Ontologies in a Data-driven World

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Textbook

Pascal Hitzler, Markus Krötzsch, Sebastian Rudolph

Foundations of Semantic Web Technologies

Chapman & Hall/CRC, 2010

Choice Magazine Outstanding Academic Title 2010 (one out of seven in Information & Computer Science)

http://www.semantic-web-book.org

Foundations of **Semantic Web** Technologies

Pascal Hitzler
Markus Krötzsch
Sebastian Rudolph

WRIGHT STATE UNIVERSITY

Pascal Hitzler, Markus Krötzsch, Sebastian Rudolph

语义**Web**技术基础

Tsinghua University Press (清华大学出版社), 2013.

Translators:

Yong Yu, Haofeng Wang, Guilin Qi (俞勇，王昊奋，漆桂林)

http://www.semantic-web-book.org

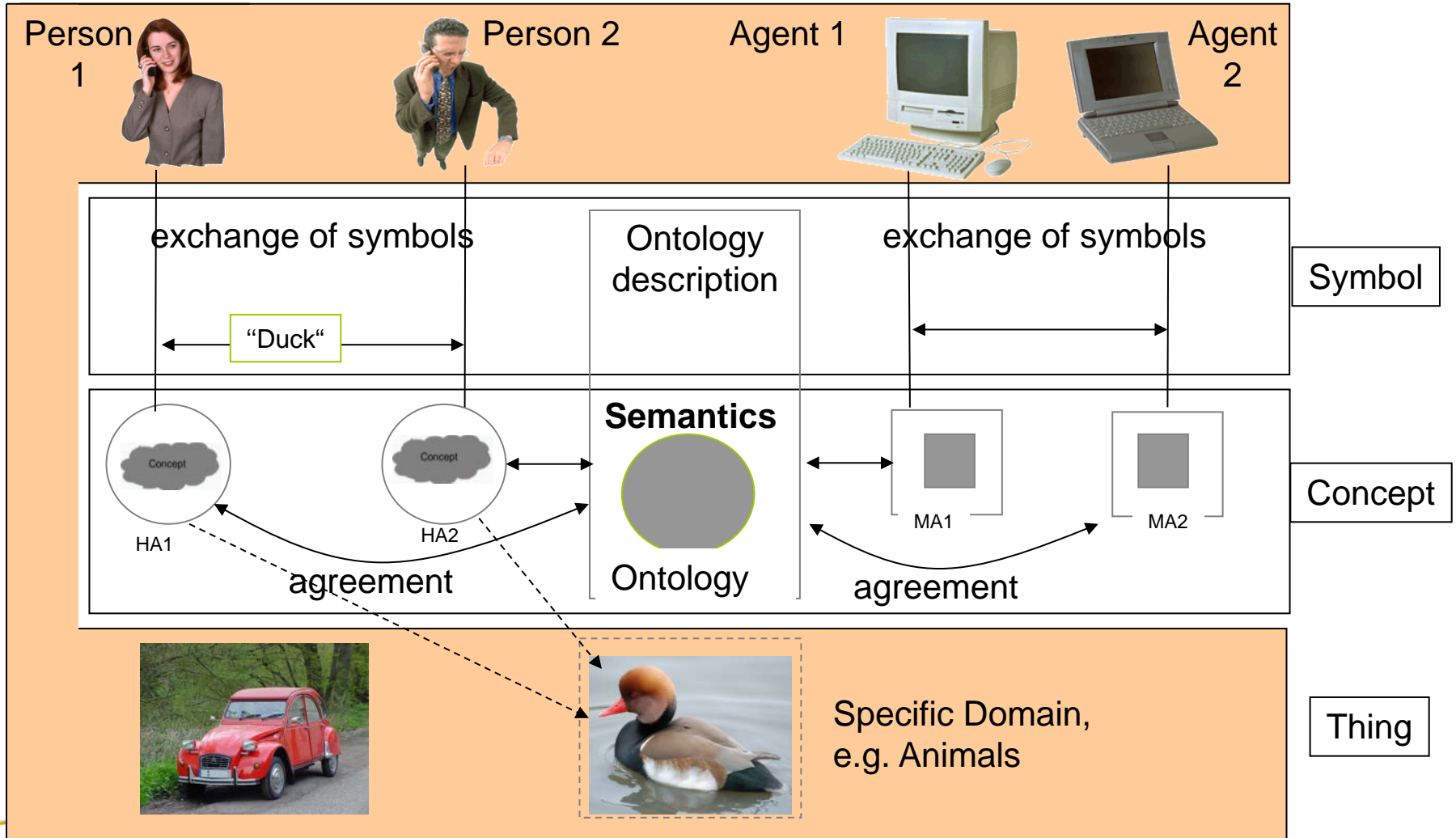# Semantic Web journal

- **EiCs:**   **Pascal Hitzler**
                        Krzysztof Janowicz

- **New journal with significant uptake.**

- **We very much welcome contributions at the "rim" of traditional Semantic Web research – e.g., work which is strongly inspired by a different field.**

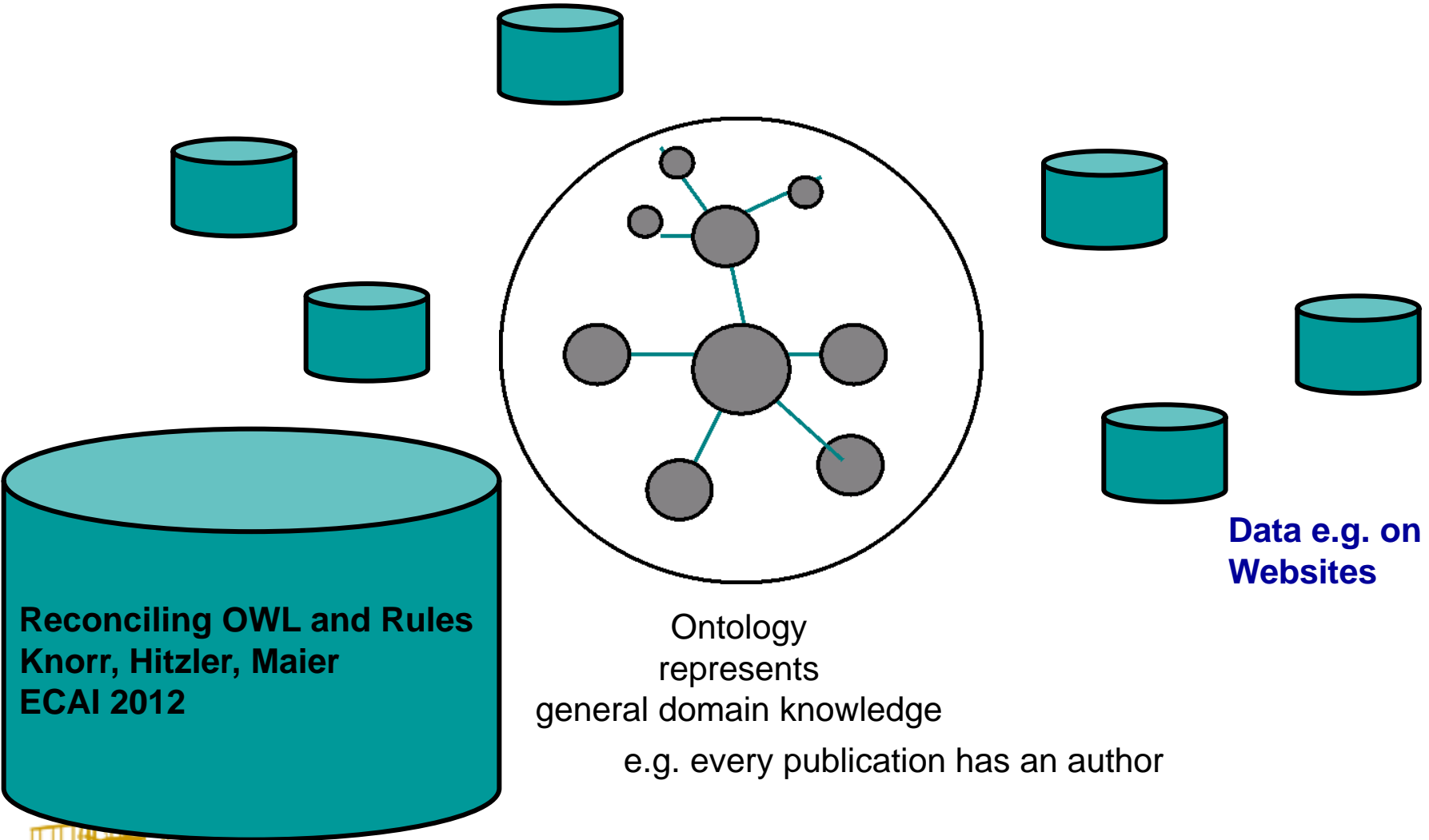- **Non-standard (open & transparent) review process.**

- **http://www.semantic-web-journal.net/**
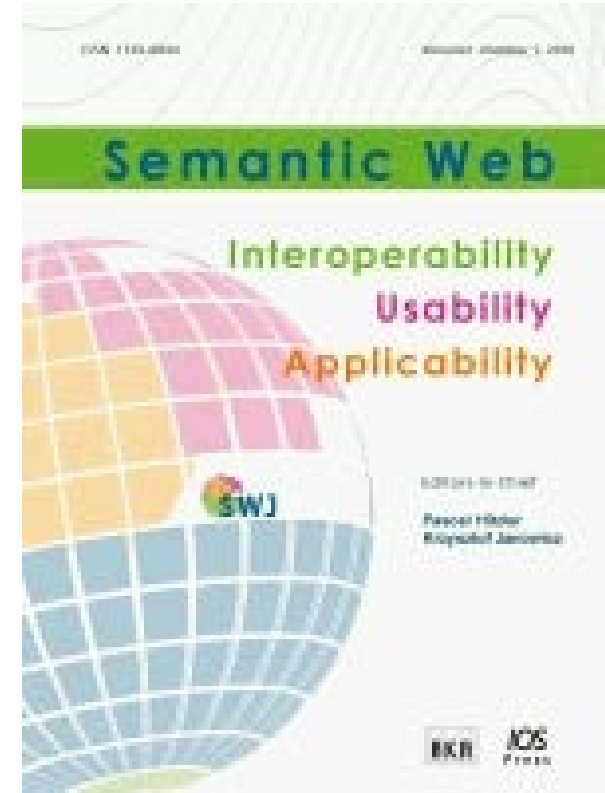
Ontologies?

A Basic Idea of the Semantic Web

Person 1   Person 2   Agent 1   Agent 2

exchange of symbols   Ontology description   exchange of symbols   **Symbol**

"Duck"

Semantics   **Concept**

Concept — HA1   Concept — HA2   Ontology   MA1   MA2

agreement   agreement

Specific Domain, e.g. Animals   **Thing**

A Basic Idea of the Semantic Web

Reconciling OWL and Rules
Knorr, Hitzler, Maier
ECAI 2012

Ontology
represents
general domain knowledge

e.g. every publication has an author

Data e.g. on Websites

A Basic Idea of the Semantic Web

DaSe Lab

Title
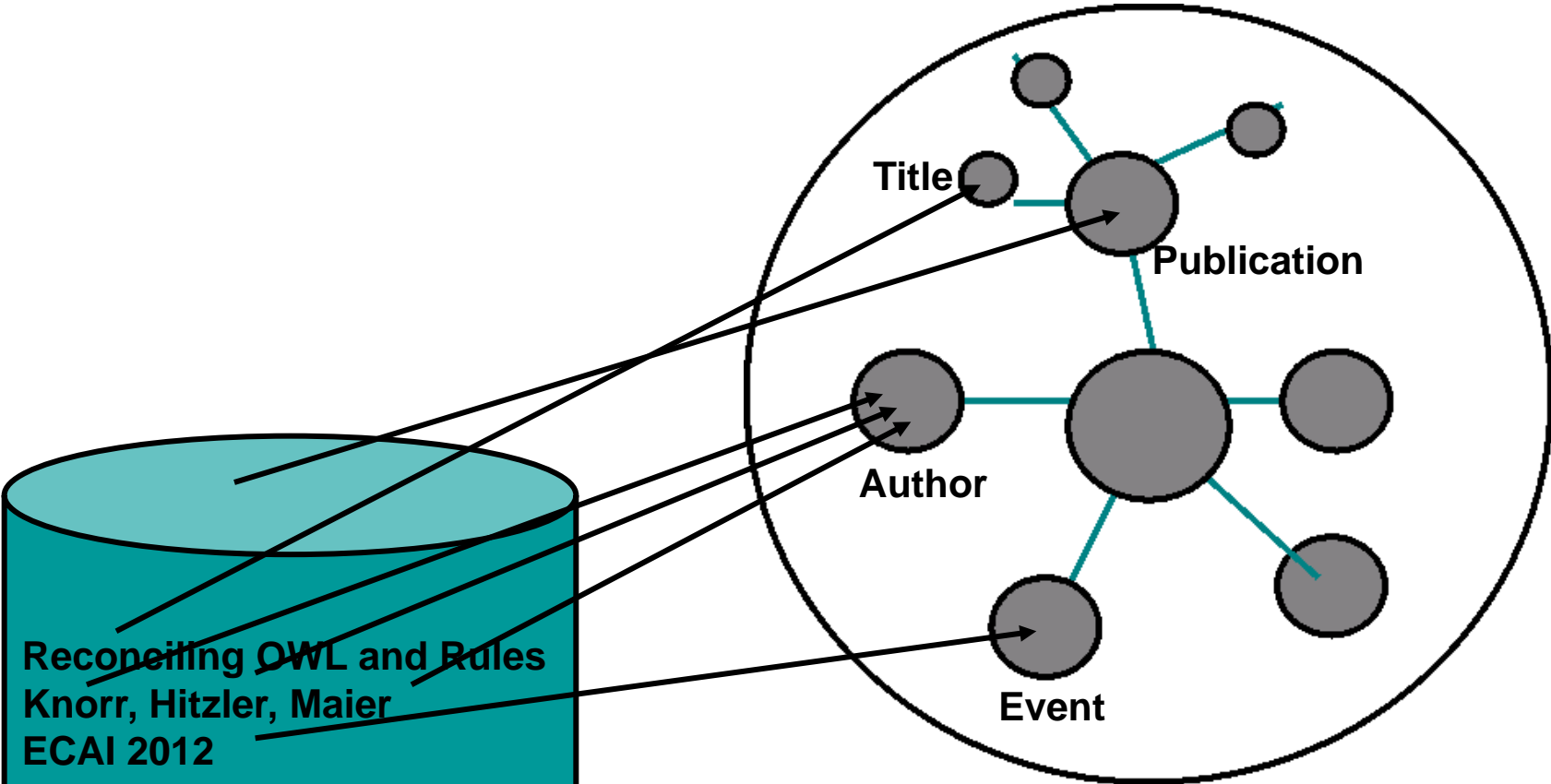
Publication

Author

Reconciling OWL and Rules
Knorr, Hitzler, Maier
ECAI 2012

Event

e.g. every publication has an author

WRIGHT STATE
UNIVERSITY

A Basic Idea of the Semantic Web

Reconciling OWL and Rules
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Ontology
represents
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Data e.g. on Websites

The ontology hype
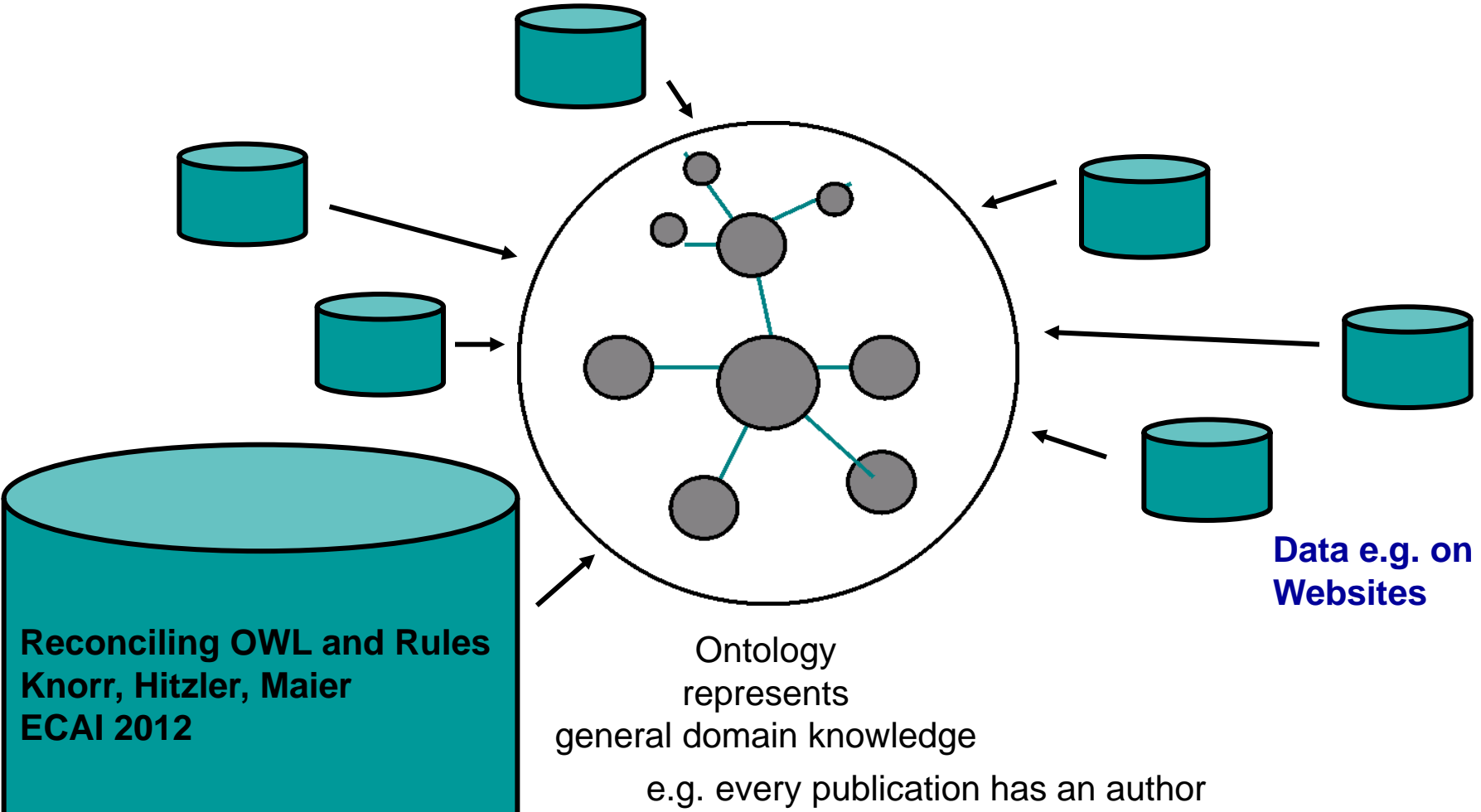
- **Large, well-thought-out ontologies (foundational/domain/etc).**
- **Networked, interlinked ontologies**

- **"You just have to get your formal definitions right, and a lot of the rest will just fall into place."**

- **"You just have to get your formal definitions right, and a lot of the rest will just fall into place."**

  - **This does not even work for**
    - **scientists**
    - **wanting to share and reuse scientific data**
    - **through well-kept data repositories**

  - **So how is this supposed to work for the web at large?**

Multiple perspectives

- **Try to find a universal definition for**
  - **Forest**
  - **Mountain**
  - **City**
  - **River**

  - **Etc.**

- **The stronger our ontological commitments, the more we loose reusability.**

- **We need to accept that conceptualizations are often very local, resulting in "micro-ontologies".**

$$a\text{:flowsInto} \sqsubseteq a\text{:IsConnected} \quad (1)$$

$$a\text{:IrrigationCanal} \sqsubseteq a\text{:Canal} \quad (2)$$

$$\exists a\text{:flowsInto}.a\text{:AgriculturalField} \sqsubseteq a\text{:IrrigationCanal} \quad (3)$$

$$a\text{:Waterbody} \sqcap a\text{:Land} \sqsubseteq \bot \quad (4)$$

$$a\text{:AgriculturalField} \sqsubseteq a\text{:Land} \quad (5)$$

$$b\text{:flowsInto} \sqsubseteq b\text{:IsConnected} \quad (6)$$

$$b\text{:Canal} \sqsubseteq (\geq 2\ b\text{:IsConnected}.b\text{:Waterbody}) \quad (7)$$

$$b\text{:IrrigationCanal} \equiv (=1\ b\text{:isConnected}.b\text{:Waterbody})$$

$$\sqcap (=1\ b\text{:flowsInto}.b\text{:AgriculturalField}) \quad (8)$$

Two ontologies.

Left: transportation domain

Right: agriculture domain

We cannot simply equate a:Canal and b:Canal !

The well-done ontologies

- **Brittle**
- **Expensive**
- **Sometimes unintuitive**
- **Unwieldy**
- **Single-perspective**
- **Difficult to reuse**

- **Work in some contexts.**
- **Work if a lot of central control is imposed.**
- **Take a lot of manpower.**

- **Foundational ontologies**
- **Networked ontologies**
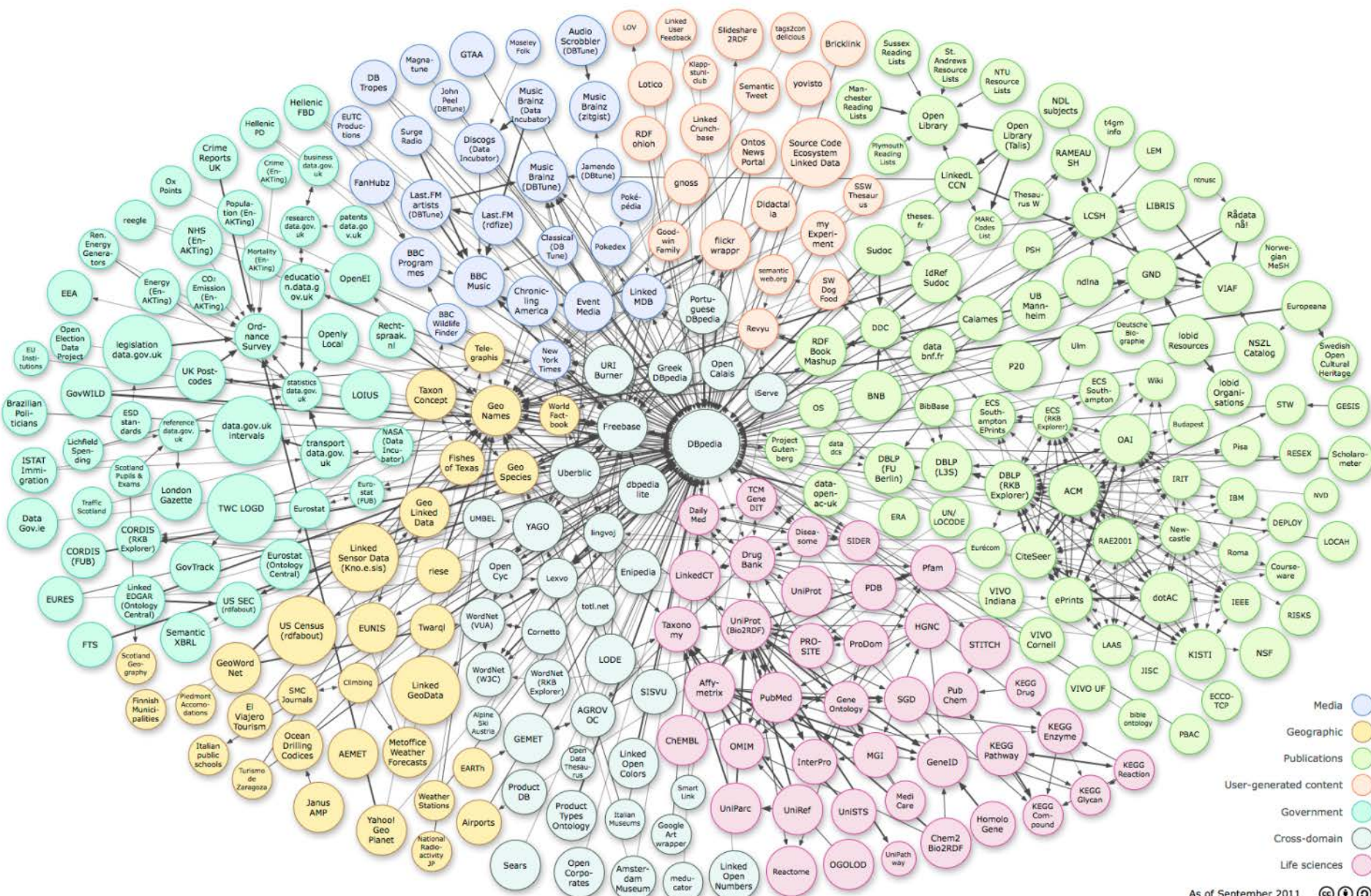- **Sophisticated ontology languages**

Scientific Hypothesis:

These will solve your data and information management problems

Remember that scientific progress is fundamentally about falsification, not verification ☺

Linked Data?

The linked data counter-hype

- **"Ontologies don't work, let's just link data"**

- **"Okay, with a little bit of ontologies on top."**

- **"The Linked Data Web is the true Semantic Web."**

As of September 2011

DBpedia: LOTR page

dbpedia-owl:thumbnail	• http://upload.wikimedia.org/wikipedia/commons/thumb/6/62/Jrrt_lotr_cover_design.jpg/200px-Jrrt_lotr_cover_design.jpg
dbpedia-owl:wikiPageExternalLink	• http://lotr.wikia.com • http://www.glyphweb.com/arda/ • http://www.tolkienlibrary.com/ • http://www.tolkien.co.uk/ • http://www.houghtonmifflinbooks.com/features/lordoftheringstrilogy/
dbpprop:author	• dbpedia:J._R._R._Tolkien
dbpprop:books	• dbpedia:The_Two_Towers • dbpedia:The_Return_of_the_King • dbpedia:The_Fellowship_of_the_Ring • "Volumes:"
dbpprop:country	• England
dbpprop:expiry	• 20 (xsd:integer)
dbpprop:genre	• dbpedia:Adventure_novel • dbpedia:High_fantasy
dbpprop:hasPhotoCollection	• http://www4.wiwiss.fu-berlin.de/flickrwrappr/photos/The_Lord_of_the_Rings
dbpprop:imageCaption	• Tolkien's own cover designs for the three volumes
dbpprop:language	• English
dbpprop:mediaType	• Print
dbpprop:name	• The Lord of the Rings
dbpprop:pages	• 1216 (xsd:integer)
dbpprop:precededBy	• dbpedia:The_Hobbit
dbpprop:pubDate	• 21 (xsd:integer)
dbpprop:publisher	• dbpedia:Allen_&_Unwin
dbpprop:small	• yes
dbpprop:wikiPageUsesTemplate	• dbpedia:Template:Infobox_book_series • dbpedia:Template:Pp-vandalism
dcterms:subject	• category:Monomyths • category:High_fantasy_novels • category:Middle-earth_books • category:British_fantasy_novels • category:Fantasy_books_by_series • category:1950s_fantasy_novels • category:Sequel_novels • category:The_Lord_of_the_Rings • category:English_novels

Information as RDF graph

LOTR   hasAuthor   Tolkien .
Hobbit hasAuthor   Tolkien .
LOTR   hasCharacter   Bilbo .
Hobbit hasCharacter   Bilbo .

Hobbit

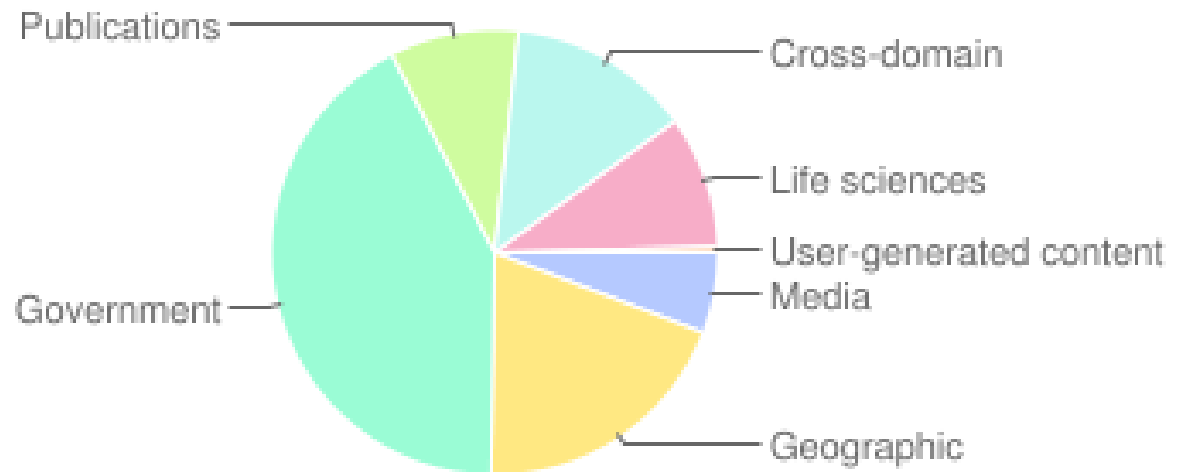Tolkien

hasAuthor

hasAuthor

hasCharacter

LOTR

hasCharacter

Bilbo
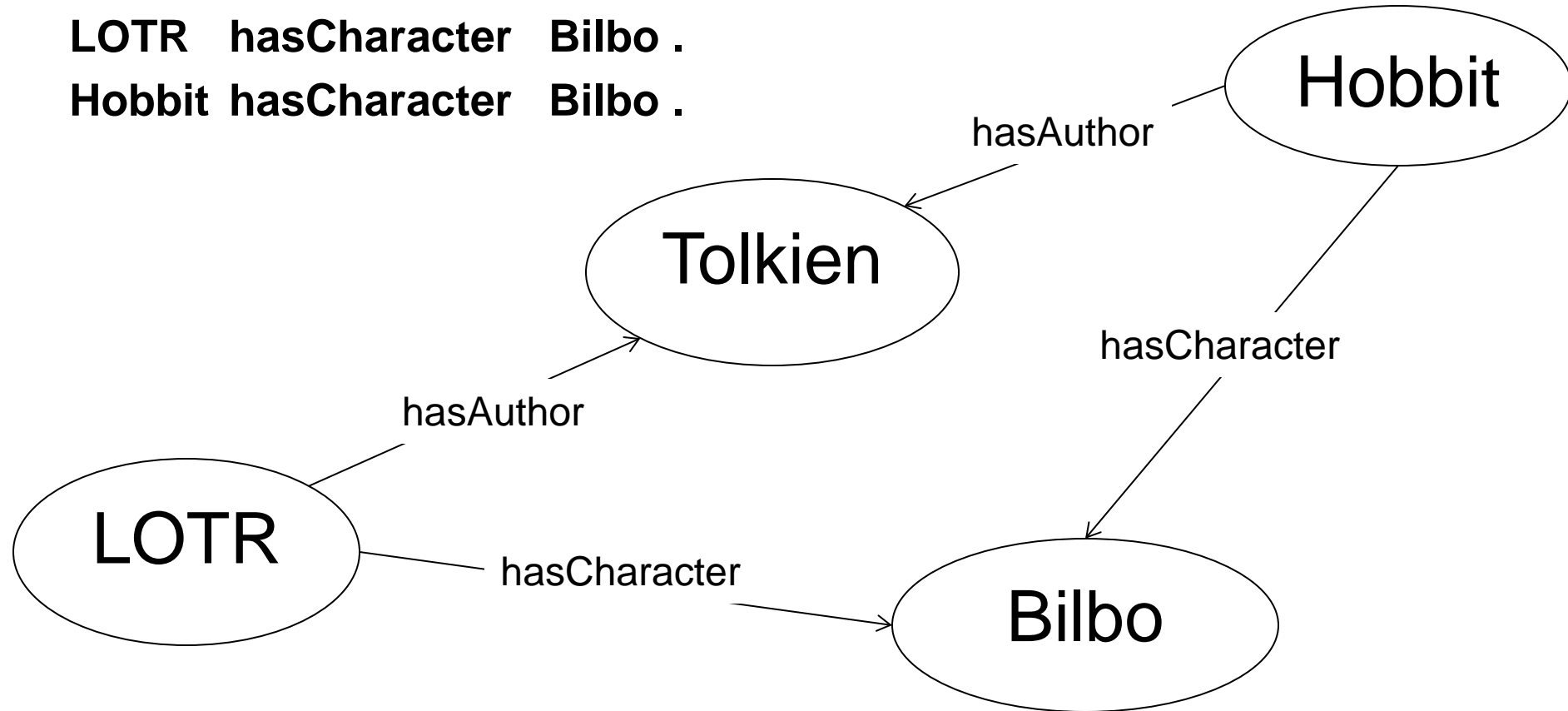
Linked Data: Volume

Number of Datasets

2011-09-19	**295**
2010-09-22	**203**
2009-07-14	**95**
2008-09-18	**45**
2007-10-08	**25**
2007-05-01	**12**

Number of triples (Sept 2011)

31,634,213,770

with 503,998,829 out-links

From http://www4.wiwiss.fu-berlin.de/lodcloud/state/

Geoindexed Linked Data – courtesy of Krzysztof Janowicz

http://stko.geog.ucsb.edu/location_linked_data
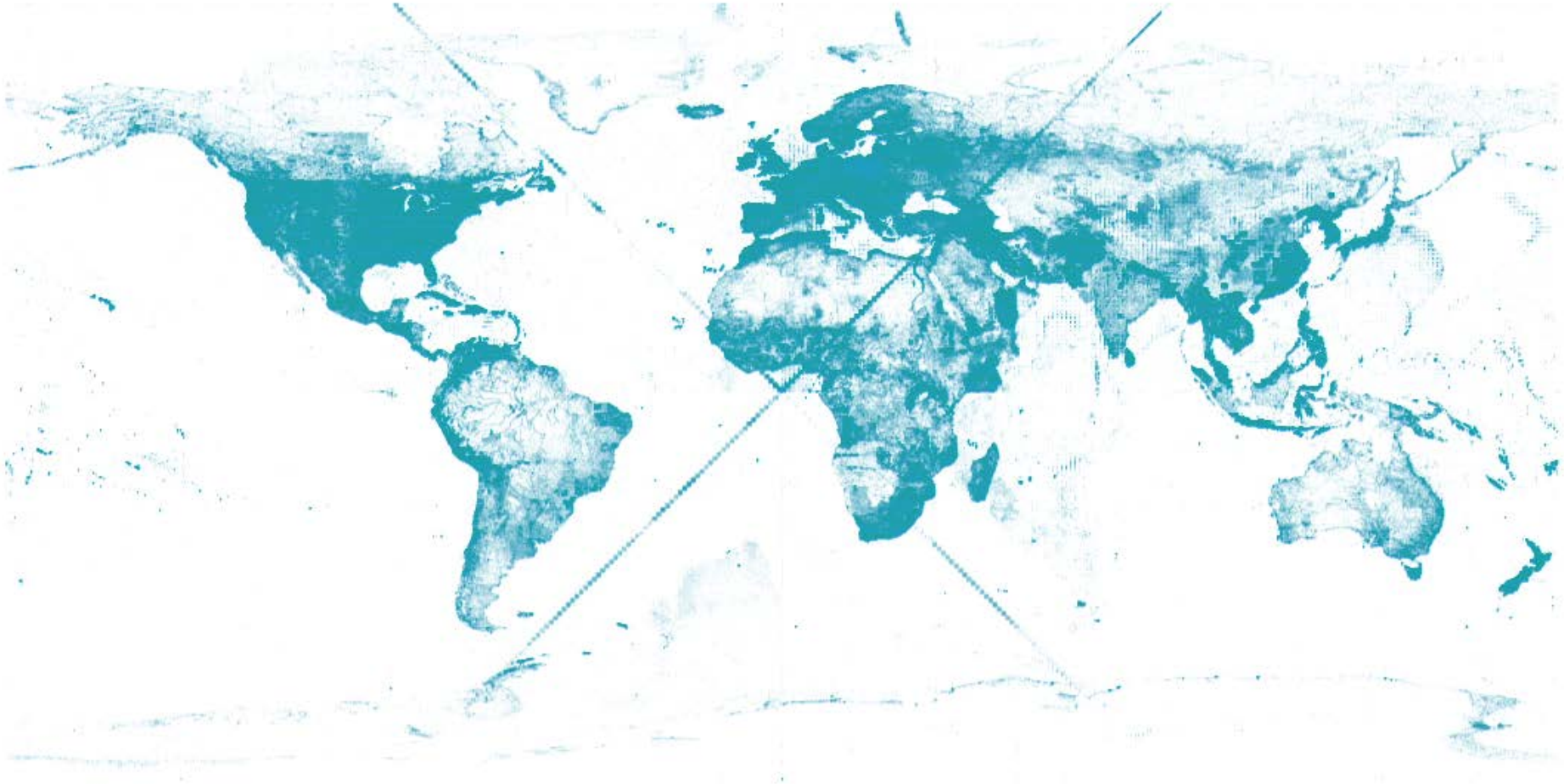
October 2013:

Ca. 25,000,000,000 schema.org references on the web.

15% of all pages now have schema.org markup.
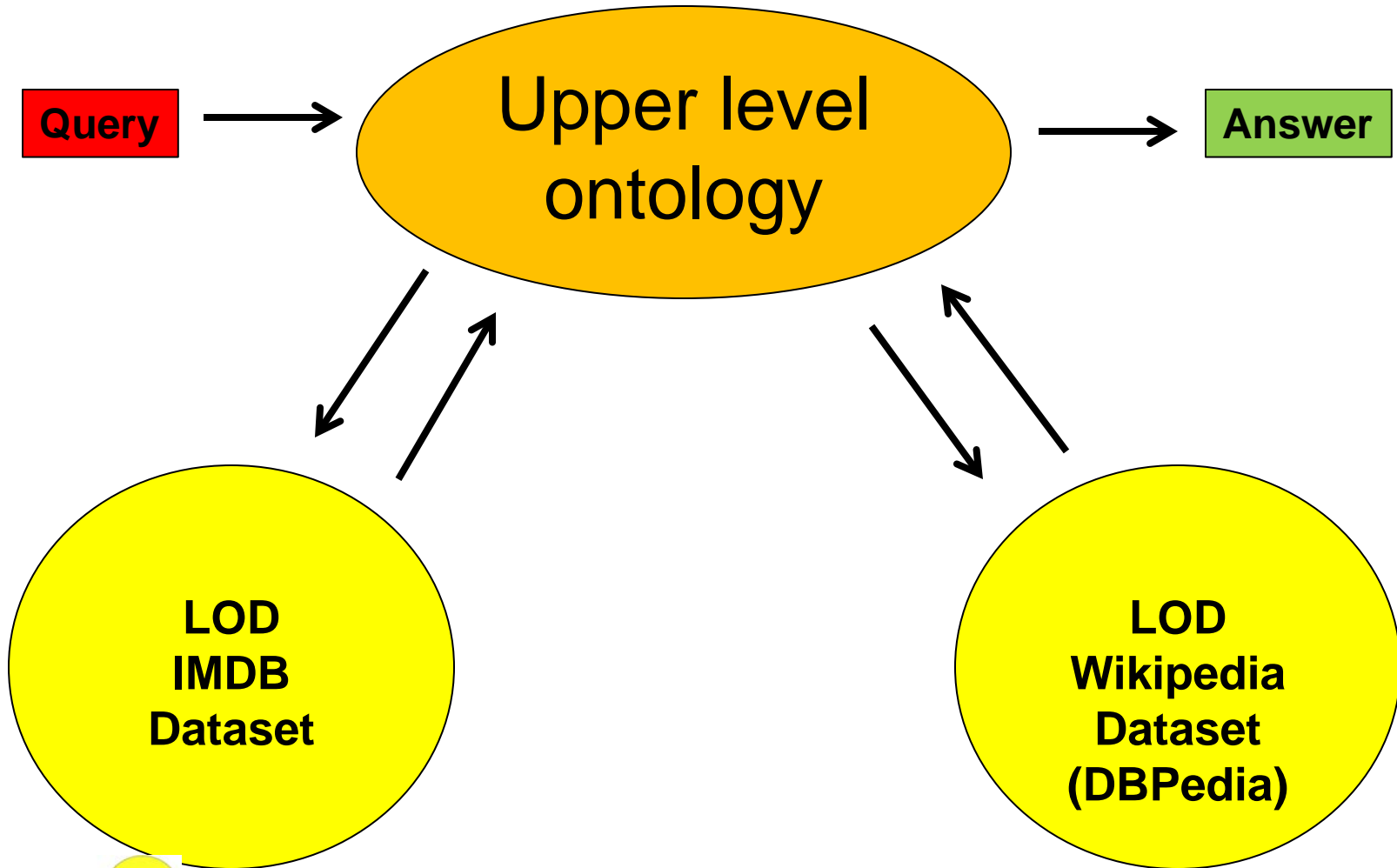
That's just schema.org references …

Example querying LoD

"Identify congress members, who have voted "No" on pro environmental legislation in the past four years, with high-pollution industry in their congressional districts."

In principle, all the knowledge is there:
- **GovTrack**
- **GeoNames**
- **DBPedia**
- **US Census**

But even with LoD we cannot answer this query.

Example querying LoD

"Identify congress members, who have voted "No" on pro environmental legislation in the past four years, with high-pollution industry in their congressional districts."

Some missing puzzle pieces:

- **Where is the data?**

  – **GovTrack**
      GeoNames
      US Census
      requires intimate knowledge of the LoD data sets

Example querying LoD

"Identify congress members, who have voted "No" on pro environmental legislation in the past four years, with high-pollution industry in their congressional districts."

Some missing puzzle pieces:

- **Where is the data?**
  (smart federation needed)

- **Missing background (schema) knowledge.**
  (enhancements of the LoD cloud)

- **Crucial info still hidden in texts.**
  (ontology learning from texts)

- **Added reasoning capabilities (e.g., spatial).**
  (new ontology language features)

"Nancy Pelosi voted in favor of the Health Care Bill."

Linked Data federated querying

Query → Upper level ontology → Answer

LOD IMDB Dataset

LOD Wikipedia Dataset (DBPedia)

Joshi, Jain, Hitzler et al. ODBASE 2012
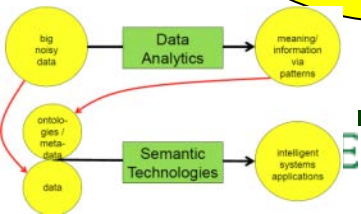
Bootstrapping-based alignment
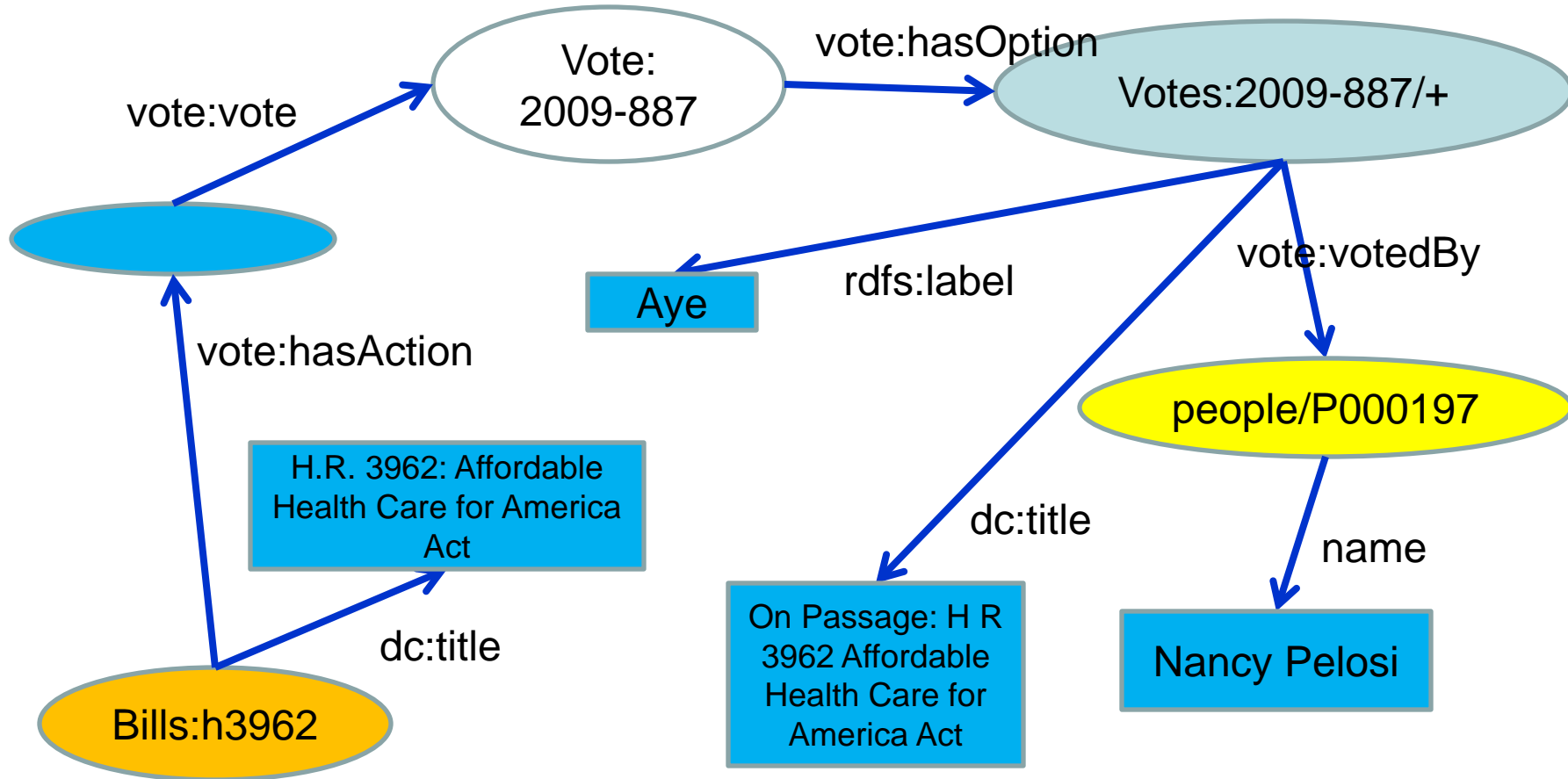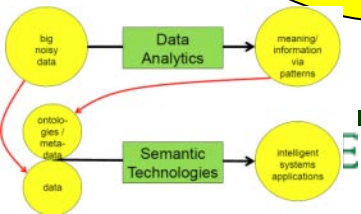
Table 4. Results of various systems for LOD Schema Alignment. Legends: Prec=Precision, Rec=Recall, M=Music Ontology, B=BBC Program Ontology, F=FOAF Ontology, D=DBpedia Ontology, G=Geonames Ontology, S=SIOC Ontology, W=Semantic Web Conference Ontology, A=AKT Portal Ontology, err=System Error, NA=Not Available

	Linked Open Data Schema Ontology Alignment											
	Alignment API		OMViaUO		RiMoM		S-Match		AROMA		BLOOMS	
Test	Prec	Rec	Prec	Rec	Prec	Rec	Prec	Rec	Prec	Rec	Prec	Rec
M,B	0.4	0	1	0	err	err	0.04	0.28	0	0	0.63	0.78
M,D	0	0	0	0	err	err	0.08	0.30	0.45	0.01	0.39	0.62
F,D	0	0	0	0	err	err	0.11	0.40	0.33	0.04	0.67	0.73
G,D	0	0	0	0	err	err	0.23	1	0	0	0	0
S,F	0	0	0	0	0.3	0.2	0.52	0.11	0.30	0.20	0.55	0.64
W,A	0.12	0.05	0.16	0.03	err	err	0.06	0.4	0.38	0.03	0.42	0.59
W,D	0	0	0	0	err	err	0.15	0.50	0.27	0.01	0.70	0.40
Avg.	0.07	0.01	0.17	0	NA	NA	0.17	0.43	0.25	0.04	0.48	0.54

Jain, Hitzler et al, ISWC2010

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Query → **Upper level ontology** → **Answer**

LOD IMDB Dataset

LOD Wikipedia Dataset (DBPedia)
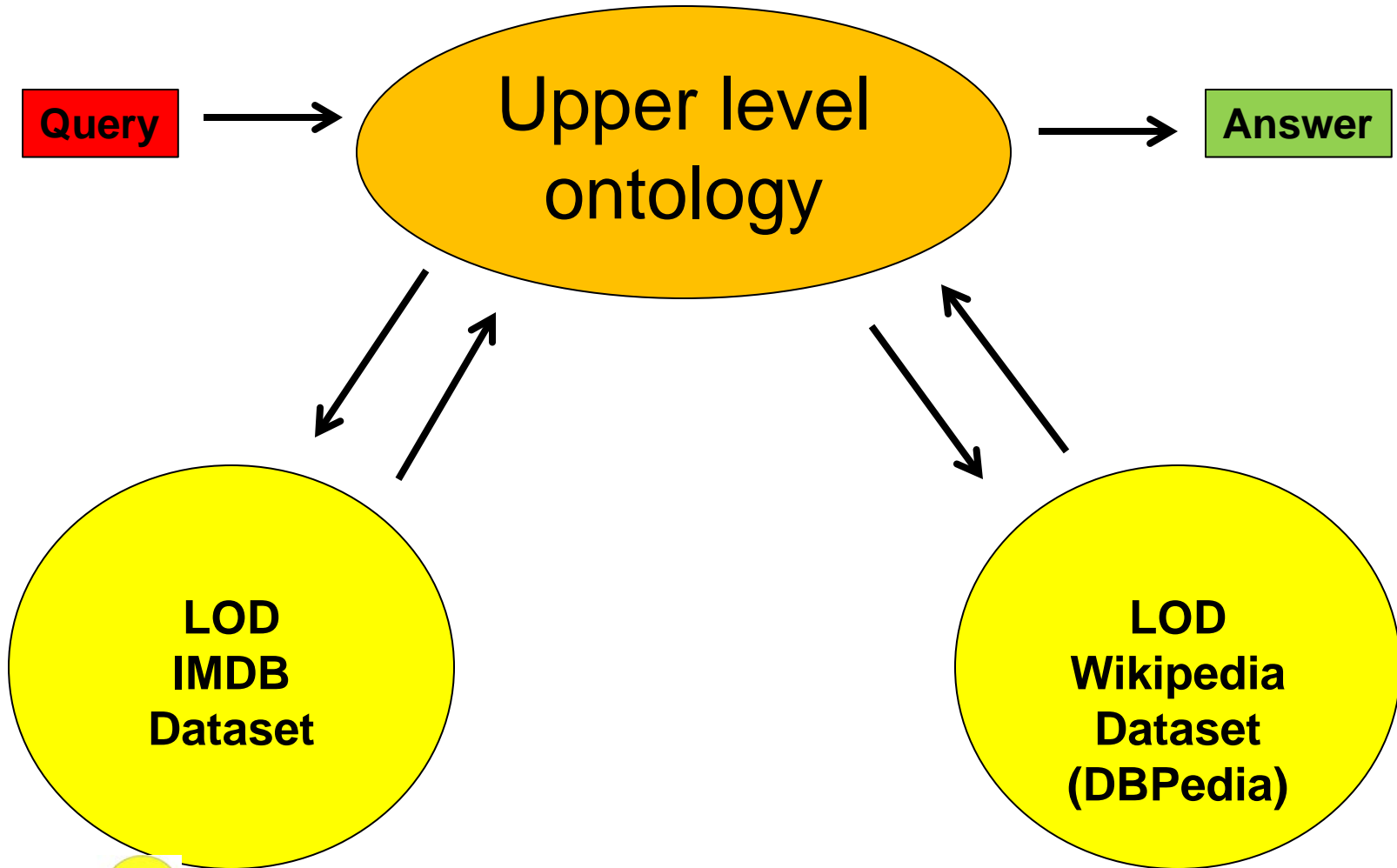
Joshi, Jain, Hitzler et al. ODBASE 2012

"Identify films, the nations where they were shot and the population of these countries"

SELECT ?film ?nation ?pop

WHERE {
?film   protonu:ofCountry   ?nation.
?film   rdf:type   protonu:Movie.
?film   rdfs:label   ?film_name.
?nation protont:populationCount   ?pop.
}
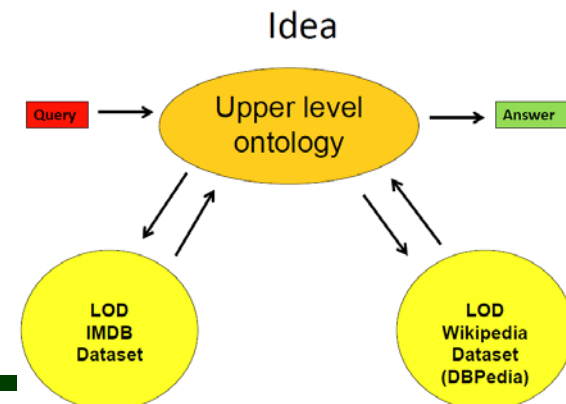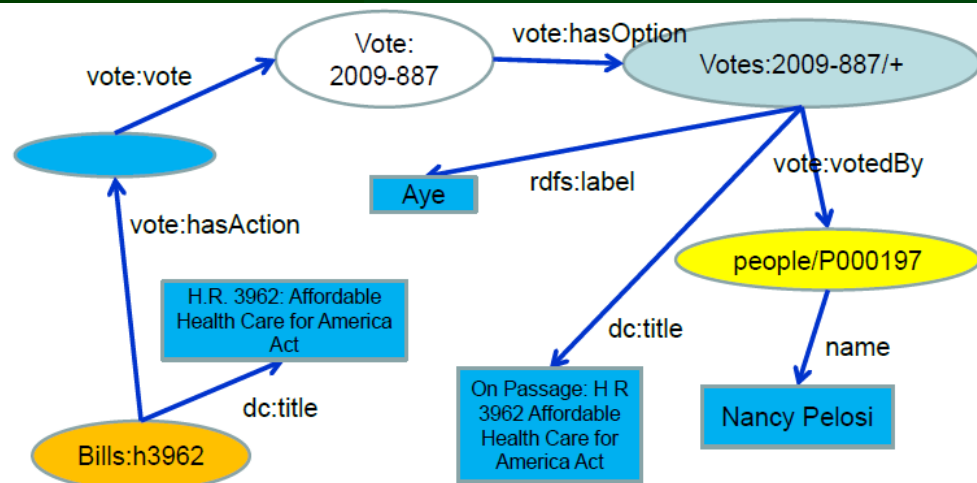
Works very well, but only in some very limited cases.

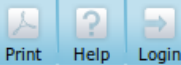**Cannot deal with graph representations of even very minimal complexity.**

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BCO-DMO:

foaf:Person

type

Person_752

name

givenName

familyName

"John Smith"

"Smith"

"John"

R2R:

foaf:Person

type

person/101396

name

"Smith, John"

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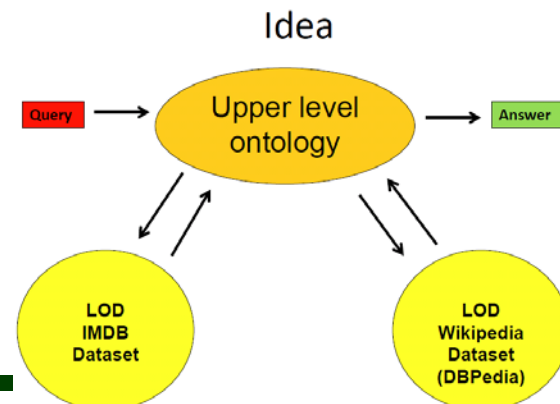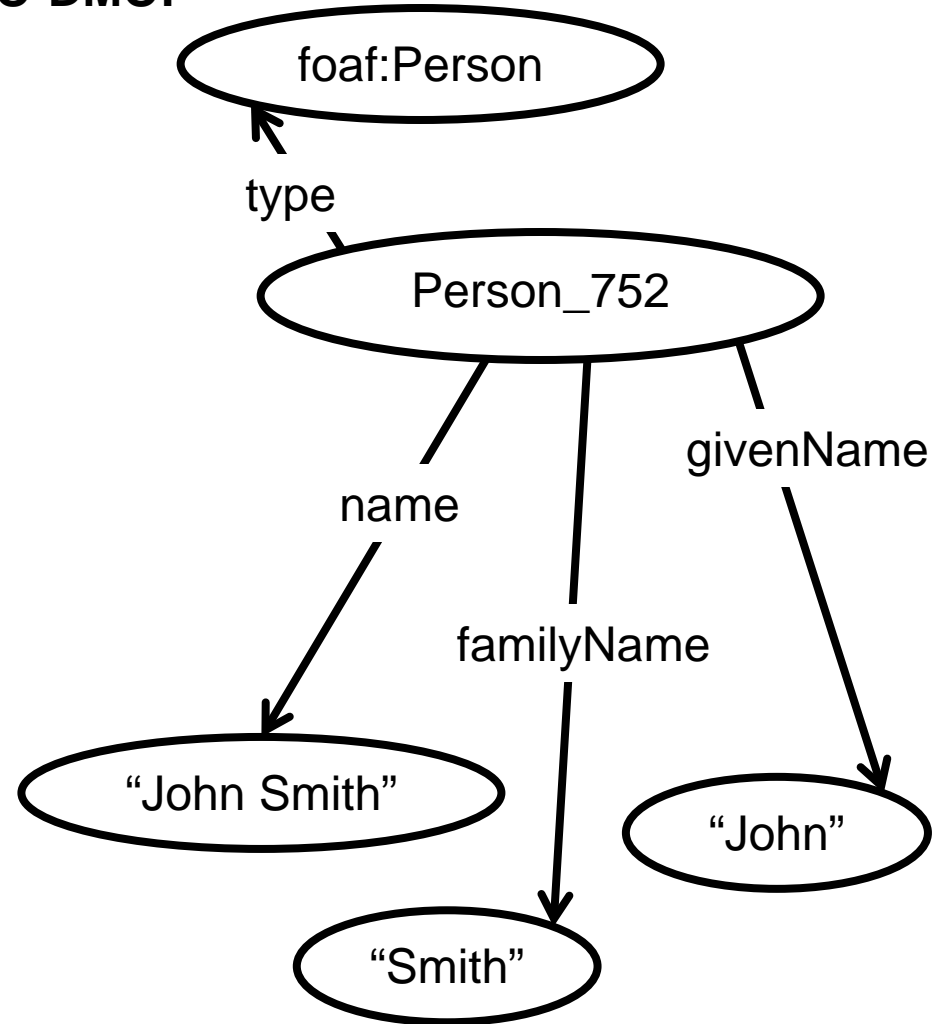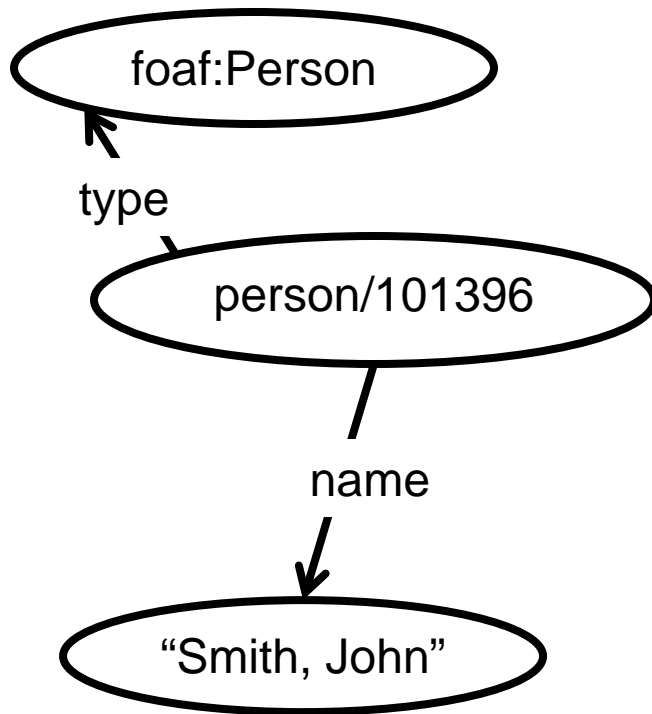
a:hasWife $\sqsubseteq$ a:hasSpouse

symmetric(a:hasSpouse)

$\exists$a:hasSpouse.a:Female $\sqsubseteq$ a:Male

$\exists$a:hasSpouse.a:Male $\sqsubseteq$ a:Female

a:hasWife(a:john, a:mary)

b:Male(a:john)

b:Female(a:mary)

a:Male $\sqcap$ a:Female $\sqsubseteq$ $\bot$

symmetric(b:hasSpouse)

b:hasSpouse(b:mike, b:david)

b:Male(b:david)

b:Male(b:mike)

b:Female(b:anna)

Automated federation?

Copernicus lunar crater located on earth – courtesy of Krzysztof Janowicz http://stko.geog.ucsb.edu/location_linked_data (missing reference coordinate system)

The linked data counter-hype

- **"Ontologies don't work, let's just link data"**

- **"Okay, with a little bit of ontologies on top."**

- **But then we don't even know how to effectively query over multiple linked datasets (without using a lot of manpower to manually integrate them).**

- **It seems rather obvious that we need to get ontologies into the picture, but how to do it while avoiding the drawbacks of strong ontological commitments?**

So What Now?

Ways forward?

How to establish a flexible conceptual architecture using data and ontological modeling?

Ontology Design Patterns

"An ontology design pattern is a reusable successful solution to a recurrent modeling problem."

So-called *content patterns* usually encode specific abstract notions, such as process, event, agent, etc.

Ontology Design Patterns

- **Bottom-up homogenization of data representation.**

- **Avoidance of strong ontological commitments.**

- **Avoidance of standardization of specific modeling details.**

- **Well thought-out patterns can be very strong and versatile, thus serve many needs.**

We are currently establishing many geo-patterns in a series of hands-on workshops, the GeoVoCamps, see http://vocamp.org/

Ontology Design Patterns

Pattern1

Pattern2

Pattern2

Pattern3

Pattern1
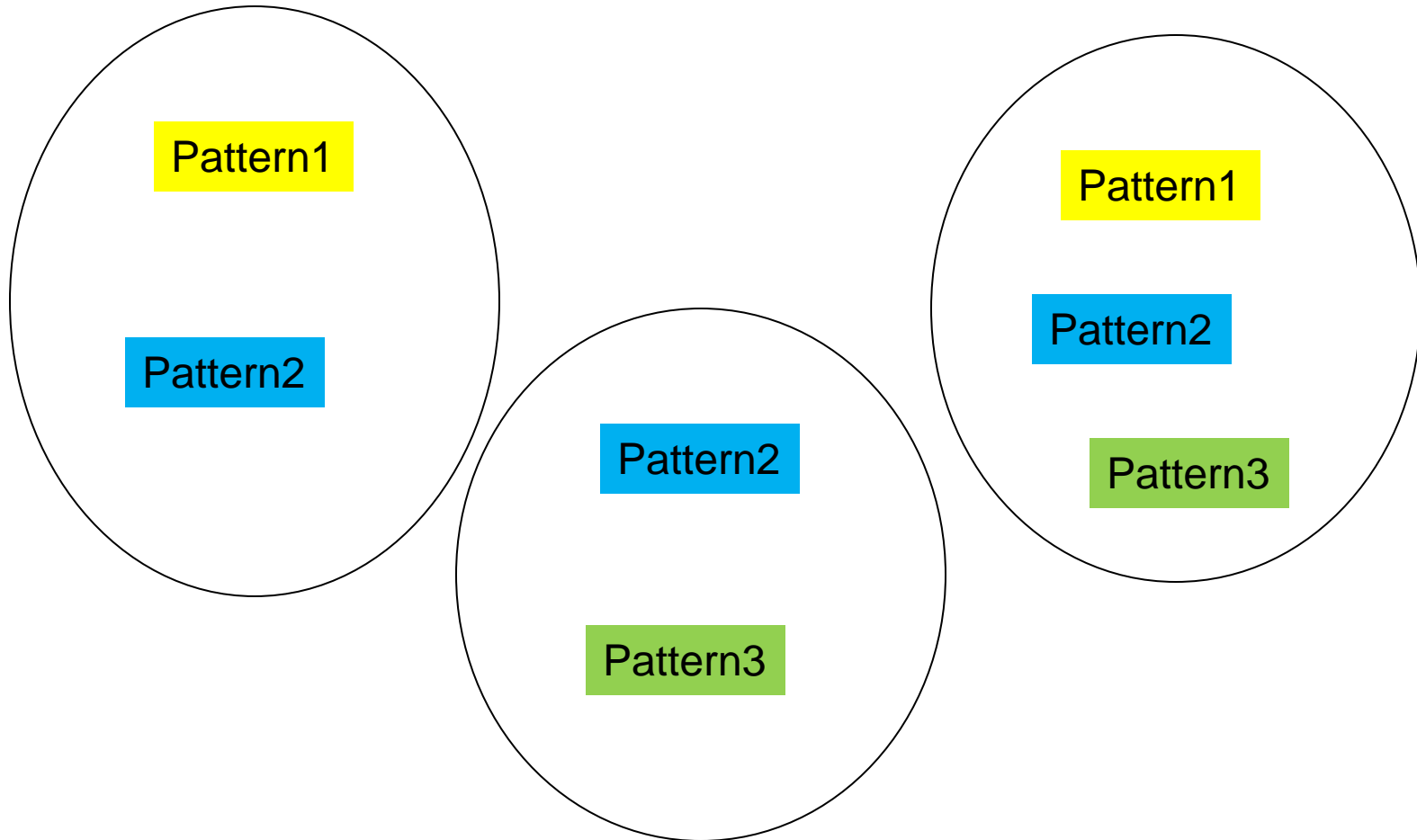
Pattern2

Pattern3

"Horizontal" alignment via patterns

Semantic Trajectories

Raw trajectory data — Geographic information — Domain knowledge — Device information
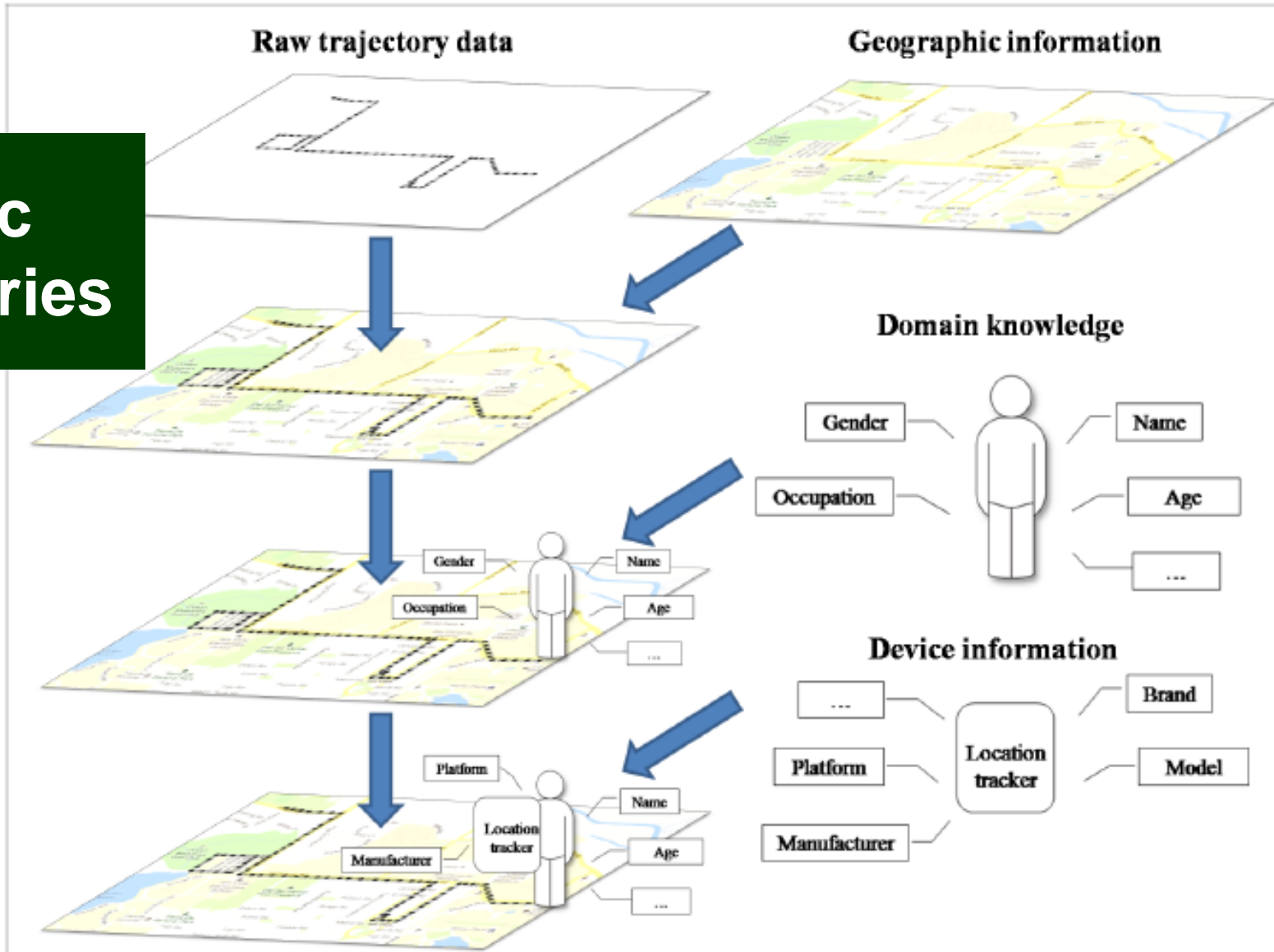
[Hu, Janowicz, Carral, Scheider, Kuhn, Berg-Cross, Hitzler, Dean, COSIT2013]

WRIGHT STATE UNIVERSITY
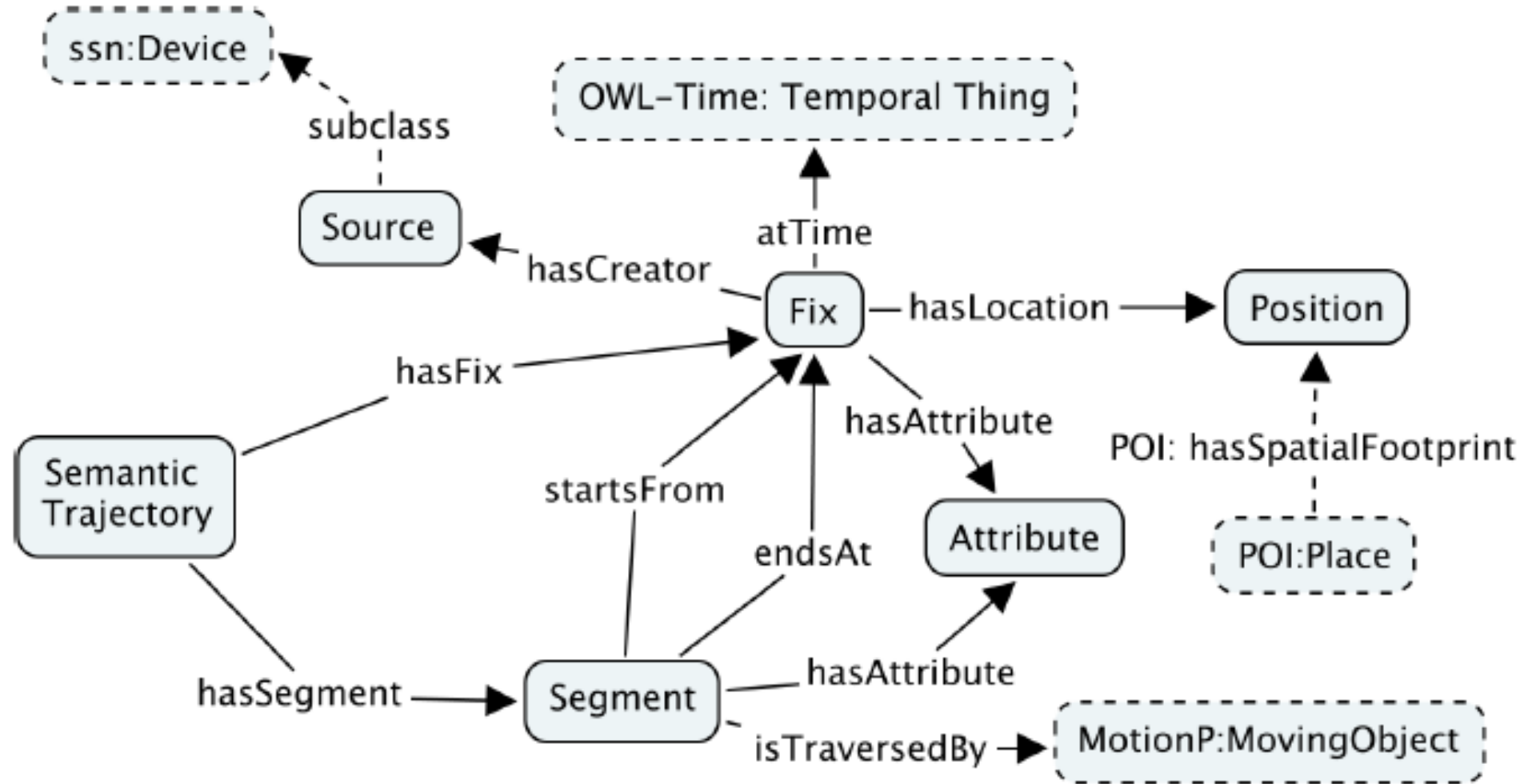
Semantic Trajectories

$$Fix \sqsubseteq \exists atTime.OWL\text{-}Time:Temporal \; Thing \sqcap \exists hasLocation.Position$$

$$\sqcap \exists hasFix^-.SemanticTrajectory \tag{1}$$

$$Segment \sqsubseteq \exists startsFrom.Fix \sqcap \exists endsAt.Fix \tag{2}$$

$$\top \sqsubseteq \; \leq 1\, startsFrom.\top \tag{3}$$

$$\top \sqsubseteq \; \leq 1\, endsAt.\top \tag{4}$$

$$Segment \sqsubseteq \exists hasSegment^-.SemanticTrajectory \tag{5}$$

$$startsFrom^- \circ endsAt \sqsubseteq hasNext \tag{6}$$

$$hasNext \sqsubseteq hasSuccessor \tag{7}$$

$$hasSuccessor \circ hasSuccessor \sqsubseteq hasSuccessor \tag{8}$$

$$hasNext^- \sqsubseteq hasPrevious \tag{9}$$

$$hasSuccessor^- \sqsubseteq hasPredecesor \tag{10}$$

$$Fix \sqcap \neg \exists endsAt.Segment \sqsubseteq StartingFix \qquad (11)$$

$$Fix \sqcap \neg \exists startsFrom.Segment \sqsubseteq EndingFix \qquad (12)$$

$$Segment \sqcap \exists startsFrom.StartingFix \sqsubseteq StartingSegment \qquad (13)$$

$$Segment \sqcap \exists endsAt.EndingFix \sqsubseteq EndingSegment \qquad (14)$$

$$SemanticTrajectory \sqsubseteq \exists hasSegment.Segment \qquad (15)$$

$$hasSegment \circ startsFrom \sqsubseteq hasFix \qquad (16)$$

$$hasSegment \circ endsAt \sqsubseteq hasFix \qquad (17)$$

$$\exists hasSegment.Segment \sqsubseteq SemanticTrajectory \qquad (18)$$

$$\exists hasSegment^-.SemanticTrajectory \sqsubseteq Segment \qquad (19)$$
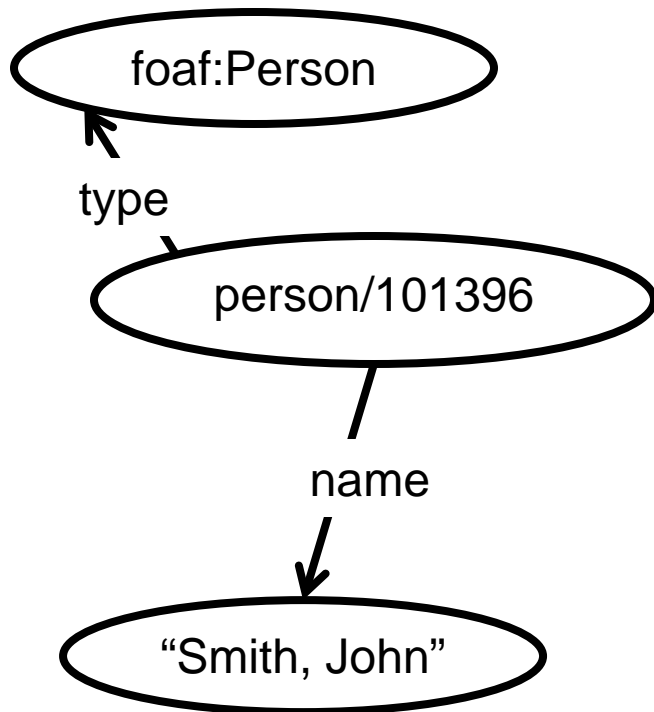
$$\exists hasFix.Segment \sqsubseteq SemanticTrajectory \qquad (20)$$

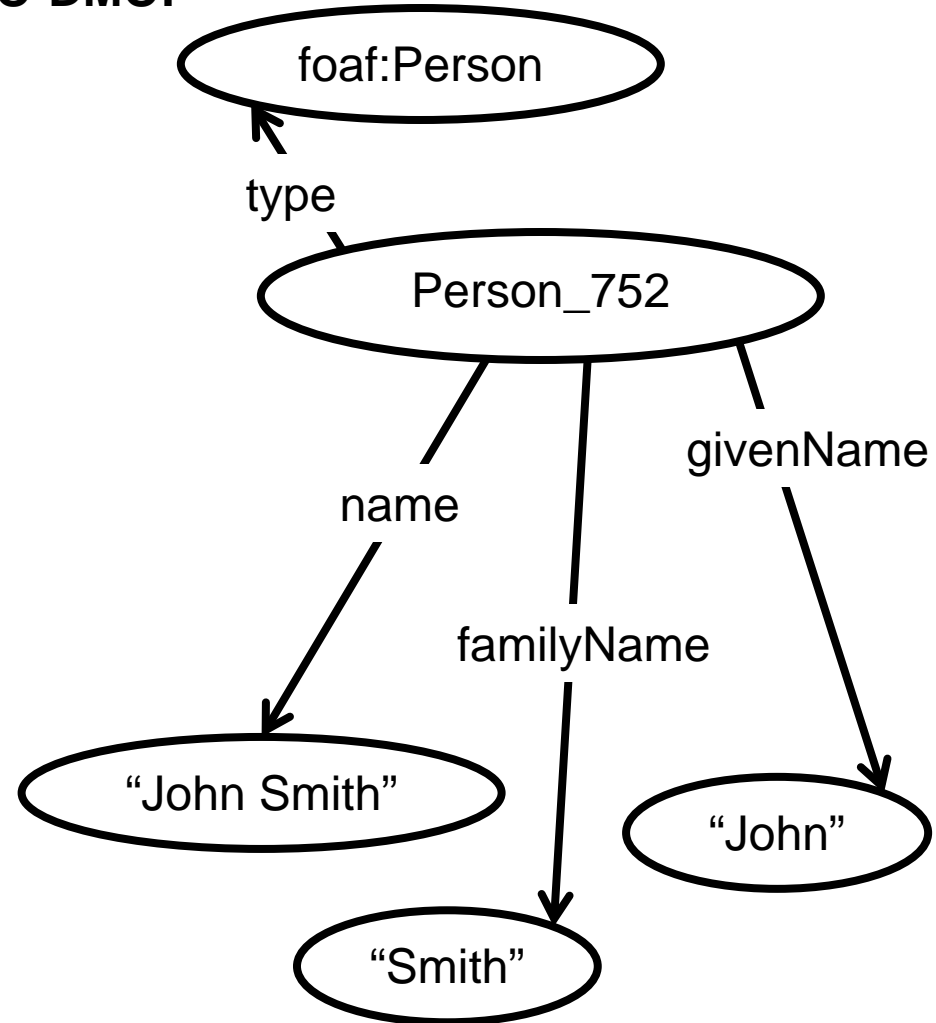$$\exists hasFix^-.SemanticTrajectory \sqsubseteq Fix \qquad (21)$$

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Even minimalistic reuse is helpful:

BCO-DMO:

R2R:

Patterns

- **Help to focus when modeling (one key notion at a time).**

- **Good ontology modeling implicitly employs the patterns idea anyway. It's just that you expose the patterns.**

- **An ontology composed of patterns exposes its internal conceptual structure (as a composition of formal vocabulary pieces).**

- **Well-designed patterns are widely reusable and adaptable.**

- **You don't have to buy a whole ontology when you adopt a few patterns from it.**

- **You can easily modify a pattern without giving up on a lot of similarity to the original pattern (which can be leveraged for data integration).**

- **You can separate the patterns from specific (application-driven) modifications.**

- **You can separate the patterns from specific axiomatically defined "views".**

NSF EarthCube project "OceanLink":

- **Integration of existing ocean science data repositories.**

- **For faceted browsing and semantic search.**

- **To be done in a flexible, extendable, modular way.**

- **With minimal effort for additional data providers to integrate their content.**

OceanLink and EarthCube

EarthCube:

Developing a Community-Driven Data and Knowledge Environment for the Geosciences

"concepts and approaches to create integrated data management infrastructures across the Geosciences."

"EarthCube aims to create a well-connected and facile environment to share data and knowledge in an open, transparent, and inclusive manner, thus accelerating our ability to understand and predict the Earth system."

OceanLink patterns
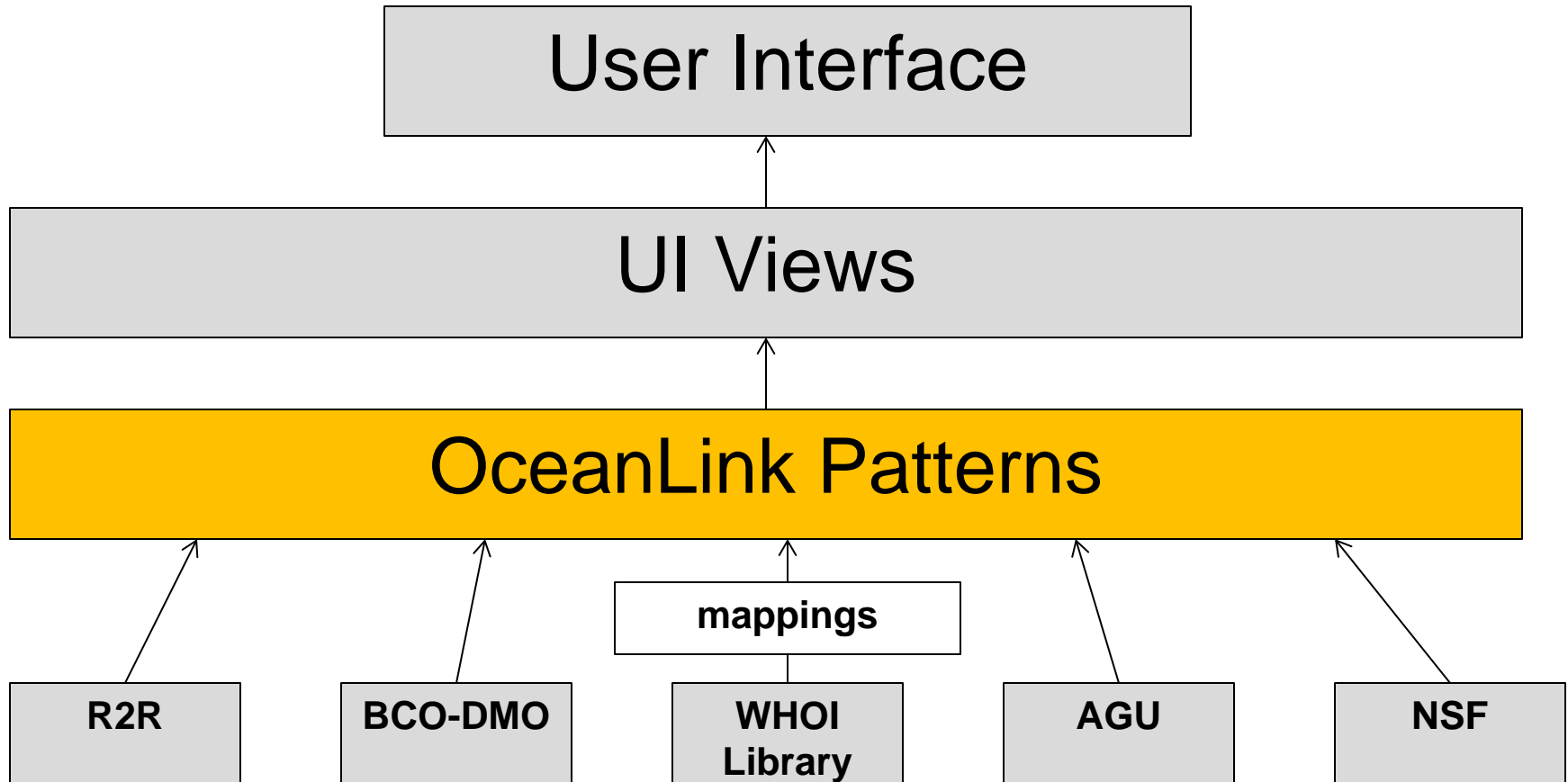
Some central patterns:

- **Cruise**
- **Trajectory**
- **Person**
- **Organization**
- **Roles of Agents**
- **Repository Object**
- **Data Set**
- **Document**

We're not starting from zero of course.
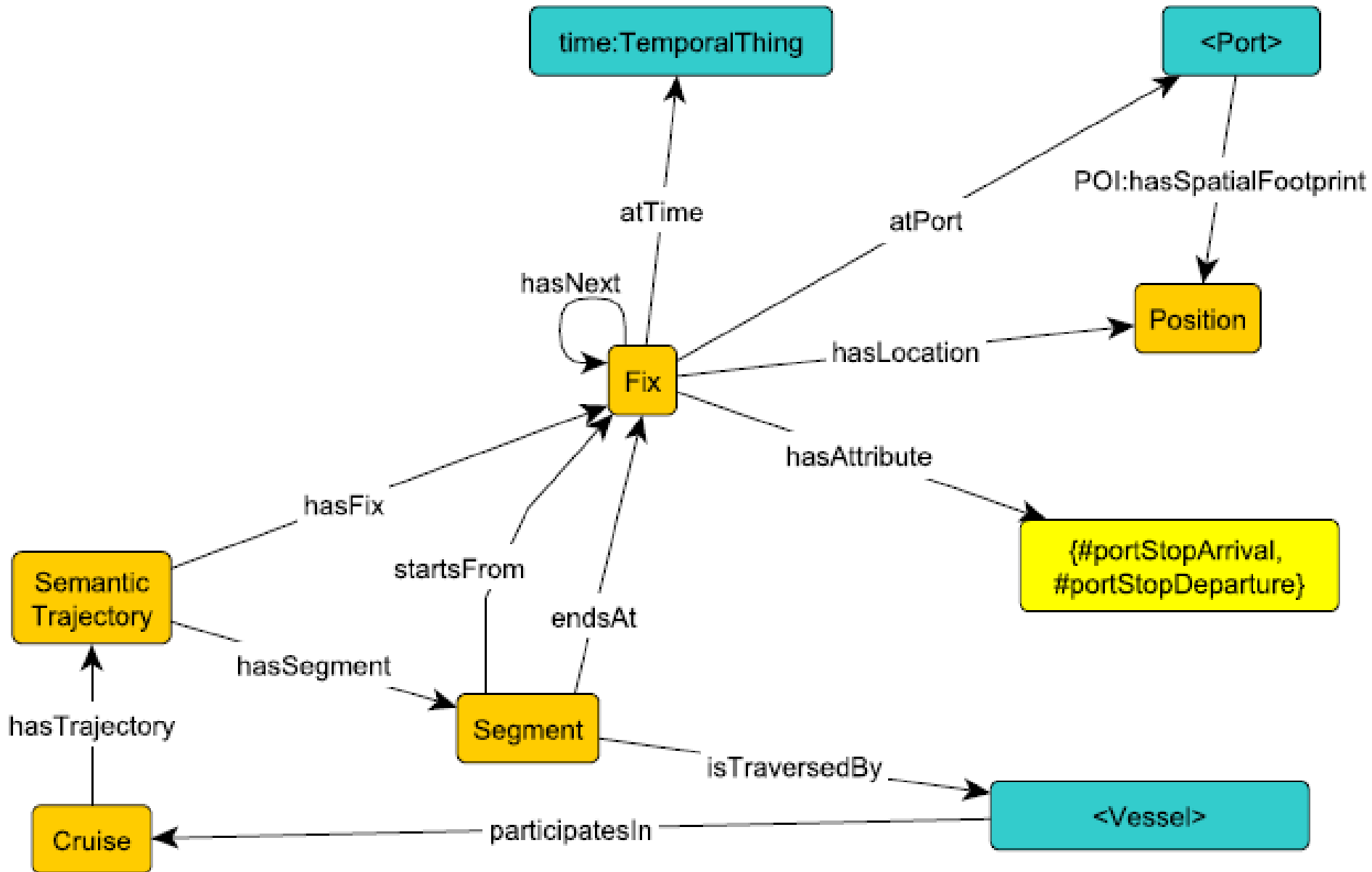
Ocean Science Cruise (draft)

Cruise trajectory (draft)

$$\text{Cruise}(x) \wedge \text{hasTrajectory}(x, y)$$
$$\wedge \text{hasSegment}(y, z) \wedge \text{isTraversedBy}(z, v)$$
$$\rightarrow \text{participatesIn}(v, z)$$
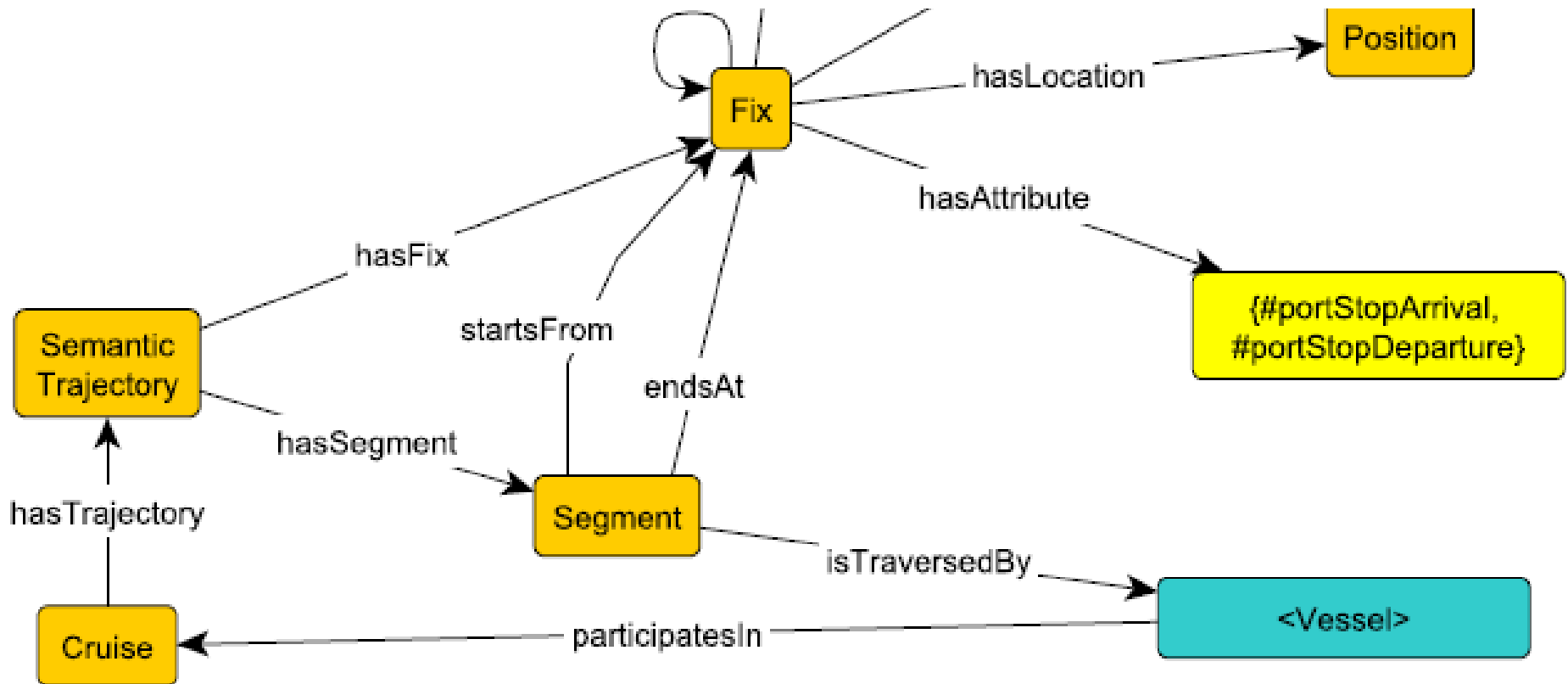
$$\mathrm{Cruise}(x) \wedge \mathrm{hasTrajectory}(x, y)$$
$$\wedge \, \mathrm{hasSegment}(y, z) \wedge \mathrm{isTraversedBy}(z, v)$$
$$\rightarrow \mathrm{participatesIn}(v, z)$$

$$\mathrm{Cruise} \equiv \exists \mathrm{cruise}.\mathrm{Self}$$

$$\mathrm{cruise} \circ \mathrm{hasTrajectory} \circ \mathrm{hasSegment} \circ \mathrm{isTraversedBy}$$
$$\sqsubseteq \mathrm{hasParticipant}$$

$$\mathrm{hasParticipant} \equiv \mathrm{participatesIn}^{-}$$
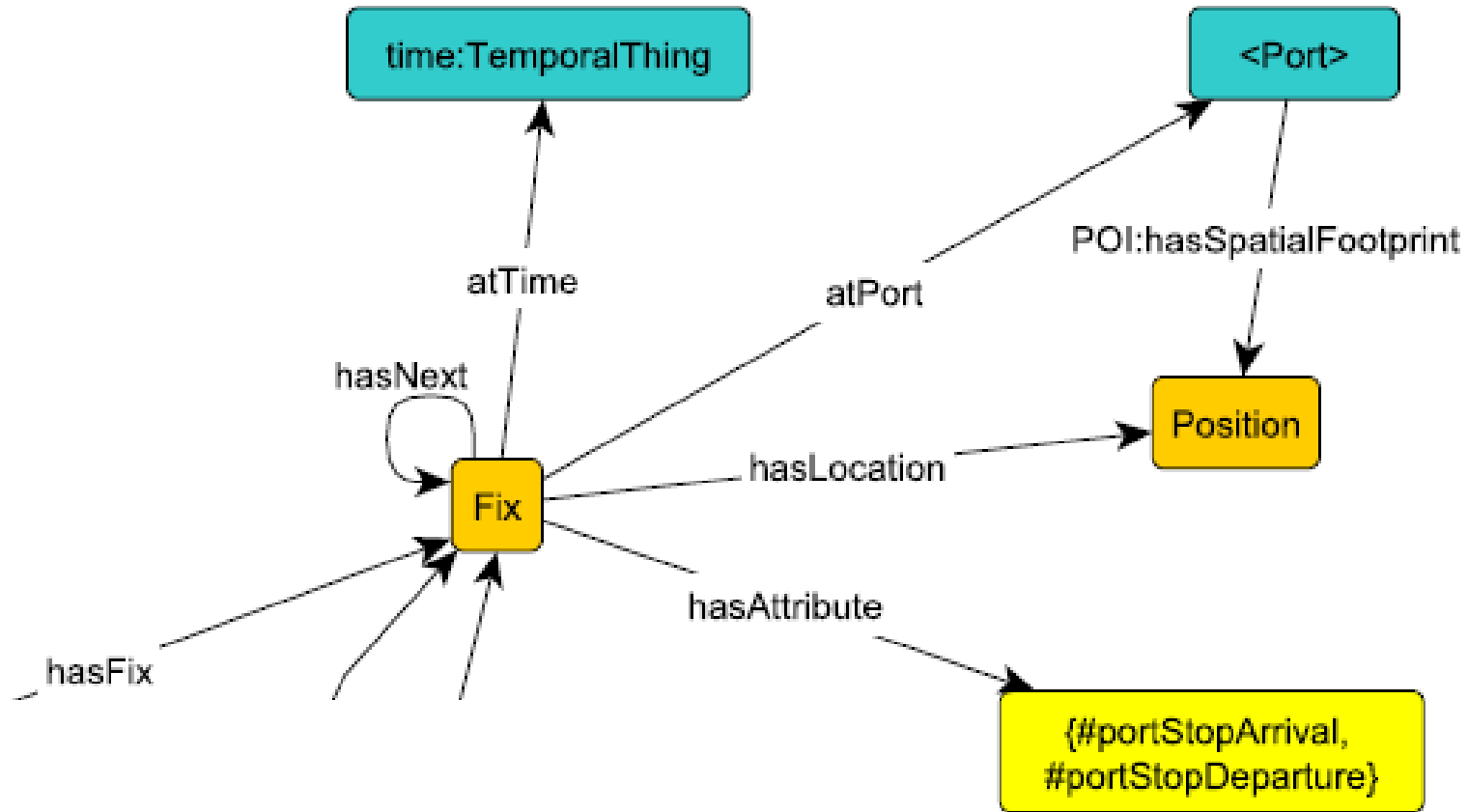
$$\text{Fix}(x) \land \text{hasAttribute}(x, \#\text{portStopArrival})$$
$$\land \text{atPort}(x, y) \land \text{hasSpatialFootprint}(y, z)$$
$$\land \text{hasLocation}(x, w) \rightarrow \text{locatedIn}(w, z)$$

$$\mathrm{Fix}(x) \wedge \mathrm{hasAttribute}(x, \#\mathrm{portStopArrival})$$
$$\wedge \mathrm{atPort}(x, y) \wedge \mathrm{hasSpatialFootprint}(y, z)$$
$$\wedge \mathrm{hasLocation}(x, w) \rightarrow \mathrm{locatedIn}(w, z)$$

$$\mathrm{Fix} \wedge \exists \mathrm{hasTrajectory}.\{\#\mathrm{portStopArrival}\} \equiv \exists \mathrm{fixps}.\mathrm{Self}$$
$$\mathrm{hasLocation}^- \circ \mathrm{fixps} \circ \mathrm{atPort} \circ \mathrm{hasSpatialFootprint}$$
$$\sqsubseteq \mathrm{locatedIn}$$

Ways forward

- **Establish a flexible conceptual architecture using data and ontological modeling.**
- **A principled use of patterns, including**
  - **the development of a theory of patterns and**
  - **the provision of a critical amount of central patterns**

  may provide a primary path forward.

Thanks!

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