if" and "only if" parts separately
  - Transform each "only if" rule into one or more Datalog$^+$ rules
  - Take note of any "if" rules that cannot be expressed in Datalog$^+$, and transform the remaining ones into Datalog$^+$

Identifying Datalog$^+$ Fragment of RCC – Example

Split defining axiom of TangentialProperPartOf into three rules:

$$
\begin{aligned}
& \mathrm{TPP}(x, y) \equiv_{\mathrm{def}} \mathrm{PP}(x, y) \wedge \exists z[\mathrm{EC}(z, x) \wedge \mathrm{EC}(z, y)] \\
\equiv \quad & (\mathrm{TPP}(x, y) \rightarrow \mathrm{PP}(x, y) \wedge \exists z[\mathrm{EC}(z, x) \wedge \mathrm{EC}(z, y)]) \wedge \\
& (\mathrm{PP}(x, y) \wedge \exists z[\mathrm{EC}(z, x) \wedge \mathrm{EC}(z, y)] \rightarrow \mathrm{TPP}(x, y)) \\
\equiv \quad & (\mathrm{TPP}(x, y) \rightarrow \mathrm{PP}(x, y)) \wedge \\
& (\mathrm{TPP}(x, y) \rightarrow \exists z[\mathrm{EC}(z, x) \wedge \mathrm{EC}(z, y)]) \wedge \\
& (\forall z(\mathrm{PP}(x, y) \wedge \mathrm{EC}(z, x) \wedge \mathrm{EC}(z, y) \rightarrow \mathrm{TPP}(x, y)))
\end{aligned}
$$

Identifying Datalog$^+$ Fragment of RCC – Example

Identify Datalog$^+$ fragment of defining axiom of ProperPartOf:

$$
\begin{aligned}
& \mathrm{PP}(x, y) \equiv_{\text{def}} \mathrm{P}(x, y) \wedge \neg \mathrm{P}(y, x) \\
\equiv \quad & (\mathrm{PP}(x, y) \rightarrow \mathrm{P}(x, y) \wedge \neg \mathrm{P}(y, x)) \\
& \wedge (\mathrm{P}(x, y) \wedge \neg \mathrm{P}(y, x) \rightarrow \mathrm{PP}(x, y)) \\
\equiv \quad & (\mathrm{PP}(x, y) \rightarrow \mathrm{P}(x, y)) \wedge (\mathrm{PP}(x, y) \rightarrow \neg \mathrm{P}(y, x)) \\
& \wedge (\mathrm{P}(x, y) \wedge \neg \mathrm{P}(y, x) \rightarrow \mathrm{PP}(x, y)) \\
\equiv \quad & (\mathrm{PP}(x, y) \rightarrow \mathrm{P}(x, y)) \wedge (\mathrm{PP}(x, y) \wedge \mathrm{P}(y, x) \rightarrow \bot) \\
& \wedge (\mathrm{P}(x, y) \wedge \neg \mathrm{P}(y, x) \rightarrow \mathrm{PP}(x, y))
\end{aligned}
$$

The first two conjuncts, which are within Datalog$^+$ expressivity, are included in GeospatialRules as two rules. These rules express the "only if" part of the axiom. Note that the third conjunct is omitted since it is beyond Datalog$^+$ expressivity.

Additional Rules

- Compensate for a portion of information that is lost when the Datalog^{+} fragment was identified
- Subsumptions between RCC relations, e.g.

```
Forall ?X ?Y (
  RCCConnected(?X ?Y) :- RCCOverlapped(?X ?Y)
)
```

- Rules from the RCC8 composition table, e.g.

```
Forall ?X ?Y ?Z (
  RCCNonTangentialProperPartOf(?X ?Z) :-
    And(RCCPartOf(?X ?Y)
        RCCNonTangentialProperPartOf(?Y ?Z))
)
```

Facts

- Describe geospatial relationships among regions in North America, as well as the Pacific and the Atlantic oceans

```
RCCProperPartOf(USA NorthAmerica)
Ocean(Pacific)
Ocean(Atlantic)
State(California)
RCCProperPartOf(California USA)
RCCExternallyConnected(Pacific USA)
RCCExternallyConnected(Pacific California)
State(Virginia)
RCCProperPartOf(Virginia USA)
RCCExternallyConnected(Atlantic USA)
RCCExternallyConnected(Atlantic Virginia)
```

Sample Query

English Query: "*Which states [in the rulebase] are tangential proper parts of the USA*?"

GeospatialRules Query:

```
And(State(?St) RCCTangentialProperPartOf(?St USA))
```

Answer: `?St=California, ?St=Virginia`

Rule applied:

```
Forall ?X ?Y ?Z (
  RCCTangentialProperPartOf(?X ?Y) :-
    And(RCCProperPartOf(?X ?Y)
        RCCExternallyConnected(?Z ?X)
        RCCExternallyConnected(?Z ?Y))
)
```

RuleML/XML Version of GeospatialRules

- GeospatialRules rulebase (42 rules, 11 facts, 3 queries) available online
  `http://deliberation.ruleml.org/1.01/exa/RulebaseCompetition2014/GeospatialRulesRCC.ruleml`
- Can be validated against Deliberation RuleML 1.01 Relax NG schema (Relaxed Serialization for Datalog$^+$)
  `http://deliberation.ruleml.org/1.01/relaxng/datalogplus_min_relaxed.rnc`
- Can be normalized and validated against Deliberation RuleML 1.01 XSD schema for Datalog$^+$
  `http://deliberation.ruleml.org/1.01/xsd/datalogplus_min_normal.xsd`
- Mathematical English definitions of each RCC relation are included as comments

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Conclusion

- We developed a Datalog$^+$ rulebase, GeospatialRules, which can be used in geospatial applications for reasoning with RCC relations (e.g., in RCC8)
- GeospatialRules consists of rules, facts, and queries
- Subsumptions between RCC relations are preserved in GeospatialRules
- An XML version of GeospatialRules complying to the Deliberation RuleML 1.01 standard is provided
- Demo available online
  `http://wiki.ruleml.org/index.php/GeospatialRules_Demo`

Future Work

- Create new GeospatialRules versions for graph queries
  - Represent regions by globally unique object identifiers
  - Use graph versions of binary RCC relations as slot names
  - Express transformation from relational to graph version of RCC as rules in PSOA RuleML
  - Create new versions of GeospatialRules
    - Mediator-style: Extend rulebase with transformation rules from relational to graph schema
    - Warehouse-style: Convert rulebase into a pure graph version using transformation rules
- Compare GeospatialRules versions using PSOA RuleML implementation based on PSOA2Prolog
  - Mediator-Warehouse trade-off
  - Readability assessment (collaboration with geospatial experts)
  - Efficiency exploration (translation and execution times, memory requirements)