Querying Incomplete Geospatial Information in RDF

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Motivation

- Increased interest in publishing geospatial datasets as **linked data** (i.e., encoded in RDF and with semantic links to other datasets)

- Geospatial information might be:
  - Quantitative (e.g., exact geometric information)
  - Qualitative (e.g., topological relations)

  ... and express **knowledge** that is

  - Complete
  - Incomplete (or indefinite)

Ordnance Survey (UK)

SO16 0AS

SO16 0AS is a Postcode Unit.

Objects related to "SO16 0AS"

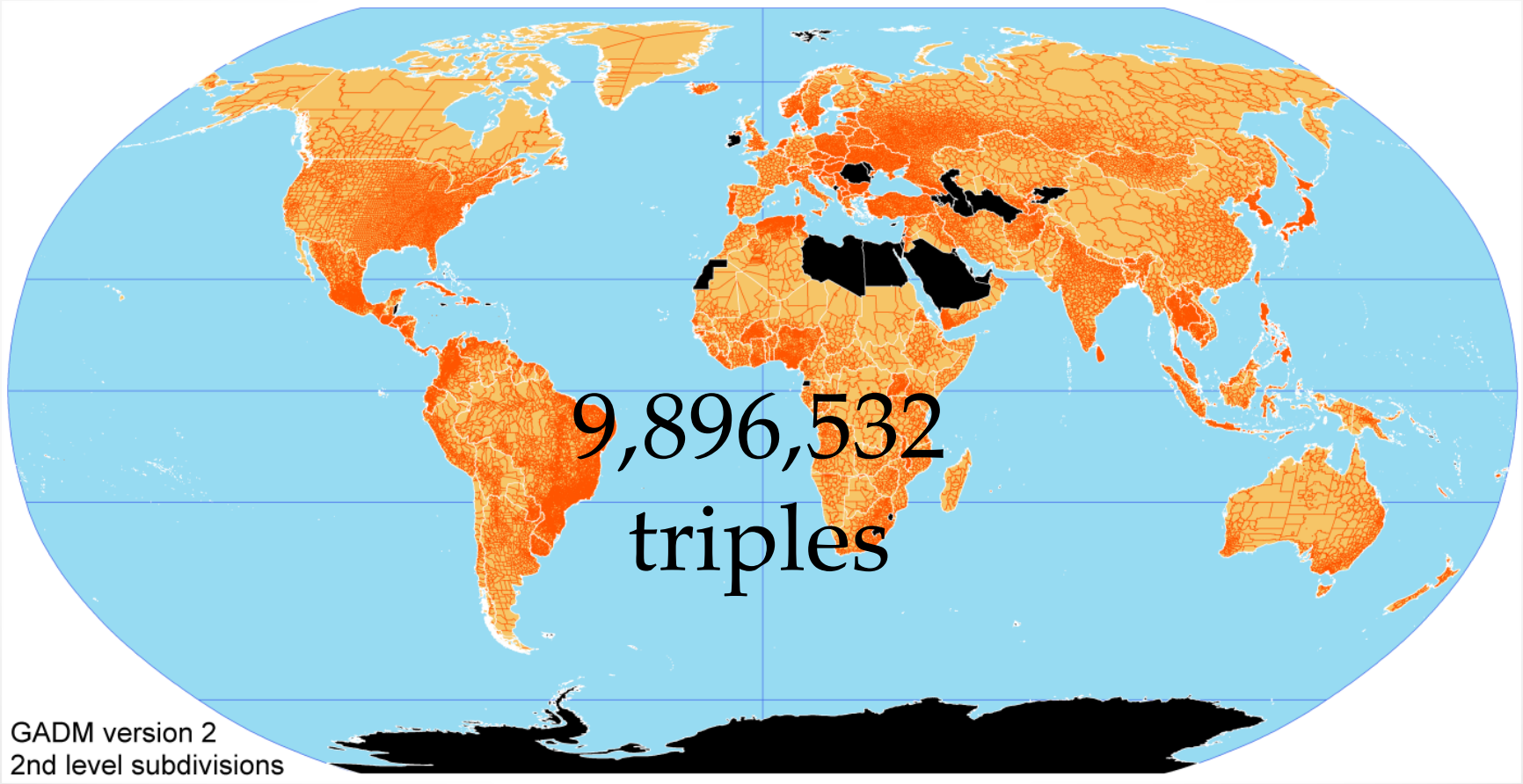
County	Hampshire
Within	SO16 0 SO SO16
NhsHA	E18000009
Nhs RegionalHA	E19000002
Positional Quality Indicator	10

73,546,231 triples

Core facts about "SO16 0AS"

Type	Postcode Unit
Label	SO16 0AS
Northing	115515.00
Easting	437293.00
Lat	50.937872
Long	-1.470616
LH	E18000009
Notation	SO16 0AS

Global Administrative Areas (GADM)



Nomenclature of Territorial Units for Statistics (NUTS)

Home

LV00 - Latvija

This file is a human-readable representation of both the feature and its geometry.

View the feature as: Turtle, RDF/XML

View the geometry as: Turtle, RDF/XML, GML, KML

Feature

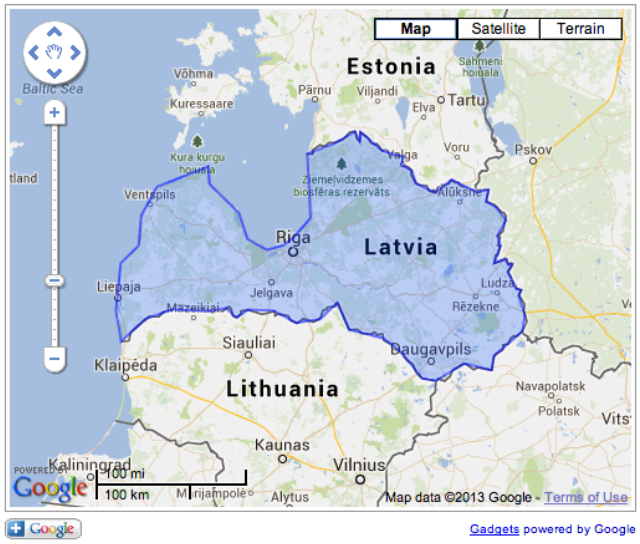
rdf:type	ramon:NUTSRegion, spatial:Feature
rdfs:label	LV00 - Latvija
ramon:name	Latvija
ramon:level	2
ramon:code	LV00
ngeo:geometry	nuts:LV00_geometry
spatial:PP	LV0
spatial:PPi	http://dbpedia.org/resource/Daugavpils
spatial:EC	http://nuts.geovocab.org/id/EE
spatial:EC	http://nuts.geovocab.org/id/LT
spatial:EC	http://nuts.geovocab.org/id/EE0
spatial:EC	http://nuts.geovocab.org/id/LT0
spatial:EC	http://nuts.geovocab.org/id/EE00
spatial:EC	http://nuts.geovocab.org/id/LT00
spatial:EC	http://nuts.geovocab.org/id/EE004
spatial:EC	http://nuts.geovocab.org/id/LT005
spatial:EC	http://nuts.geovocab.org/id/LT006
spatial:EC	http://nuts.geovocab.org/id/LT003
spatial:EC	http://nuts.geovocab.org/id/LT008
spatial:EC	http://nuts.geovocab.org/id/LT009
spatial:EC	http://nuts.geovocab.org/id/EE008
owl:sameAs	http://estatwrap.ontologycentral.com/dic/geo#LV00
owl:sameAs	http://rdfdata.eionet.europa.eu/ramon/nuts2008/LV00
owl:sameAs	http://ec.europa.eu/eurostat/ramon/rdfdata/nuts2008/LV00
owl:sameAs	http://nuts.psi.enakting.org/id/LV00

Geometry

rdf:type	ngeo:Polygon

316,246 triples

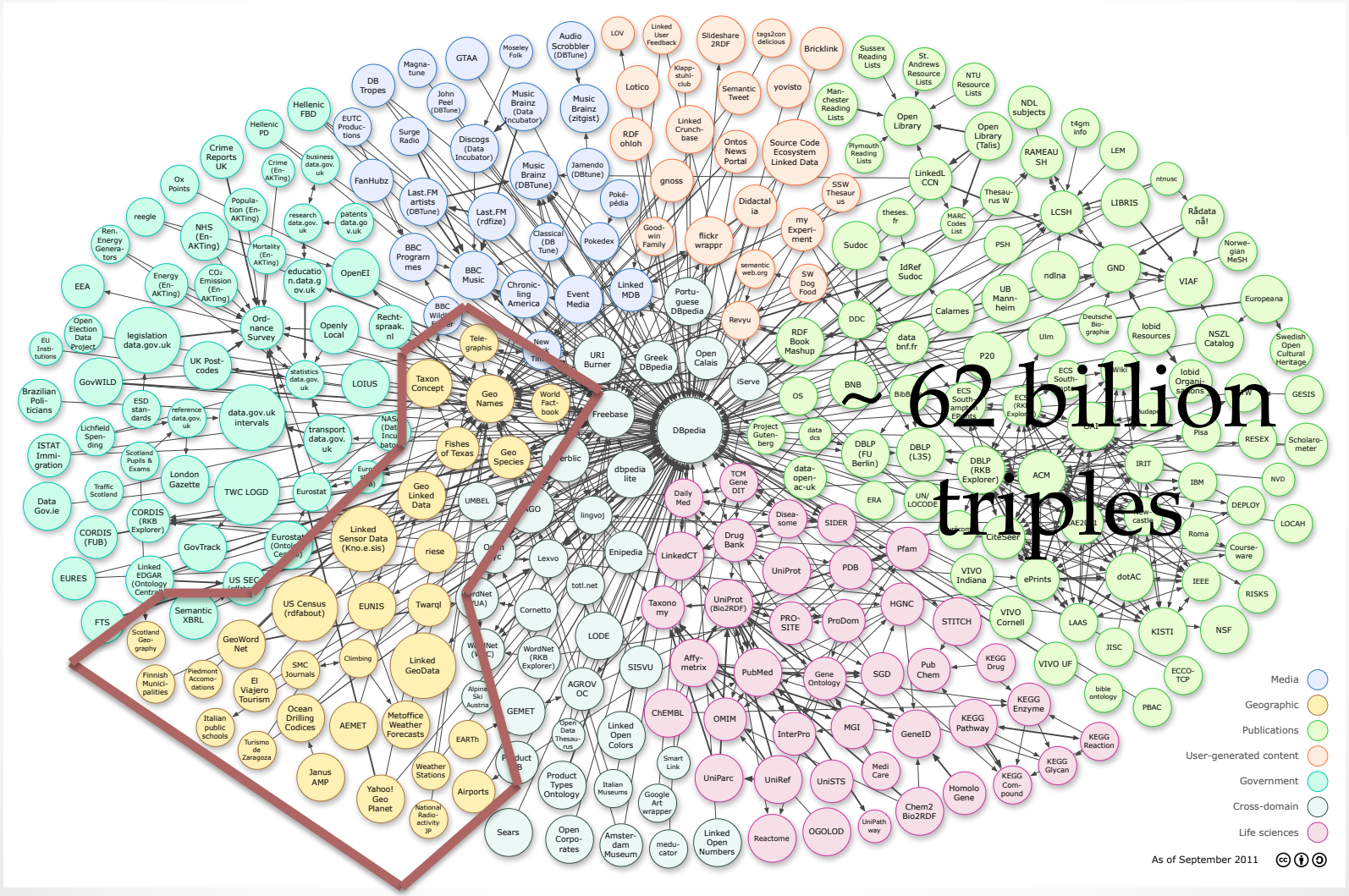
Embedded KML Viewer



Google

Gadgets powered by Google

Linked Geospatial Data



Question

How do we **manage** (represent, store, query) this data efficiently?

Challenges: Theory

① RDF extensions for **representing** and **querying** incomplete qualitative and quantitative geospatial information

- **GeoSPARQL**
  - Standard OGC query language for RDF data with geospatial information
  - Topological relations can be **expressed/queried**, but no reasoning is offered.

- We proposed **RDF^i**
  - Can work with any topological/temporal constraint language with/ without constant symbols (e.g., RCC-5, RCC-8, IA)
  - Formal semantics and algorithm for computing certain answers
  - Preliminary complexity results for various constraint languages

Open issue

- **No** published algorithm for query processing when considering RCC-8 **and** constants

RDF^{i} by example


```
gag:Region          rdfs:subClassOf geo:Feature.
gag:WestGreece      rdf:type gag:Region.
gag:Municipality    rdfs:subClassOf geo:Feature.

gag:OlympiaMuni     rdf:type gag:Municipality.

noa:Hotspot         rdfs:subClassOf geo:Feature.
noa:hotspot         rdf:type noa:Hospot.

noa:Fire            rdfs:subClassOf geo:Feature.
noa:fire            rdf:type noa:Fire.
```

```
gag:OlympiaMuni geo:hasGeometry ex:oGeo.
ex:oGeo rdf:type sf:Polygon.
ex:oGeo geo:asWKT "POLYGON((..))"^^geo:wktLiteral.

noa:hotspot geo:hasGeometry ex:rec.
ex:rec geo:asWKT "POLYGON((..))"^^geo:wktLiteral.

gag:WestGreece geo:sfContains gag:OlympiaMuni.
   noa:hotspot geo:sfContains noa:fire.
```

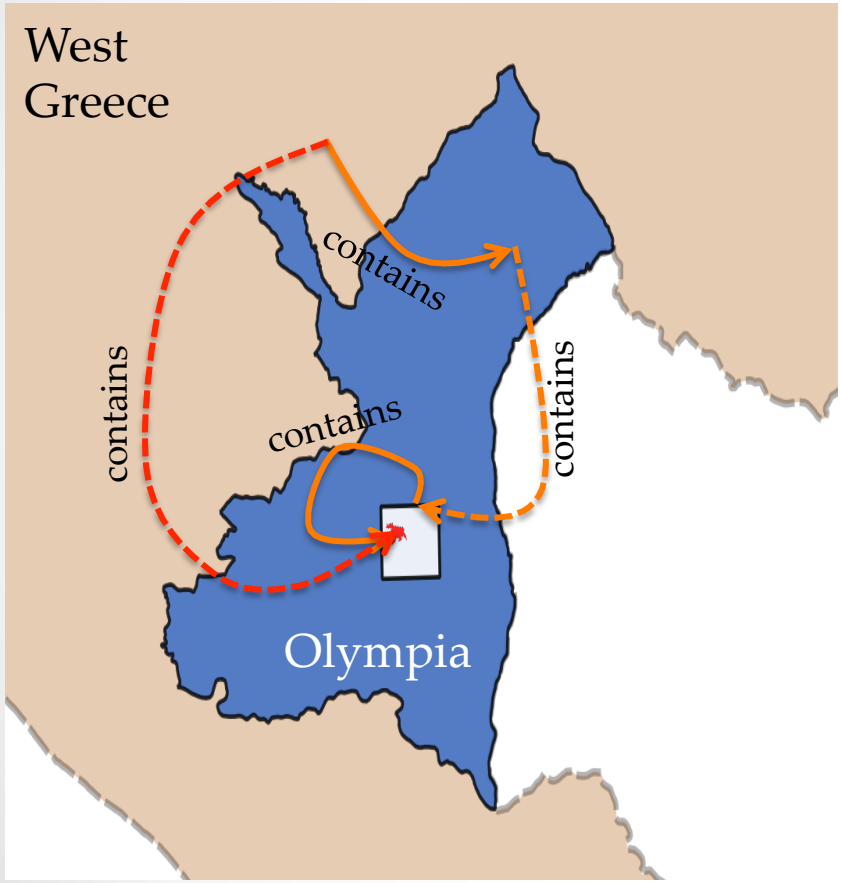
RDF^{i} by example (cont'd)

Query: Find fires inside the region of West Greece.

GeoSPARQL query:

```
CERTAIN SELECT ?f
WHERE {
   ?f rdf:type noa:Fire.
   gag:WestGreece geo:sfContains ?f.
}
```

RDF^{i} by example (cont'd)



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}
```

Challenges: Theory

② Efficient computation of the entailment relation

$$\Phi \models \Theta$$

- where Φ and Θ are quantifier-free first-order formulas of a constraint language expressing the **topological relations** of various frameworks (RCC-8, DE-9IM, etc.)

Challenges: Theory

③ Computing entailment **is equivalent to** checking consistency of formulas with constraint networks

- Constraint networks:
  - Spatial relations among regions
  - Regions might be **constant** ones (exact geometric information) or identified by a **URI**

- Most recent results considered **basic** and **complete** **RCC-5** networks with **polygonal** regions

Open issue

- For **RCC-8**, deciding consistency is NP-complete
- No published **algorithm** for checking consistency
- Are there **tractable cases**?

Challenges: Practice

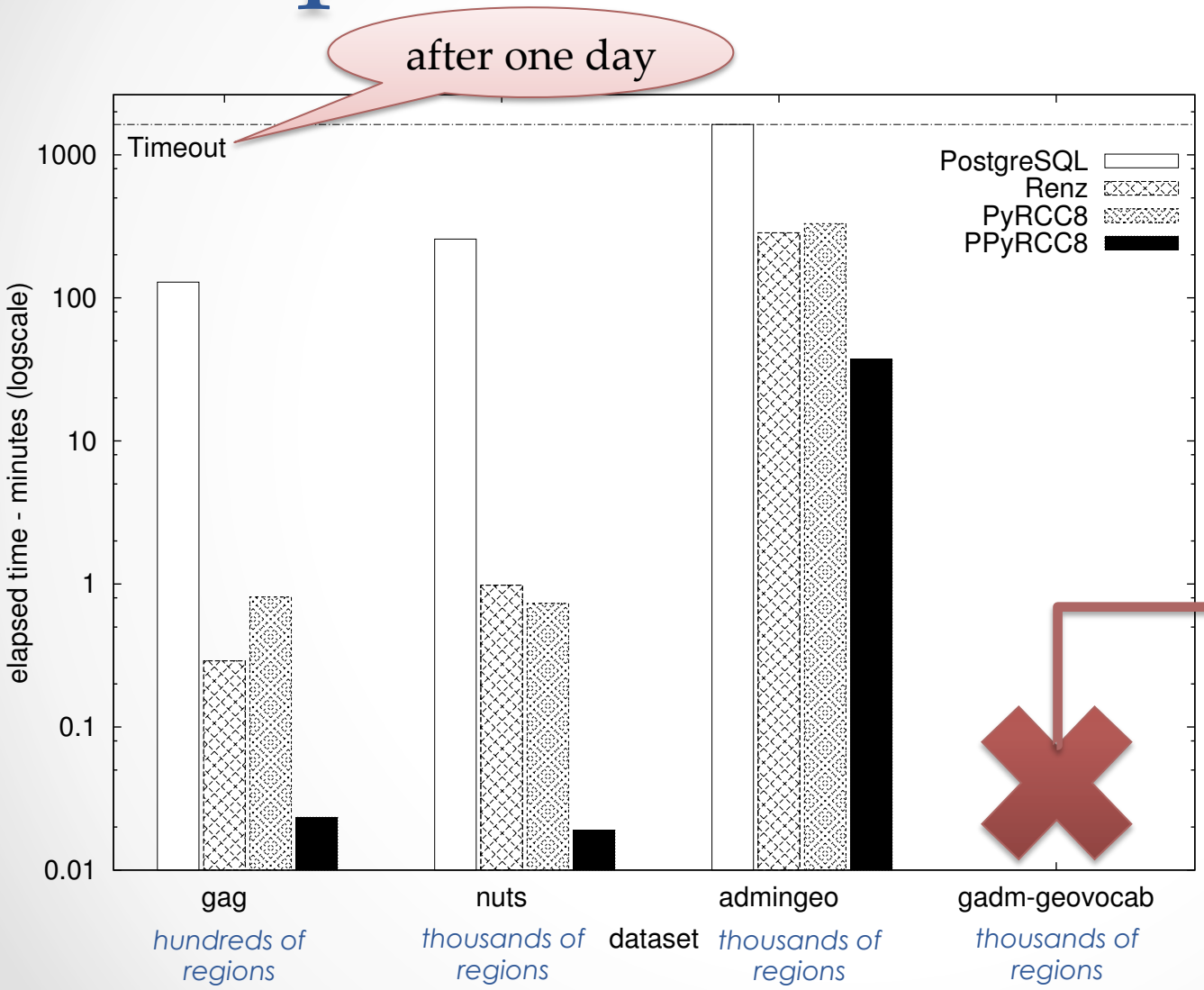
④ Scale to billions of triples

- Reasoners from QSR scale **only up to** hundreds of regions with complex spatial relations

How do they perform in our case?

- Setting:
  - Real linked geospatial datasets
  - No constants
  - Only base RCC-8 relations
  - Evaluation of **consistency checking** using the well-known path-consistency algorithm

Experimental evaluation



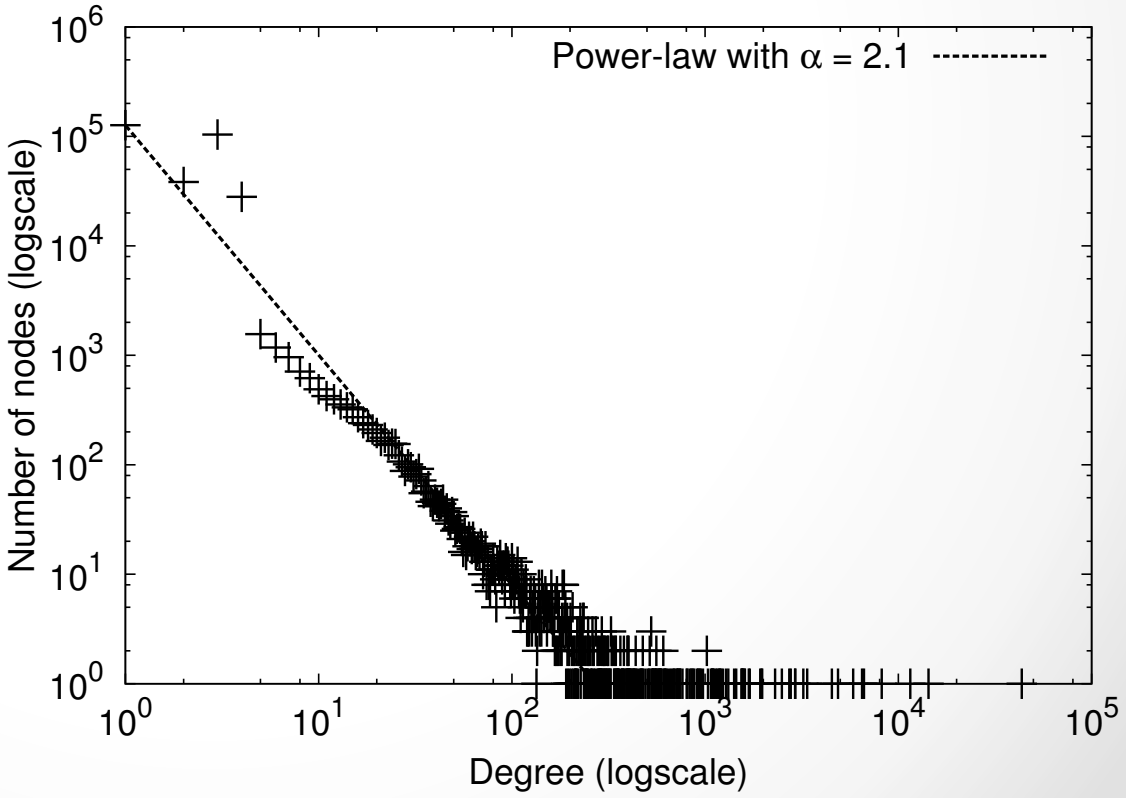
- Computation of the **complete** constraint network
- Running time: $O(n^3)$
- Memory requirements: **$O(n^2)$**

n ≈ thousands to millions

Setup: Intel Xeon E5620, 2.4 GHz, 12MB L3, 48GB RAM, RAID 5, Ubuntu 12.04

Network structure

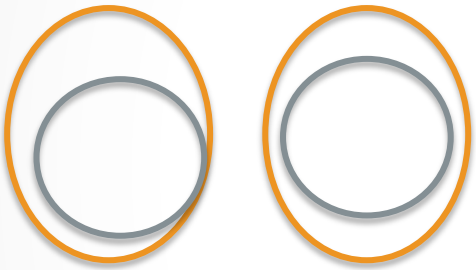
- We have started working on algorithms taking into account the structure of these networks:
  - **Node degrees** fit a power-law distribution
  - Network is sparse



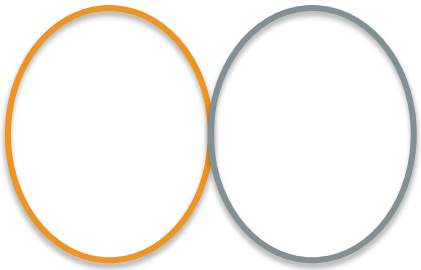
Network structure (cont'd)

- Edges of three kinds:

non-tangential proper part



externally connected



equals

- Reflect networks composed of components with hierarchical structure
  - R-tree extensions (Papadias, Kalnis, Mamoulis, AAAI'99)
- Parallel algorithms combined with backward-chaining techniques for lazy query processing
  - Graph partitioning
  - Path compression data structures and indexes

Related work: Spatial

- Qualitative spatial reasoning
  - Efficient algorithms for **consistency checking** of constraint networks (**complex** spatial relations, **few** number of regions)
  - Does not consider **query processing**

- Description logic reasoners
  - **PelletSpatial**: RCC-8 reasoning (cannot handle disjunctions)
  - **RacerPro**: RCC-8 reasoning

Related work: Temporal

- Chaudhuri (VLDB'88)
- The knowledge representation language Telos (TOIS'90)
- Foundations of temporal constraint databases (Koubarakis, PhD thesis, '94)
- Qualitative temporal reasoning community (since 80s)
- SQL+i system (BNCOD'96)
- Later system (IEEE'97)
- Hurtado and Vaisman (2006)

Conclusions

- What's the **CHALLENGE**?

Implementing an **efficient** query processing system for incomplete geospatial information in RDF[i]

- **The desired system** should:
  - **reason** about **qualitative** and **quantitative** spatial information that might be **incomplete**
  - be **scalable** to **billions** of triples in the most useful cases

Thank you

Dataset characteristics

Dataset	#triples	#regions	#RCC-8 relations
ADMGB	149 046	11 762	77 907
GAG	11 780	412	3023
NUTS-RDF	316 246	2236	3176
GADM-RDF	9 896 532	276 728	590 445
GADM-RDF-EUROPE	355 656	23 037	51 309