

Ontologies in a Data-driven World



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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>



Pascal Hitzler, Markus Krötzsch, Sebastian Rudolph

语义Web技术基础

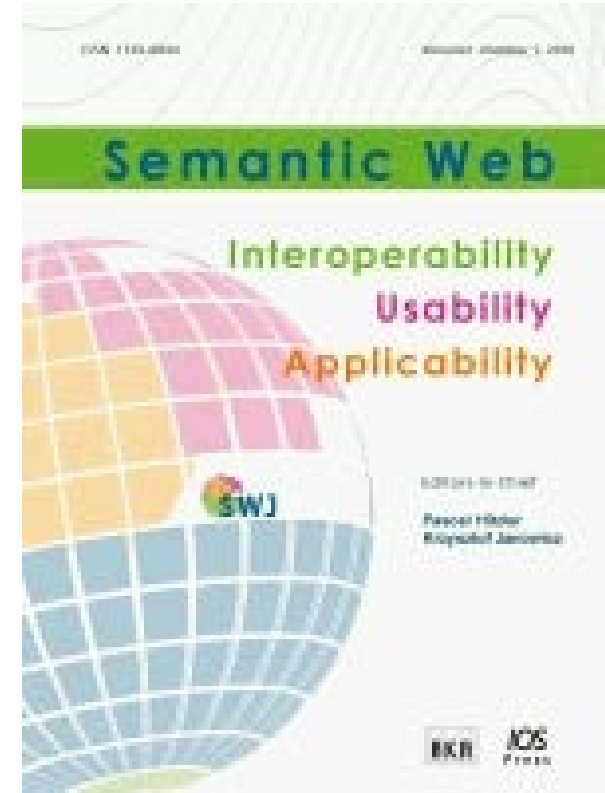
Tsinghua University Press (清华大学出版社), 2013.

Translators:

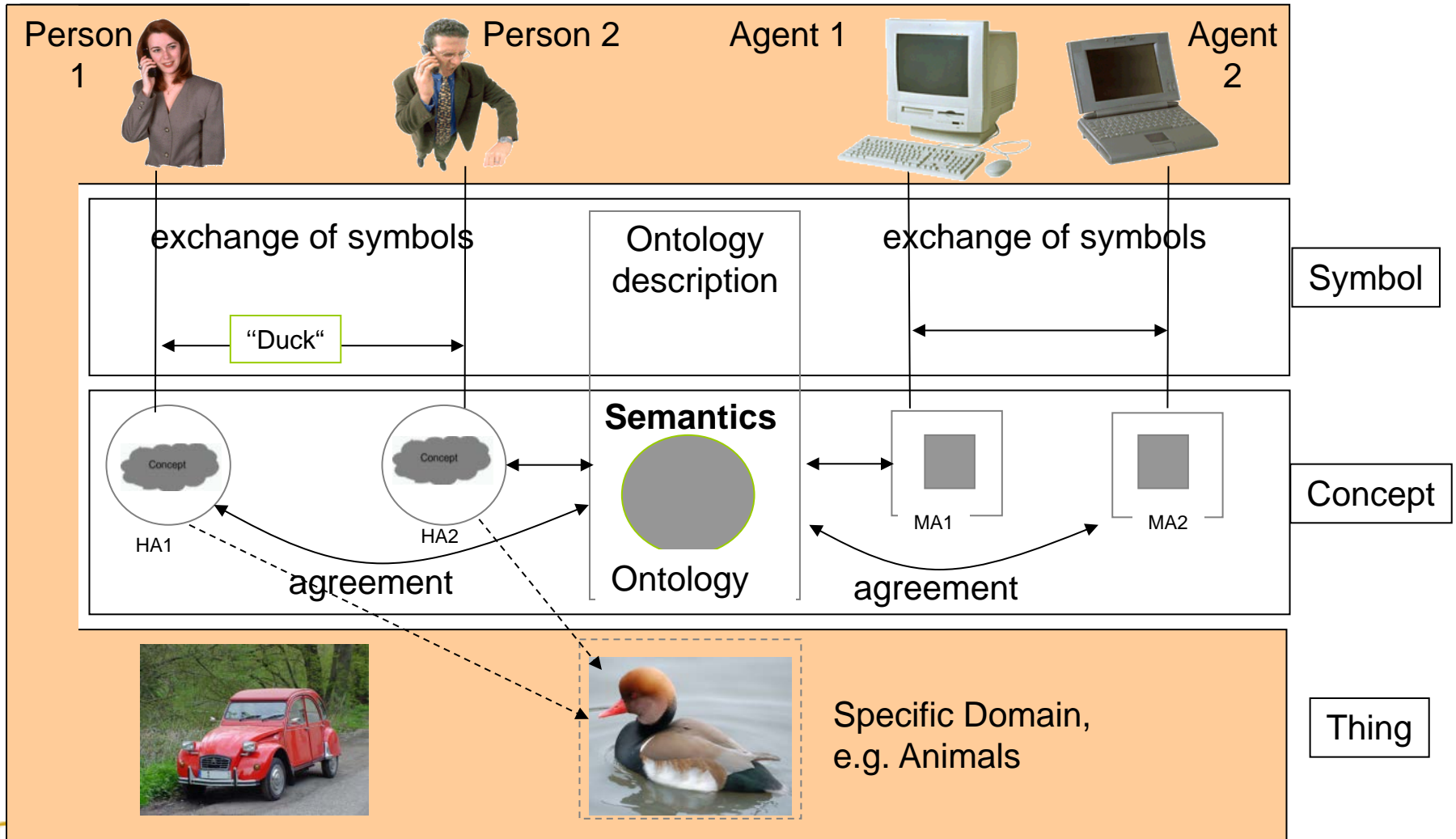
Yong Yu, Haofeng Wang, Guilin Qi (俞勇, 王昊奋, 漆桂林)

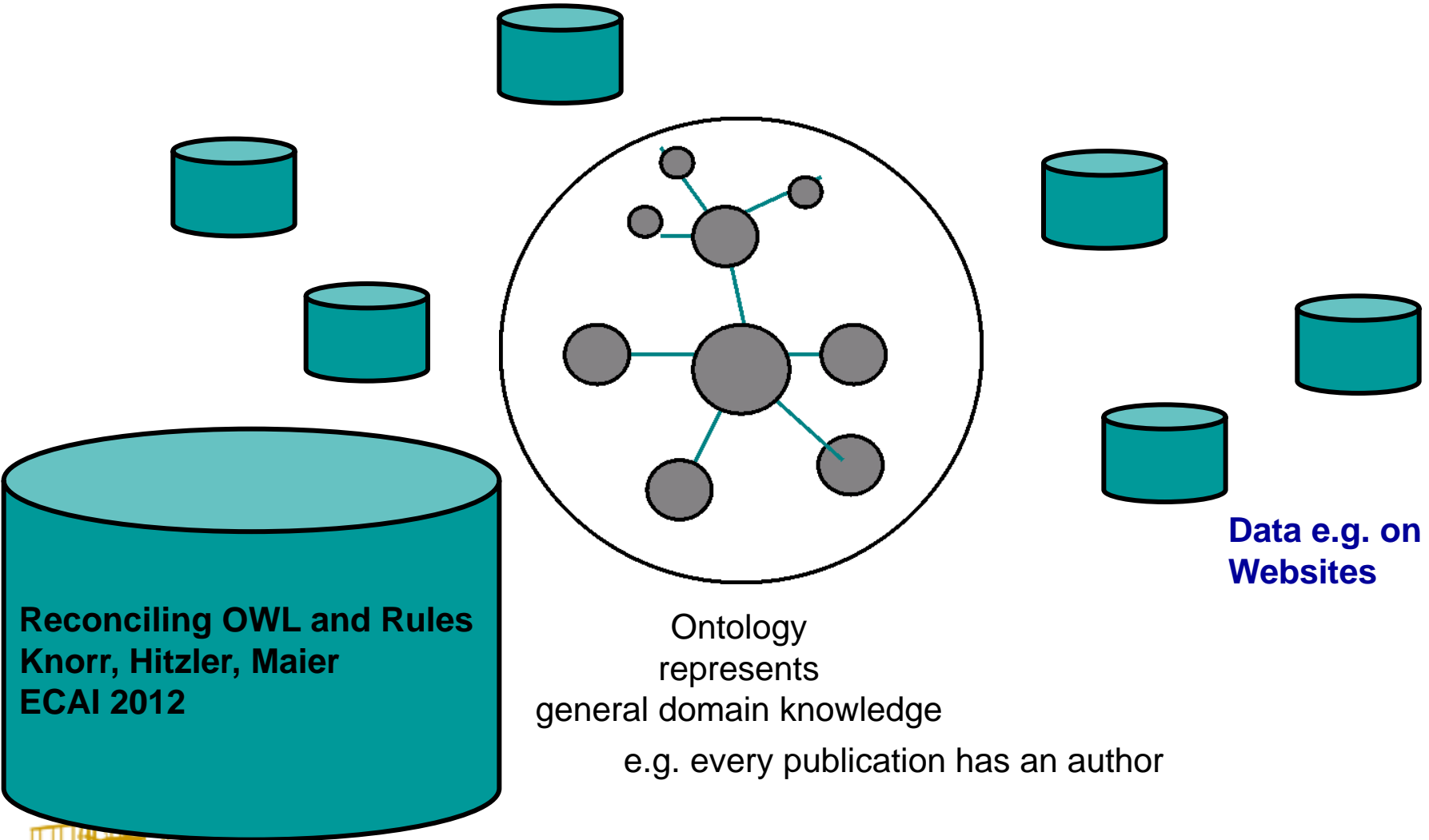
<http://www.semantic-web-book.org>

- **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/>**



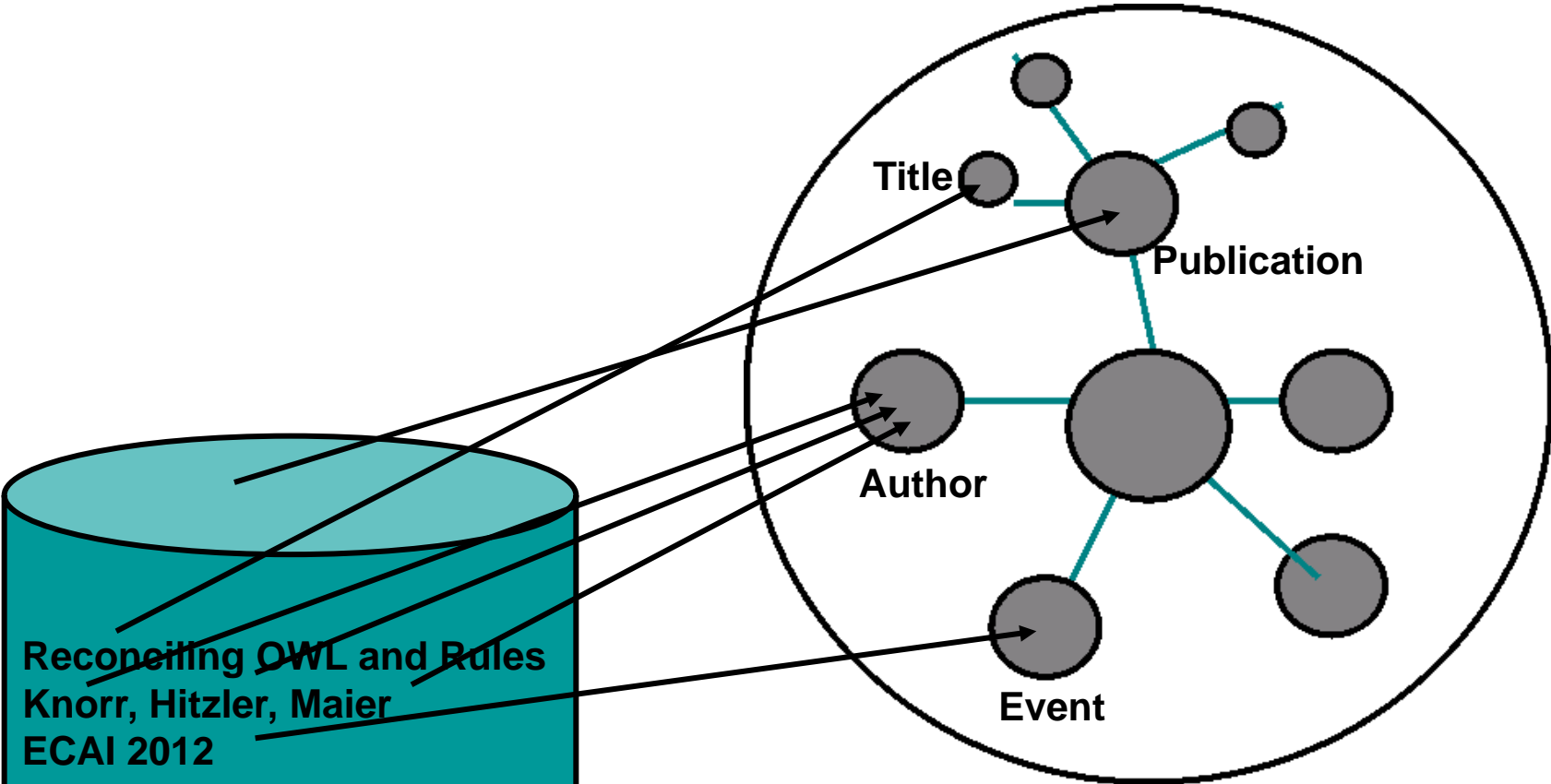
Ontologies?



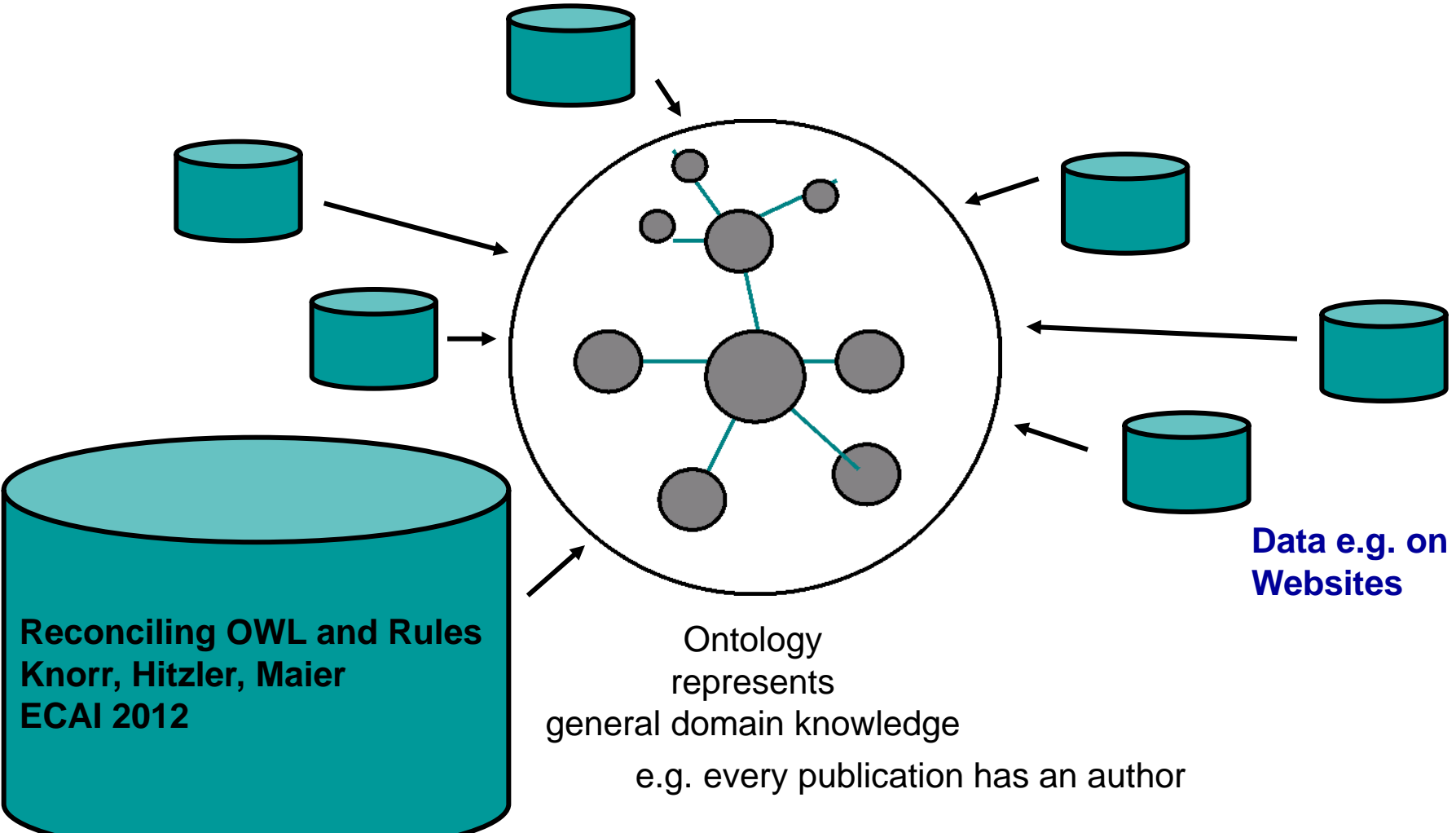


Ontology represents general domain knowledge
e.g. every publication has an author

Data e.g. on Websites



e.g. every publication has an author



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

- **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?

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

 - **Etc.**

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

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

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

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

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

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

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

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

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

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

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

Two ontologies.

Left: transportation domain

Right: agriculture domain

We cannot simply equate $a:\text{Canal}$ and $b:\text{Canal}$!

- **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:

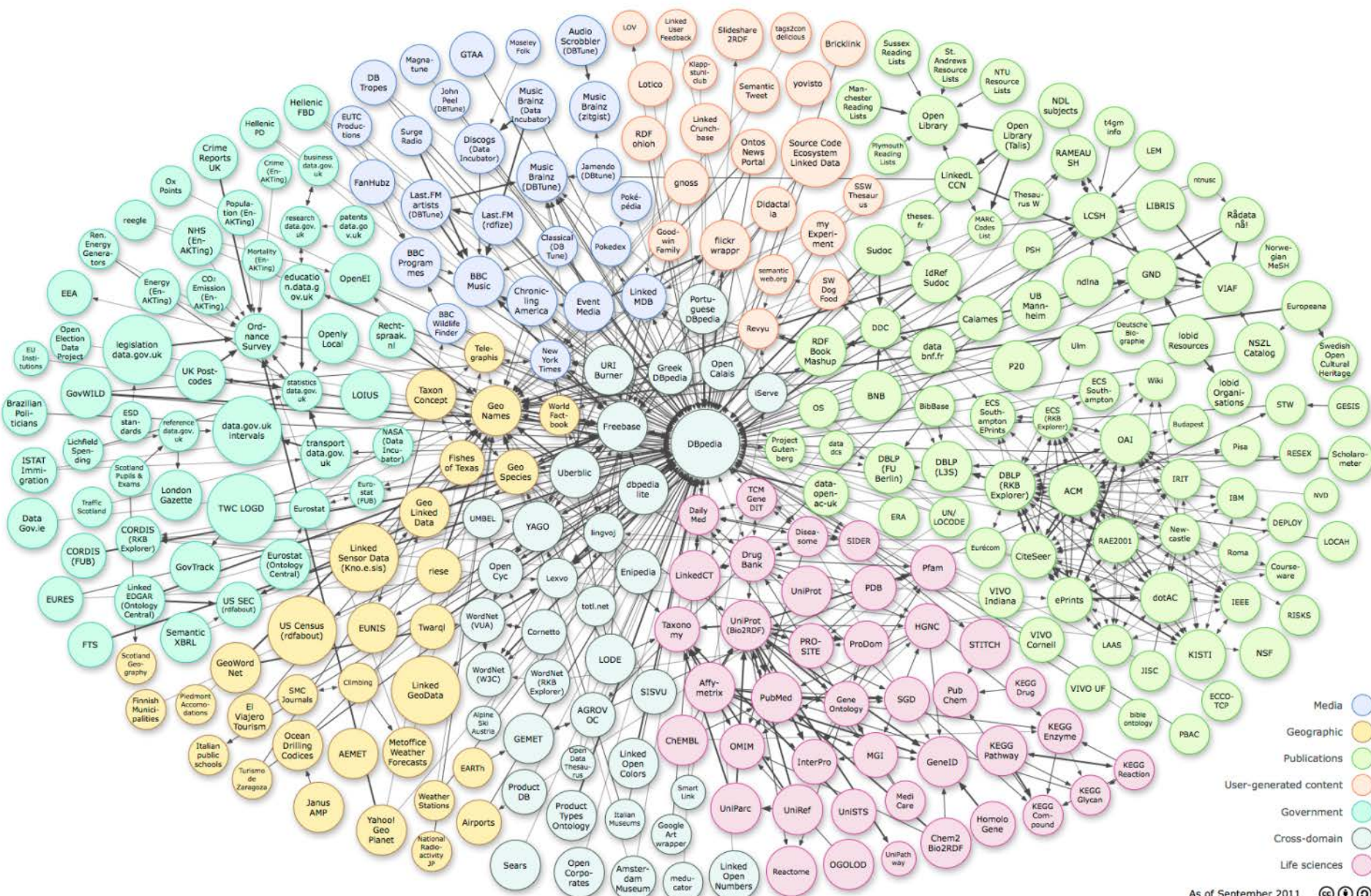
These will solve your data and information management problems

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

Linked Data?

- “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.”

Linked Data 2011



DBpedia: LOTR page

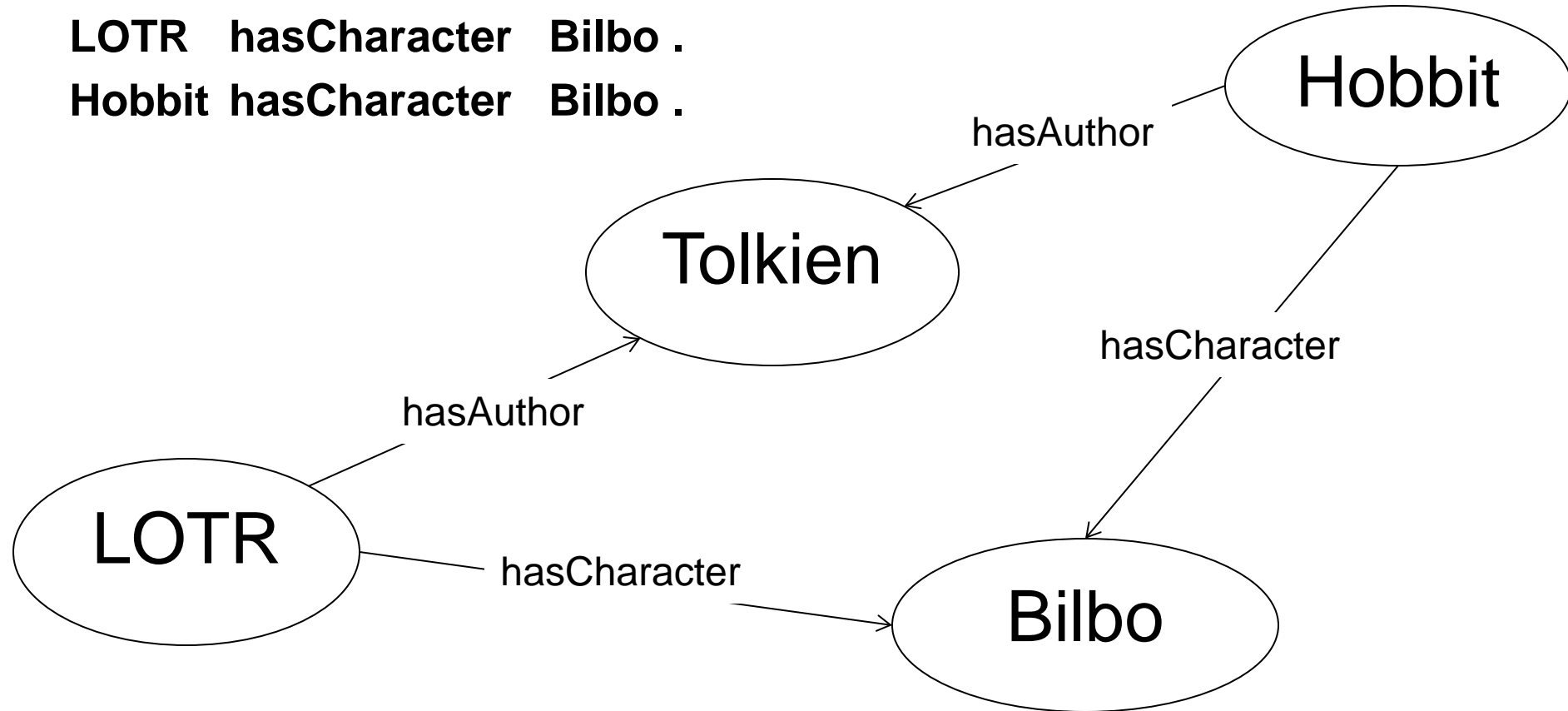
dbpedia-owl:thumbnail	<ul style="list-style-type: none">▪ http://upload.wikimedia.org/wikipedia/commons/thumb/6/62/Jrtt_lotr_cover_design.jpg/200px-Jrtt_lotr_cover_design.jpg
dbpedia-owl:wikiPageExternalLink	<ul style="list-style-type: none">▪ http://lotr.wikia.com▪ http://www.glyphweb.com/arda/▪ http://www.tolkienlibrary.com/▪ http://www.tolkien.co.uk/▪ http://www.houghtonmifflinbooks.com/features/lordoftheringstrilogy/
dbpprop:author	<ul style="list-style-type: none">▪ dbpedia:J._R._R._Tolkien
dbpprop:books	<ul style="list-style-type: none">▪ dbpedia:The_Two_Towers▪ dbpedia:The_Return_of_the_King▪ dbpedia:The_Fellowship_of_the_Ring▪ "Volumes:"
dbpprop:country	<ul style="list-style-type: none">▪ England
dbpprop:expiry	<ul style="list-style-type: none">▪ 20 (xsd:integer)
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dbpprop:hasPhotoCollection	<ul style="list-style-type: none">▪ http://www4.wiwiss.fu-berlin.de/flickrwrappr/photos/The_Lord_of_the_Rings
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dbpprop:mediaType	<ul style="list-style-type: none">▪ Print
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dbpprop:precededBy	<ul style="list-style-type: none">▪ dbpedia:The_Hobbit
dbpprop:pubDate	<ul style="list-style-type: none">▪ 21 (xsd:integer)
dbpprop:publisher	<ul style="list-style-type: none">▪ dbpedia:Allen_&_Unwin
dbpprop:small	<ul style="list-style-type: none">▪ yes
dbpprop:wikiPageUsesTemplate	<ul style="list-style-type: none">▪ dbpedia:Template:Infobox_book_series▪ dbpedia:Template:Pp-vandalism
dcterms:subject	<ul style="list-style-type: none">▪ 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

LOTR hasAuthor Tolkien .

Hobbit hasAuthor Tolkien .

LOTR hasCharacter Bilbo .

Hobbit hasCharacter Bilbo .



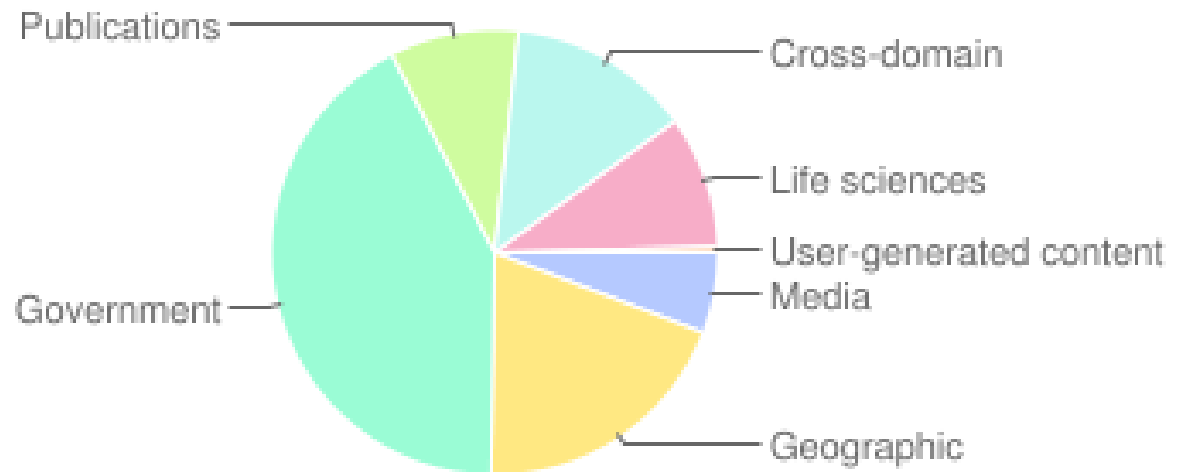
Number of Datasets

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

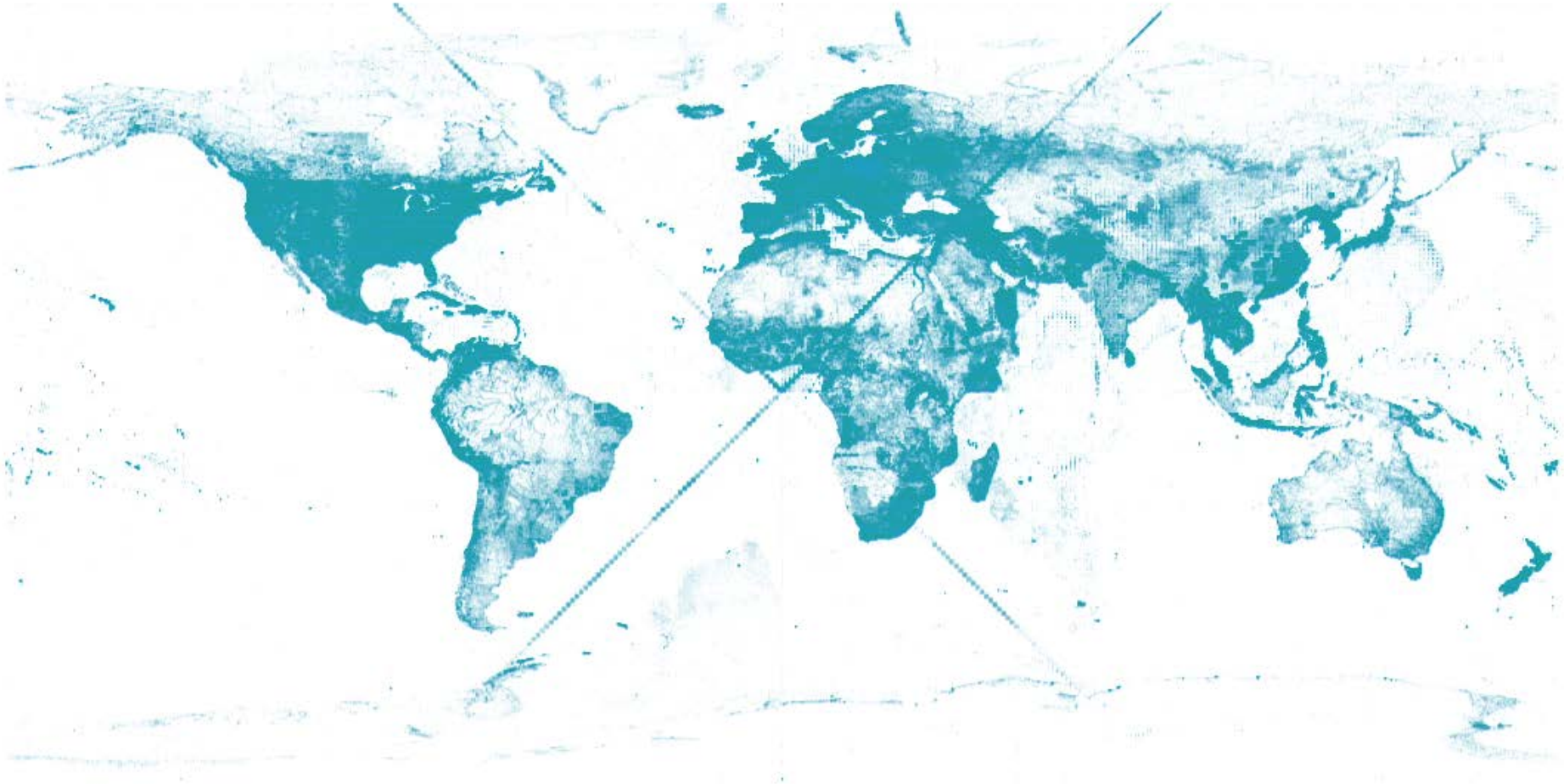


From <http://www4.wiwiss.fu-berlin.de/lodcloud/state/>

Linked Data: Volume

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 ...

“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.

“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

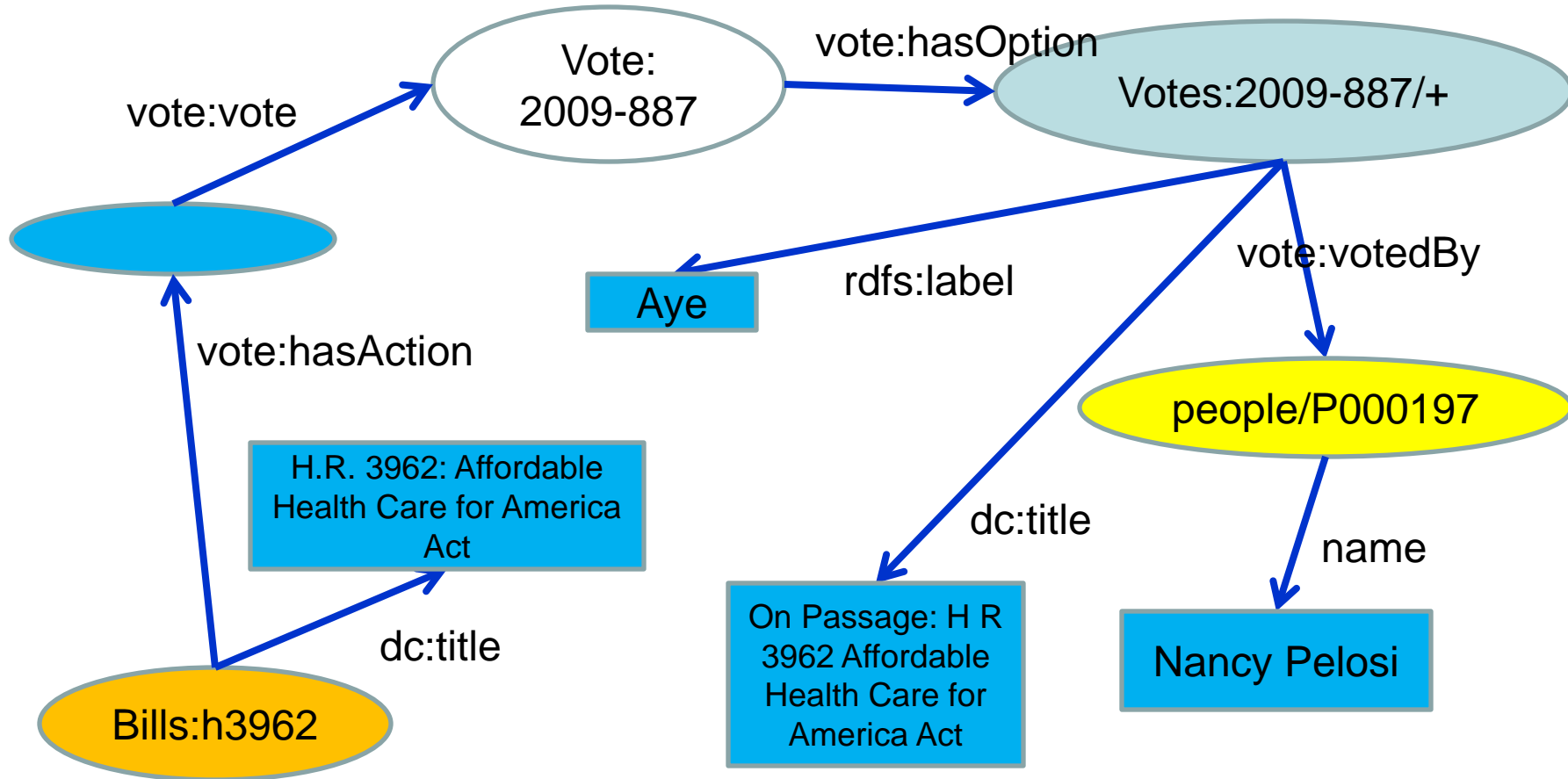
requires intimate knowledge of the LoD data sets

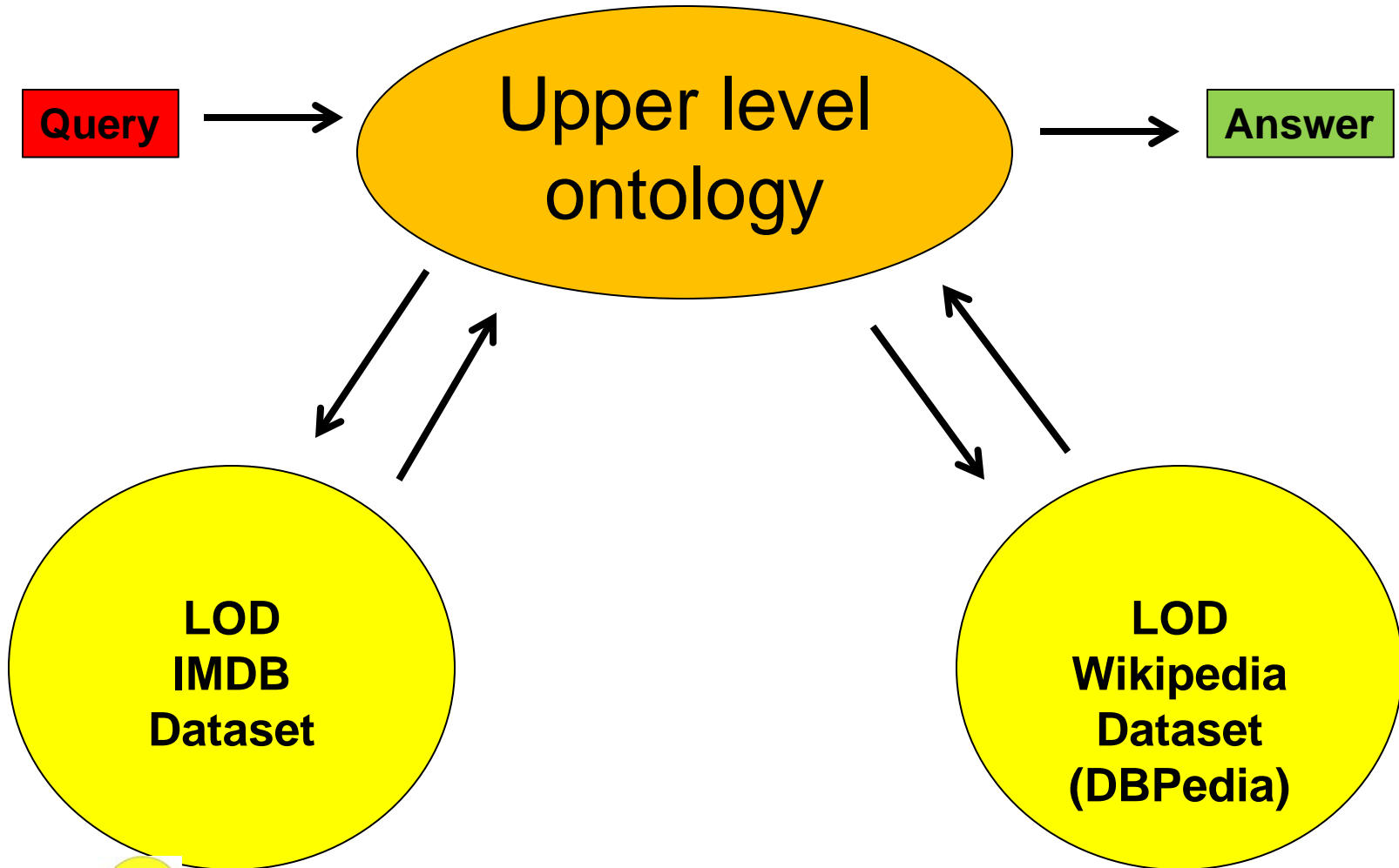
“Identify congress members, who have voted “No” on pro **environmental legislation** in the past four years, with **high-pollution industry** in their congressional districts.”

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.”

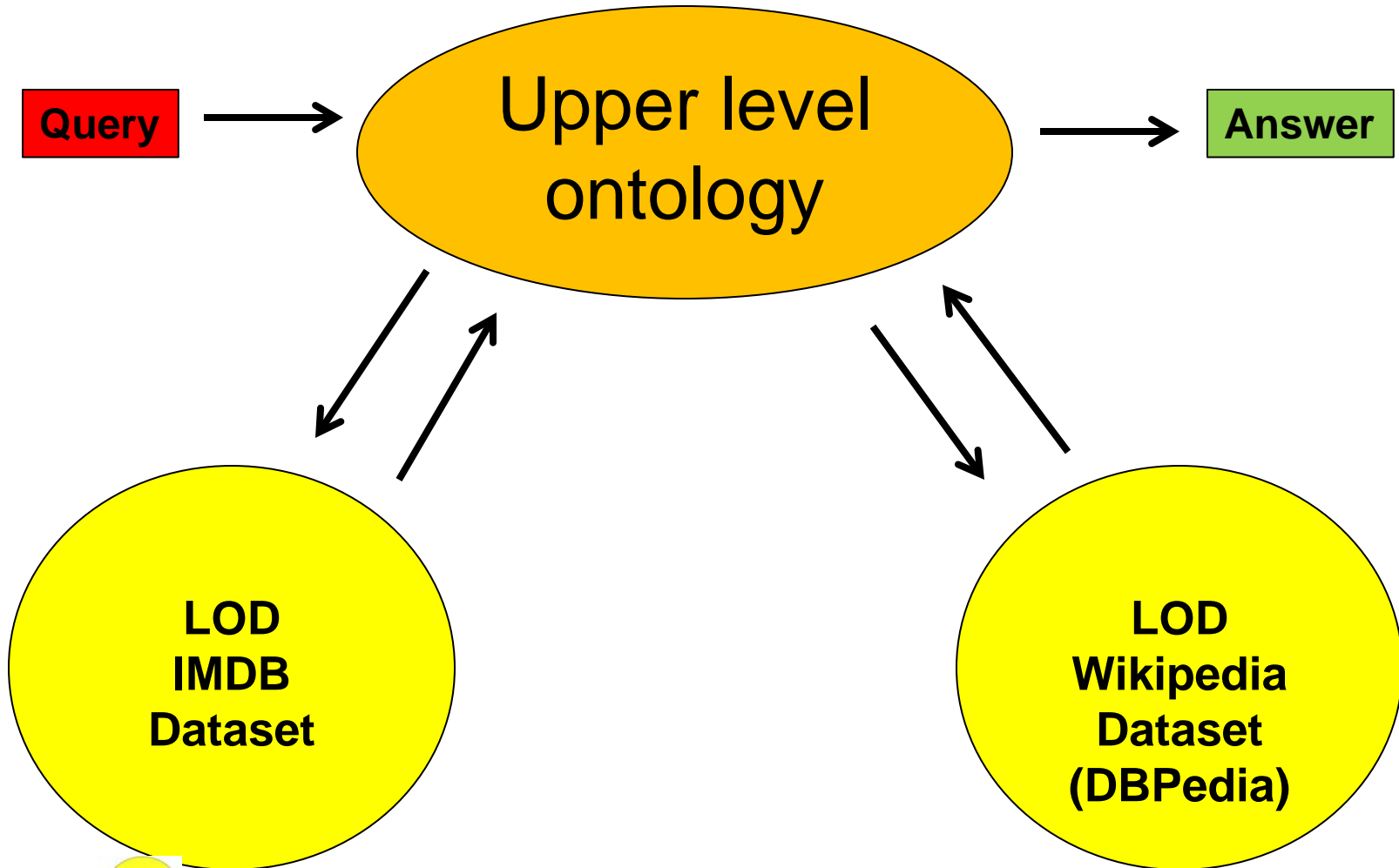




Joshi, Jain, Hitzler et al. ODBASE 2012

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												
Test	Alignment API OMViaUO		RiMoM		S-Match		AROMA		BLOOMS			
	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



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
```

```
?film rdf:type
```

```
?film rdfs:label
```

```
?nation protont:populationCount
```

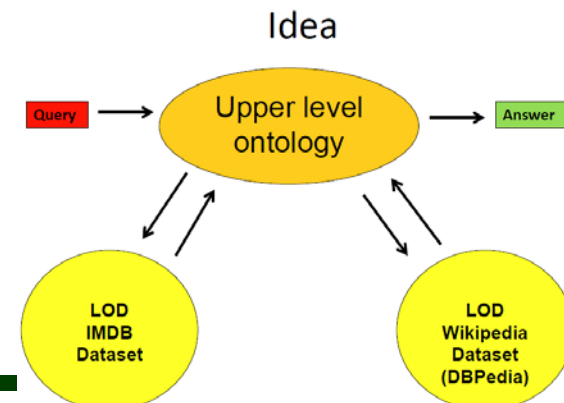
```
}
```

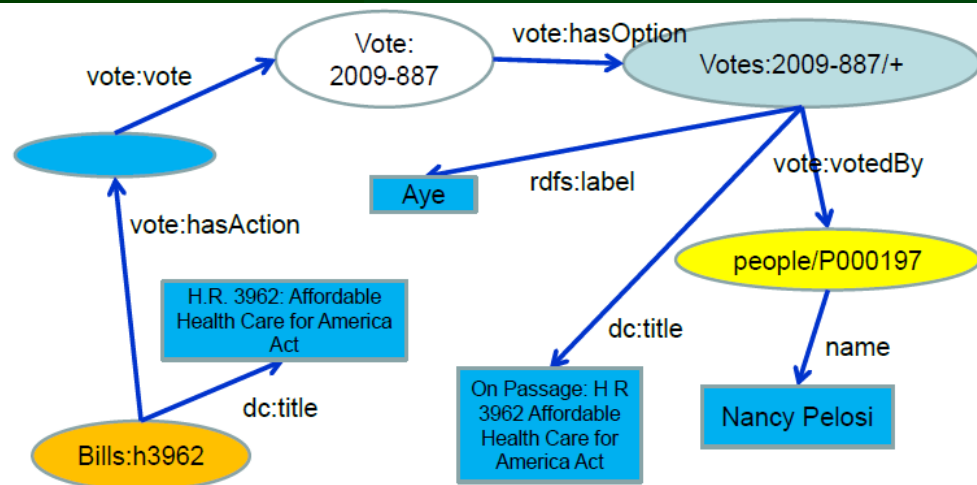
```
?nation.
```

```
protonu:Movie.
```

```
?film_name.
```

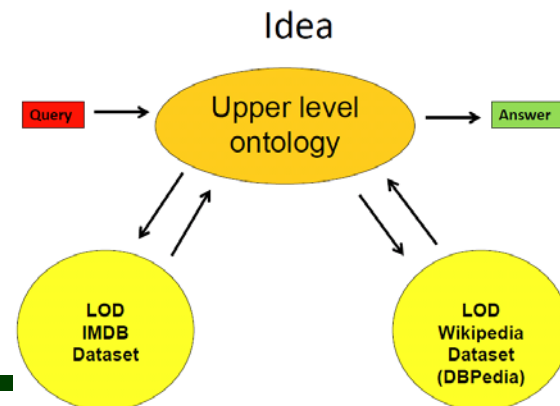
```
?pop.
```





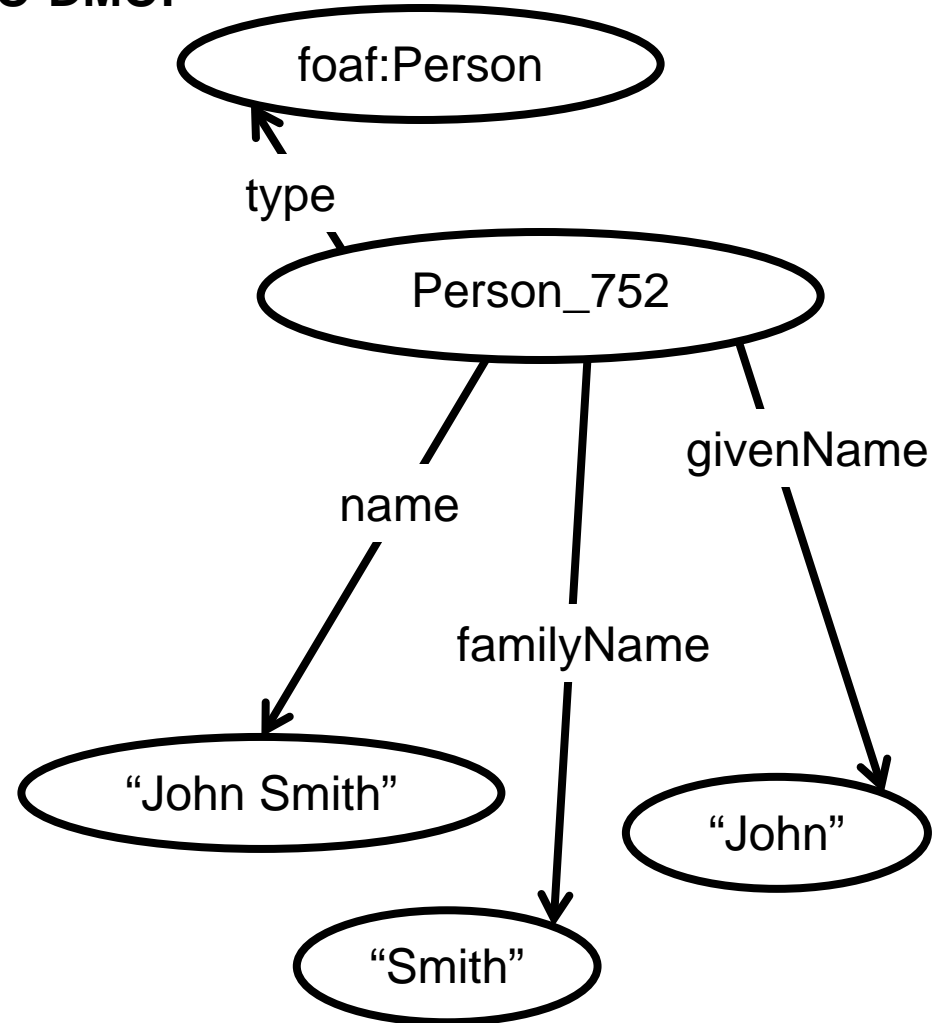
Works very well, but only in some very limited cases.

Cannot deal with graph representations of even very minimal complexity.

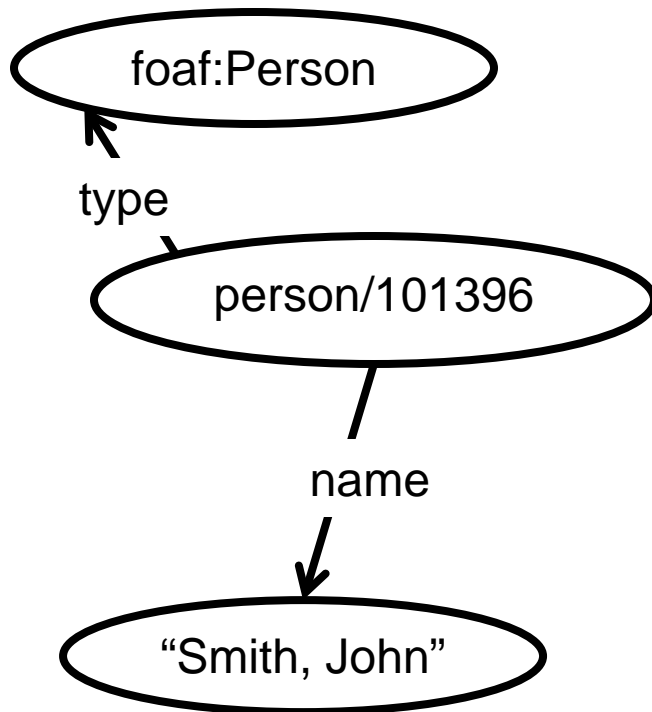


Automated federation?

BCO-DMO:



R2R:

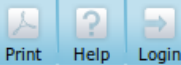


$a:\text{hasWife} \sqsubseteq a:\text{hasSpouse}$
 $\text{symmetric}(a:\text{hasSpouse})$
 $\exists a:\text{hasSpouse}.a:\text{Female} \sqsubseteq a:\text{Male}$
 $\exists a:\text{hasSpouse}.a:\text{Male} \sqsubseteq a:\text{Female}$
 $a:\text{hasWife}(a:\text{john}, a:\text{mary})$
 $b:\text{Male}(a:\text{john})$
 $b:\text{Female}(a:\text{mary})$
 $a:\text{Male} \sqcap a:\text{Female} \sqsubseteq \perp$

$\text{symmetric}(b:\text{hasSpouse})$
 $b:\text{hasSpouse}(b:\text{mike}, b:\text{david})$
 $b:\text{Male}(b:\text{david})$
 $b:\text{Male}(b:\text{mike})$
 $b:\text{Female}(b:\text{anna})$

Automated federation?

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



Copernicus (lunar crater)

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[View](#) [Revisions](#)

Copernicus is a [lunar impact crater](#) named after the astronomer [Nicolaus Copernicus](#), located in eastern [Oceanus Procellarum](#). It is estimated to be about 800 million years old, and typifies craters that formed during the [Copernican period](#) in that it has a prominent [ray system](#).

Contents

- [Characteristics](#)
- [Names](#)
- [Satellite craters](#)
- [See also](#)
- [References](#)
- [External links](#)

Characteristics

Copernicus is visible using [binoculars](#), and is located slightly northwest of the center of the Moon's Earth-facing hemisphere. South of the crater is the [Mare Insularum](#), and to the south-south west is the crater [Reinhold](#). North of Copernicus are the [Montes Carpatus](#), which lie at the south edge of [Mare Imbrium](#). West of Copernicus is a group of dispersed lunar hills. Due to its relative youth, the crater has remained in a relatively pristine shape since it formed.

The circular rim has a discernible hexagonal form, with a [terraced](#) inner wall and a 30 km wide, sloping [rampart](#) that descends nearly a kilometer to the surrounding [mare](#). There are three distinct terraces visible, and arc-shaped [landslides](#) due to slumping of the inner wall as the crater debris subsided.

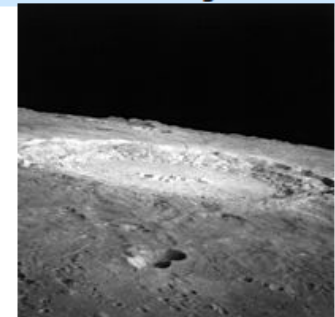
Most likely due to its recent formation, the crater floor has not been flooded

Location of Copernicus.

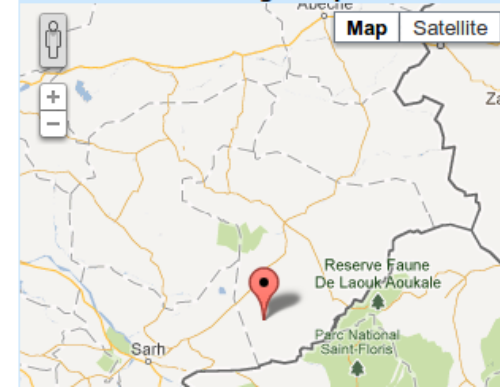


Location of Copernicus.

Image



Google Map



- “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?

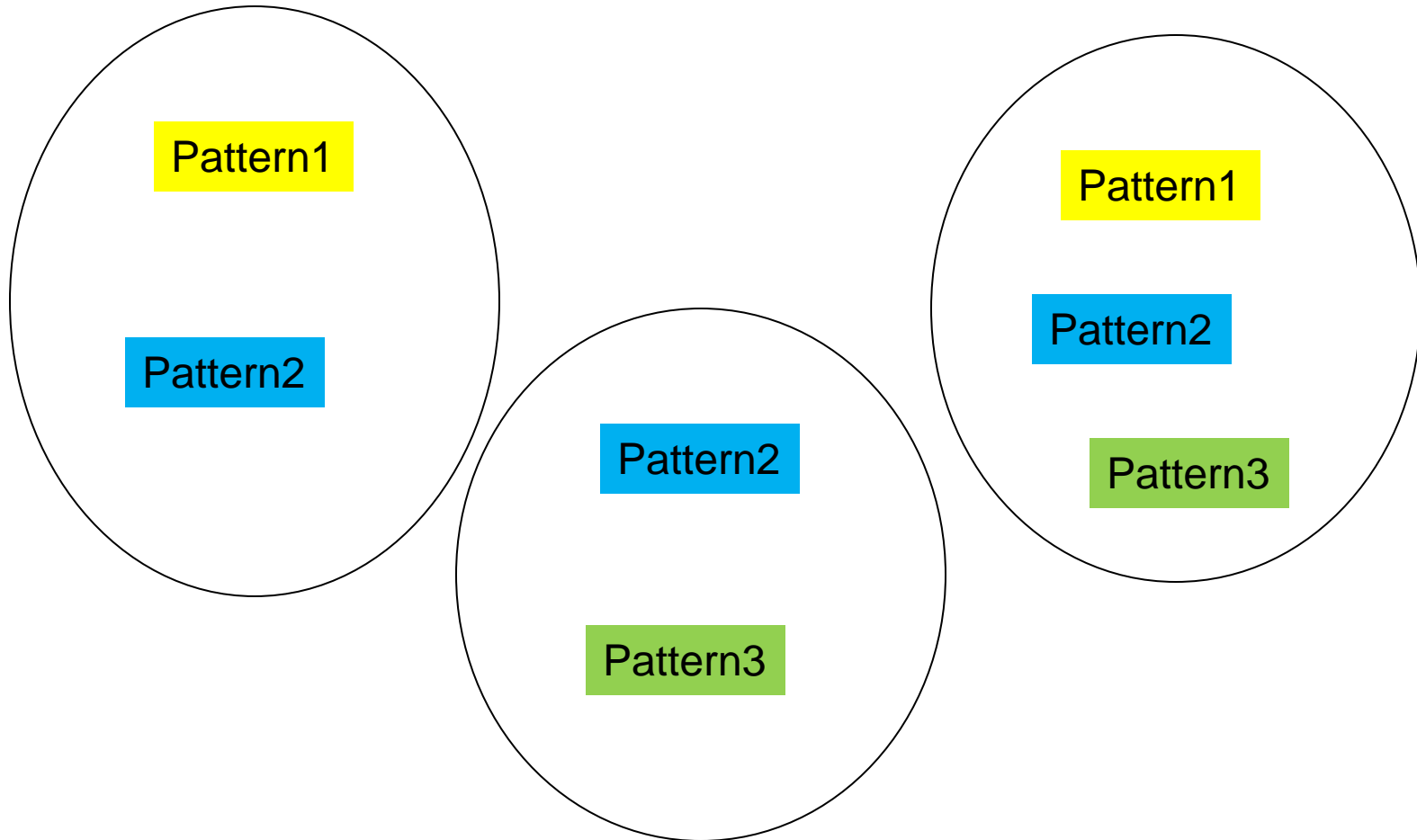
How to establish a flexible conceptual architecture using data and ontological modeling?

“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.

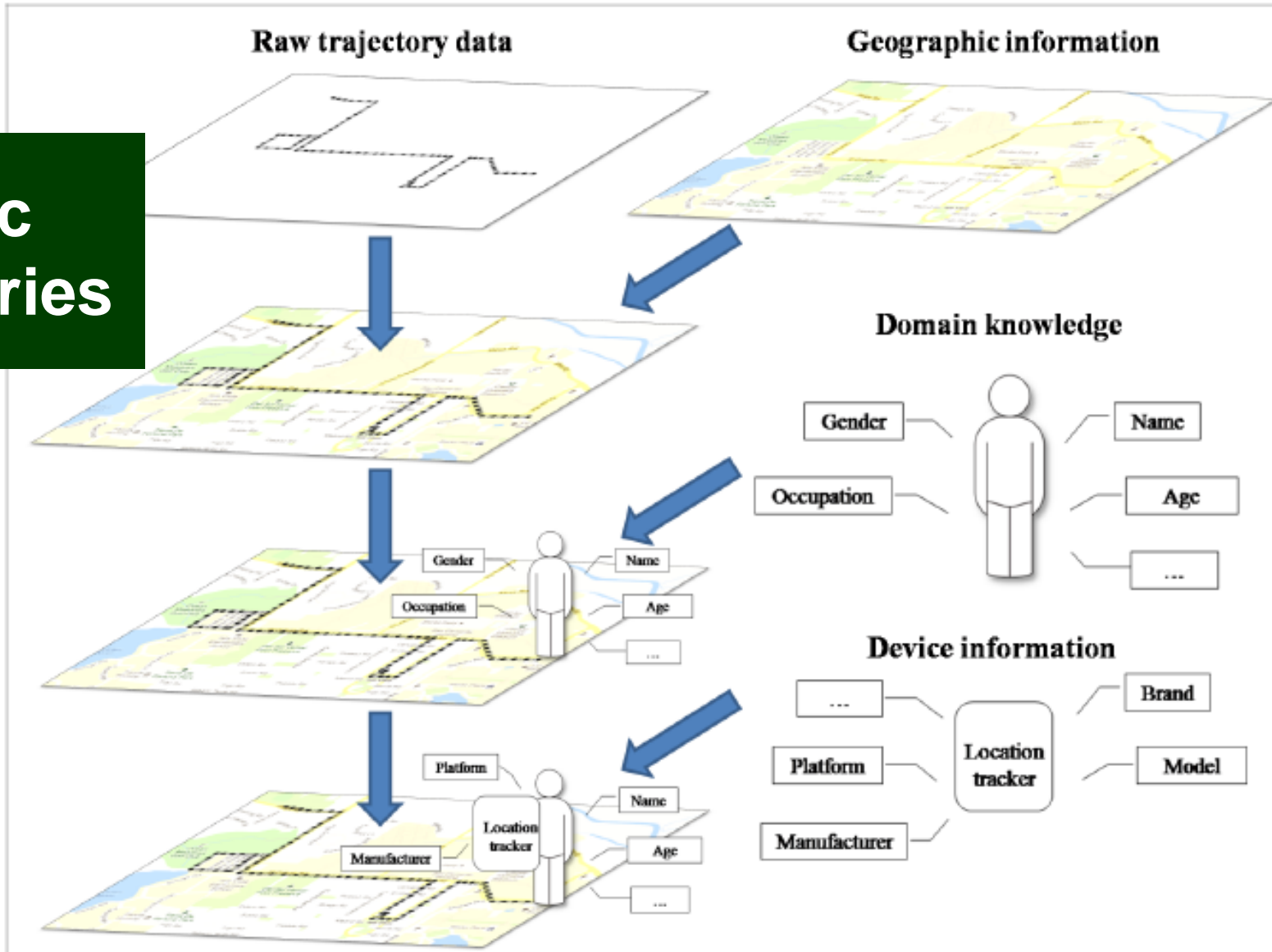
- **Bottom-up homogenization of data representation.**
- **Avoidance of strong ontological commitments.**
- **Avoidance of standardization of specific modeling details.**
- **Well thought-out patterns can be very strong and versatile, thus serve many needs.**

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

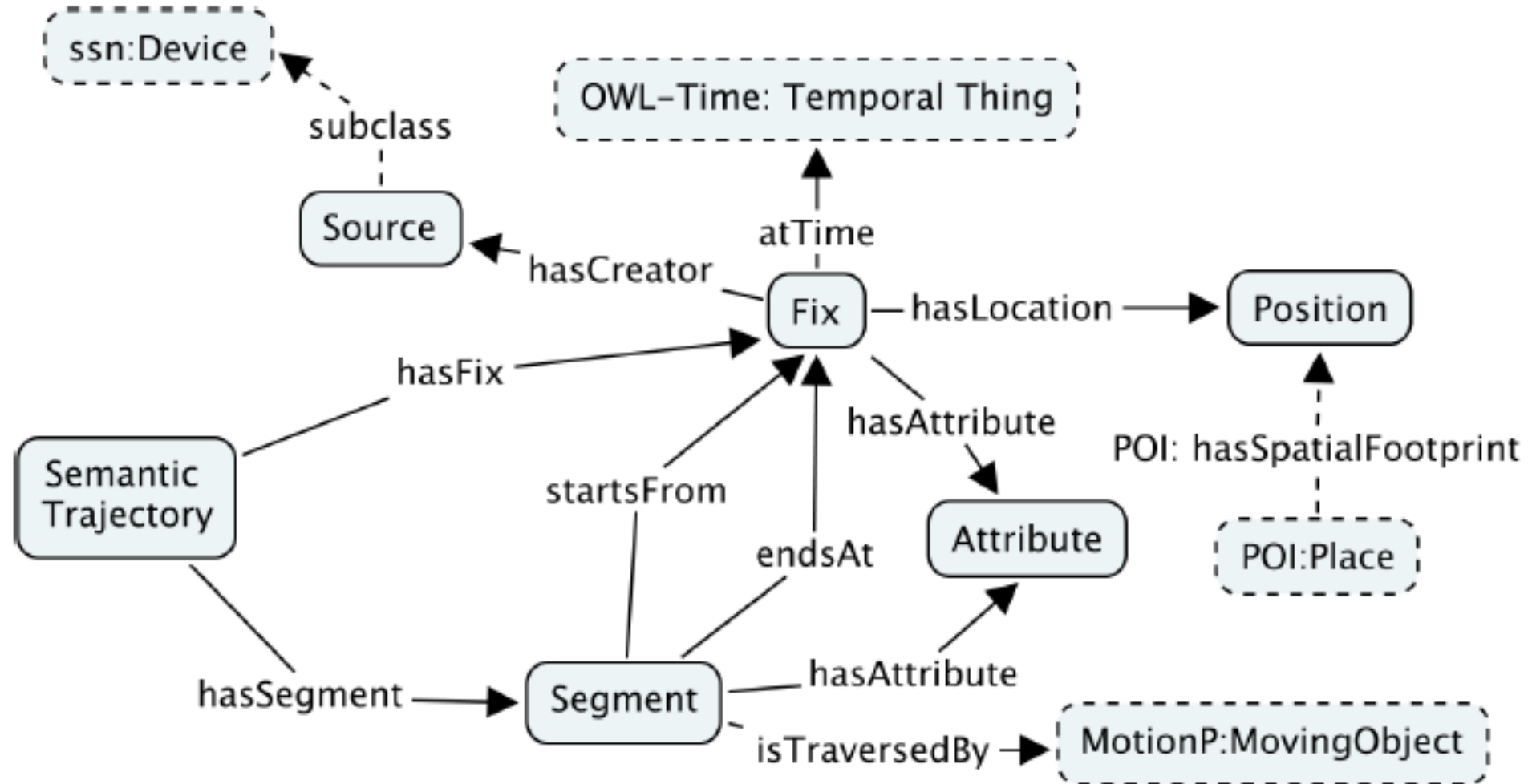


“Horizontal” alignment via patterns

Semantic Trajectories



[Hu, Janowicz, Carral, Scheider, Kuhn, Berg-Cross, Hitzler, Dean, COSIT2013]



$$\begin{aligned} \textit{Fix} \sqsubseteq & \exists \textit{atTime}. \textit{OWL-Time:Temporal Thing} \sqcap \exists \textit{hasLocation}. \textit{Position} \\ & \sqcap \exists \textit{hasFix}^- . \textit{SemanticTrajectory} \end{aligned} \quad (1)$$

$$\textit{Segment} \sqsubseteq \exists \textit{startsFrom}. \textit{Fix} \sqcap \exists \textit{endsAt}. \textit{Fix} \quad (2)$$

$$\top \sqsubseteq \leq 1 \textit{startsFrom}. \top \quad (3)$$

$$\top \sqsubseteq \leq 1 \textit{endsAt}. \top \quad (4)$$

$$\textit{Segment} \sqsubseteq \exists \textit{hasSegment}^- . \textit{SemanticTrajectory} \quad (5)$$

$$\textit{startsFrom}^- \circ \textit{endsAt} \sqsubseteq \textit{hasNext} \quad (6)$$

$$\textit{hasNext} \sqsubseteq \textit{hasSuccessor} \quad (7)$$

$$\textit{hasSuccessor} \circ \textit{hasSuccessor} \sqsubseteq \textit{hasSuccessor} \quad (8)$$

$$\textit{hasNext}^- \sqsubseteq \textit{hasPrevious} \quad (9)$$

$$\textit{hasSuccessor}^- \sqsubseteq \textit{hasPredecessor} \quad (10)$$

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

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

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

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

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

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

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

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

$$\exists hasSegment^- .SemanticTrajectory \sqsubseteq Segment \quad (19)$$

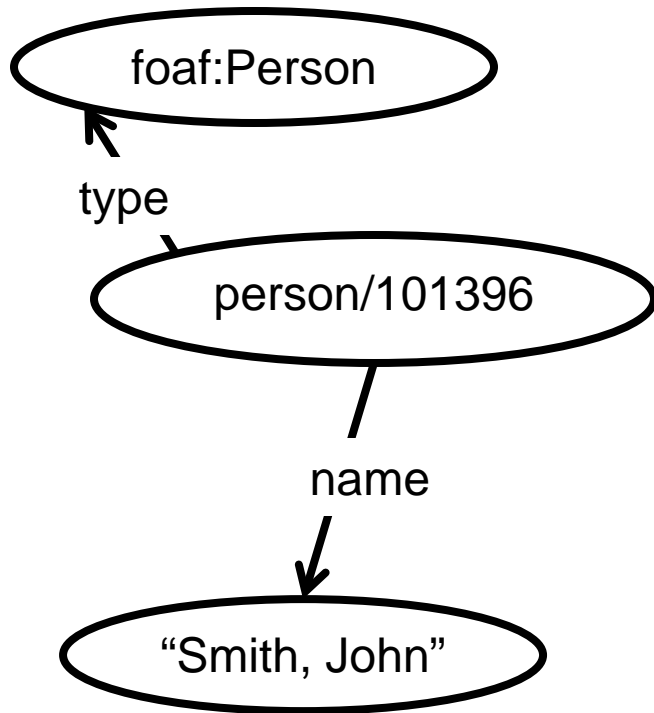
$$\exists hasFix.Segment \sqsubseteq SemanticTrajectory \quad (20)$$

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

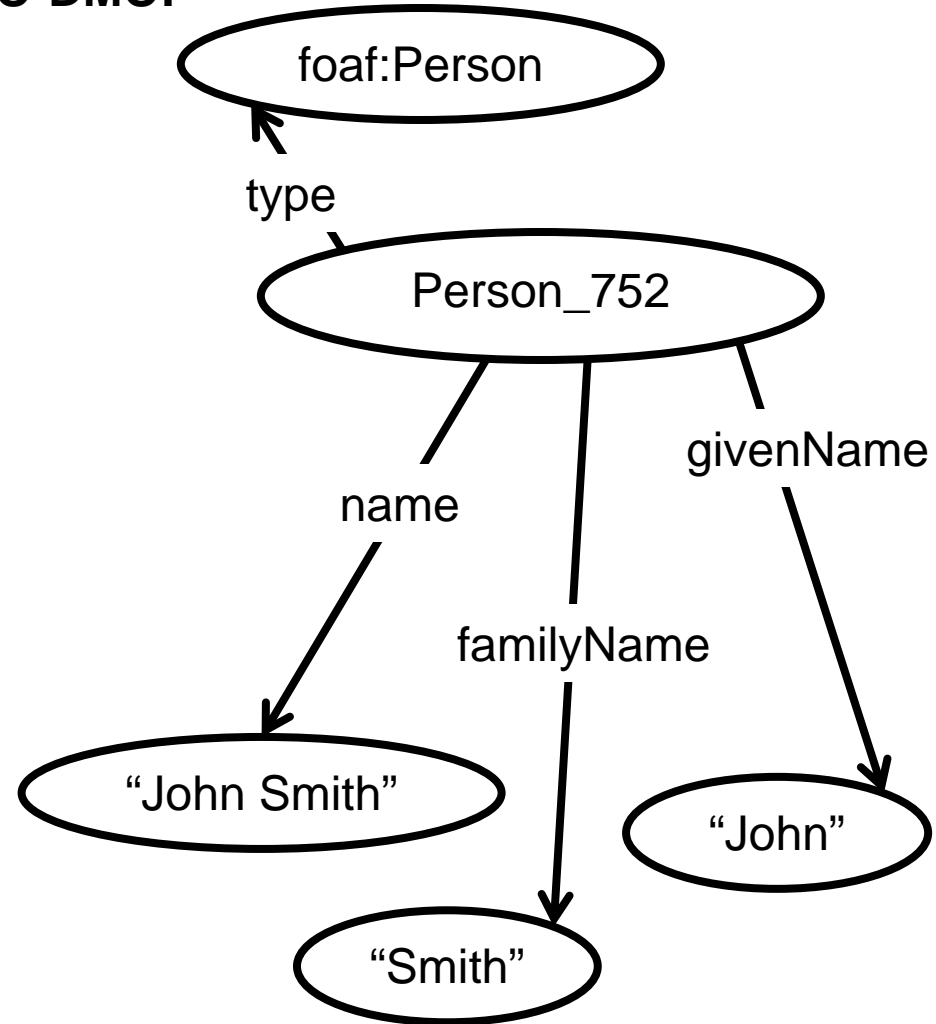
Helpfulness of patterns

Even minimalistic reuse is helpful:

R2R:



BCO-DMO:



- **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.**

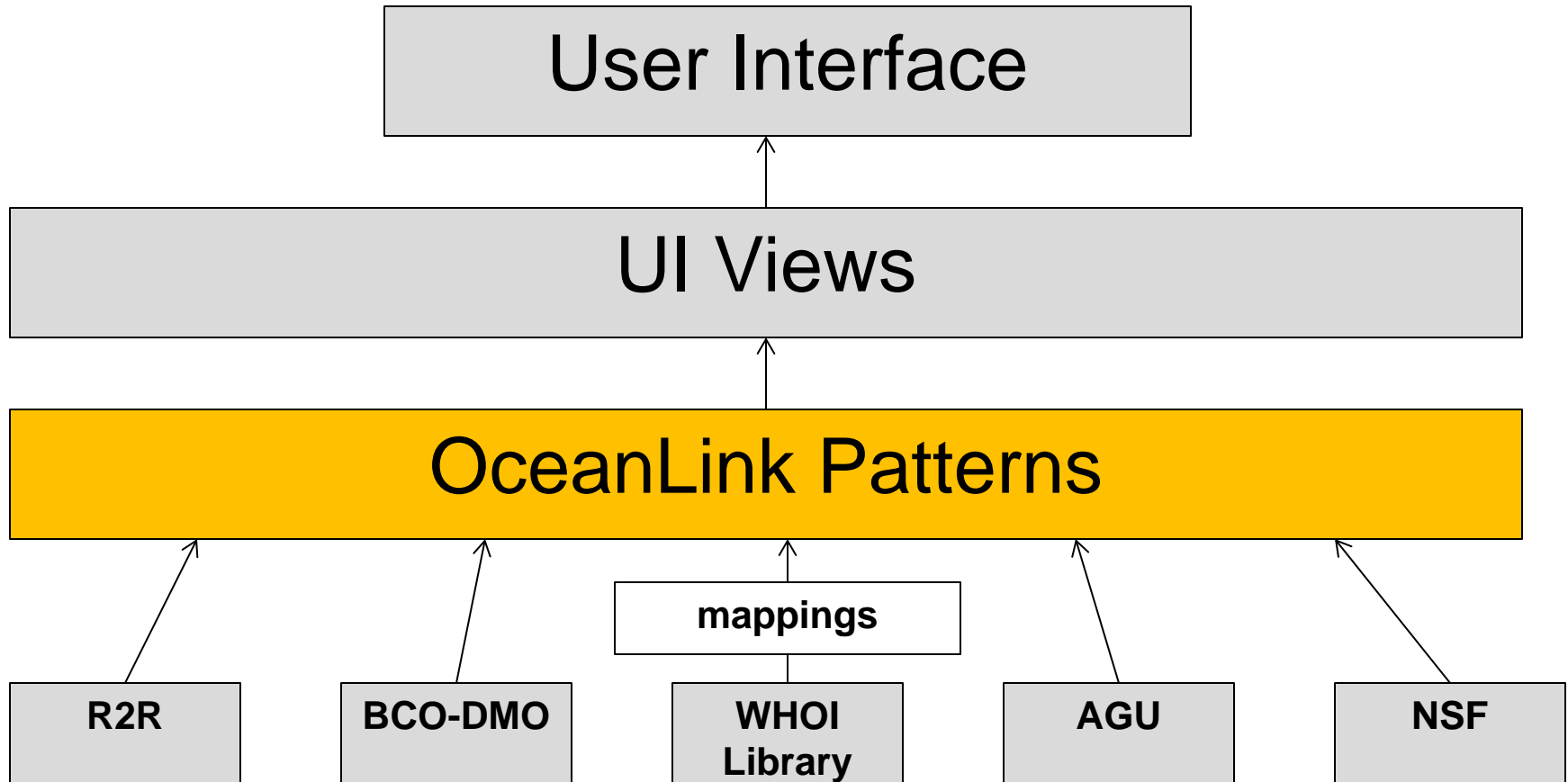
National Science Foundation award 1354778 "EAGER: Collaborative Research: EarthCube Building Blocks, Leveraging Semantics and Linked Data for Geoscience Data Sharing and Discovery."

EarthCube:

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

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

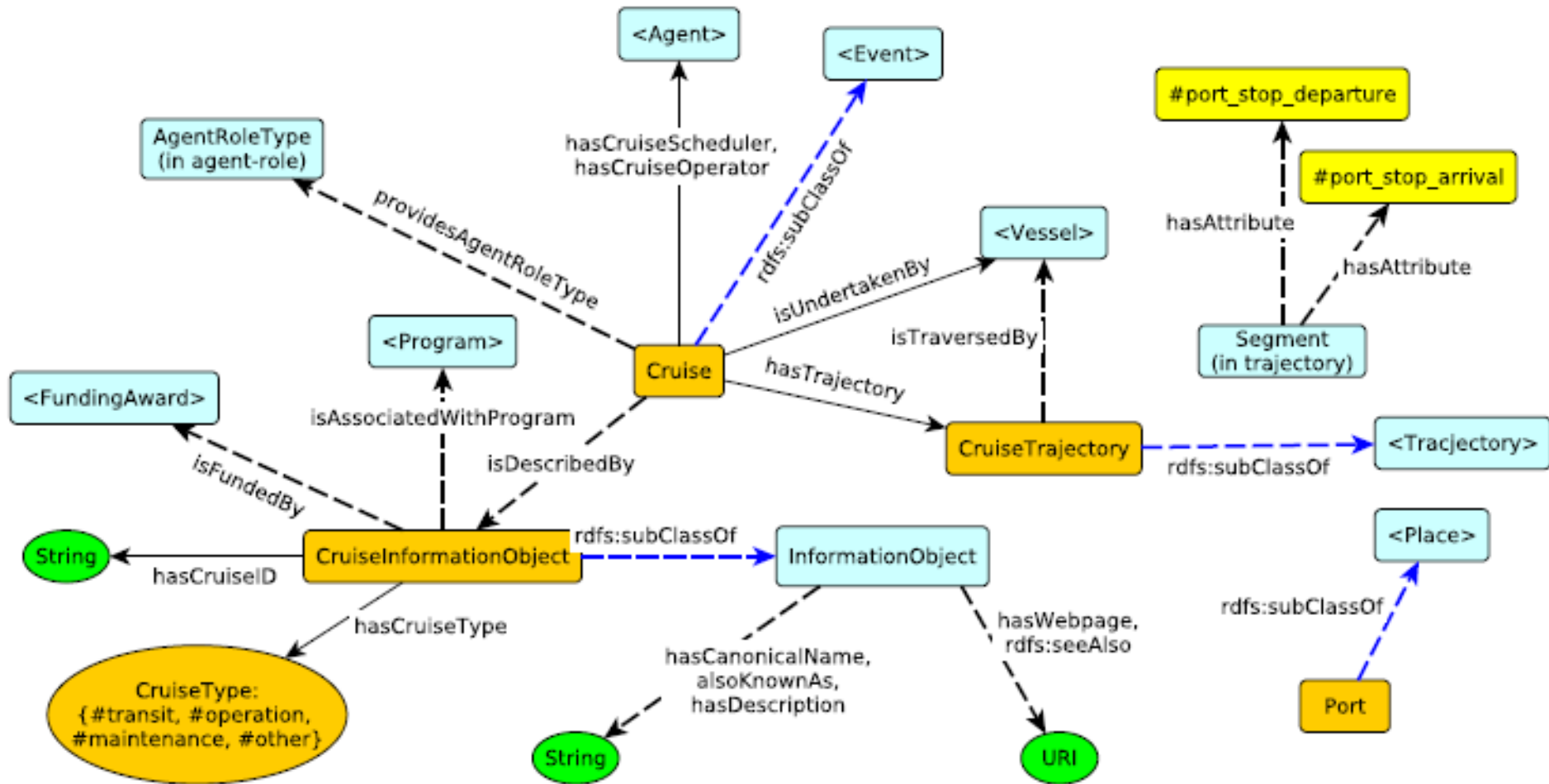
“EarthCube aims to create a well-connected and facile environment to share data and knowledge in an open, transparent, and inclusive manner, thus accelerating our ability to understand and predict the Earth system.”



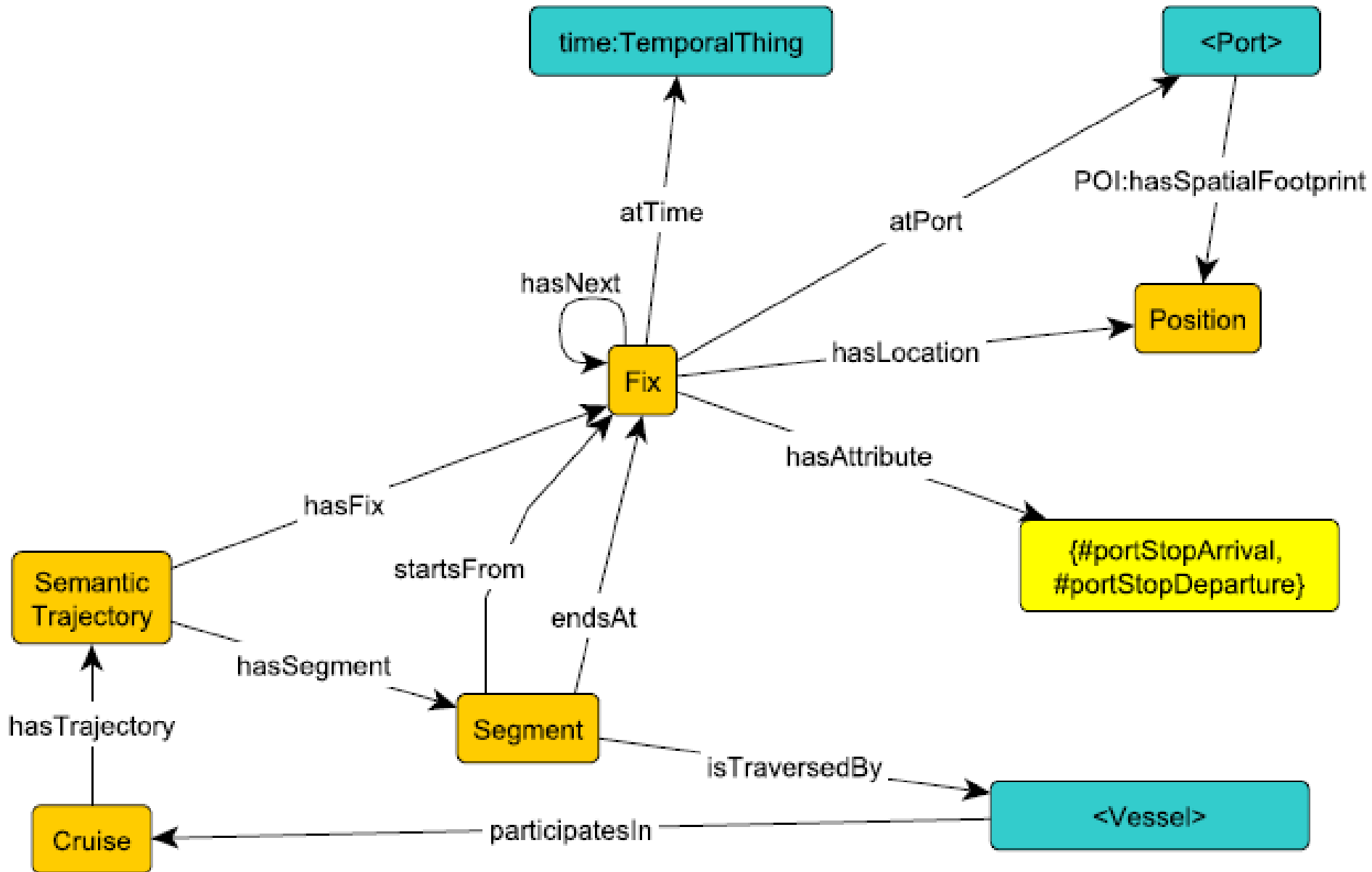
Some central patterns:

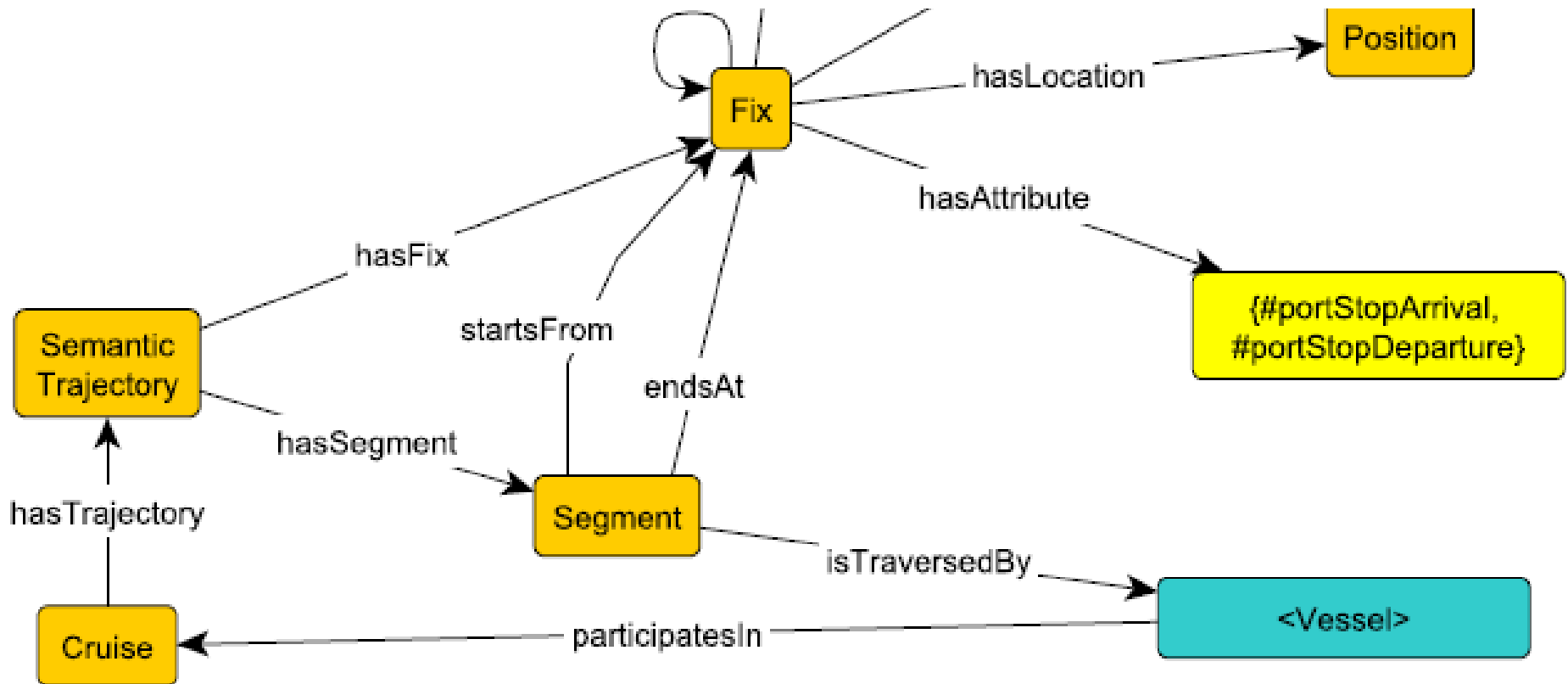
- **Cruise**
- **Trajectory**
- **Person**
- **Organization**
- **Roles of Agents**
- **Repository Object**
- **Data Set**
- **Document**

We're not starting from zero of course.

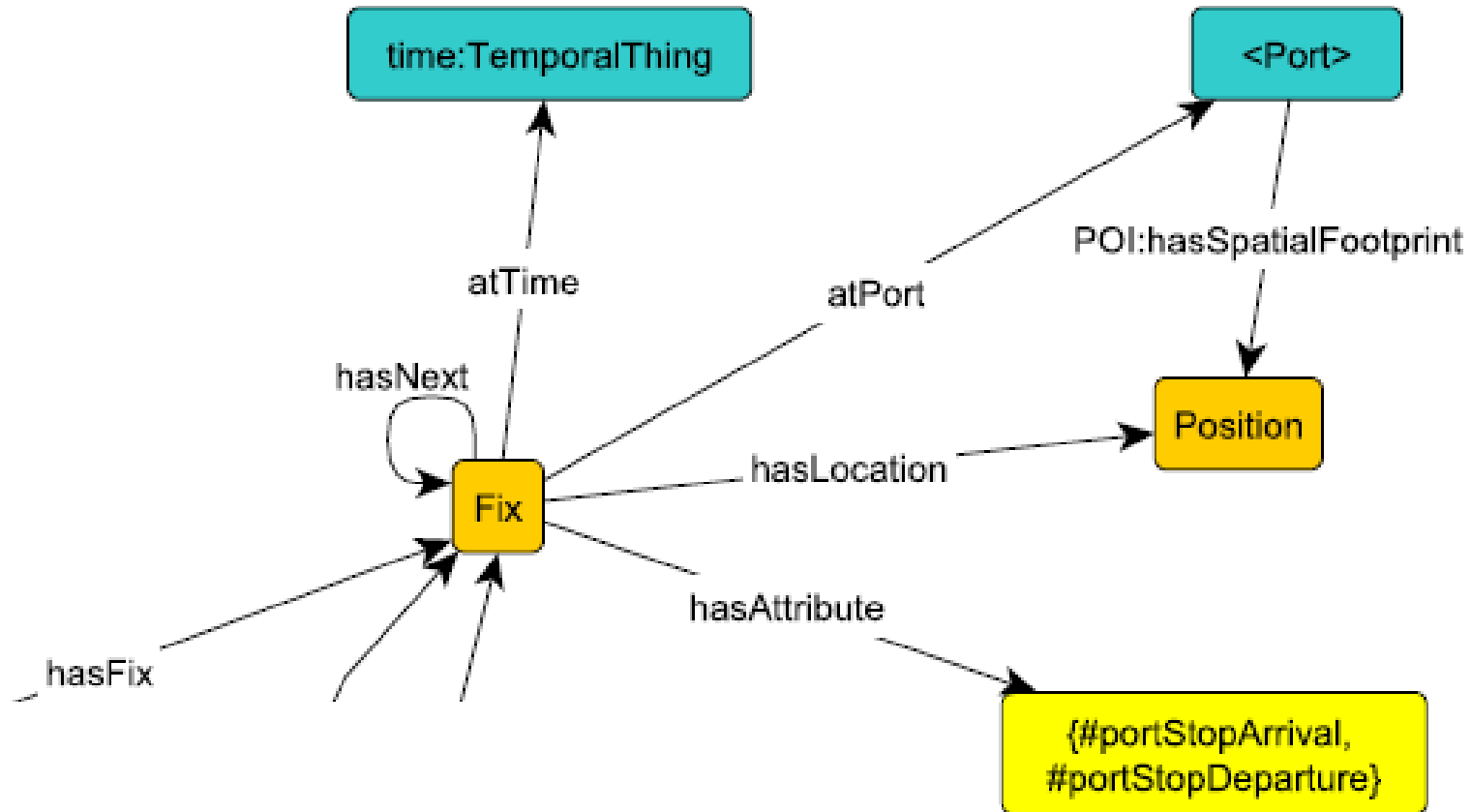


Cruise trajectory (draft)

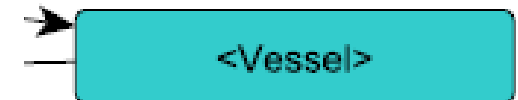


$$\begin{aligned} & \text{Cruise}(x) \wedge \text{hasTrajectory}(x, y) \\ & \quad \wedge \text{hasSegment}(y, z) \wedge \text{isTraversedBy}(z, v) \\ & \quad \rightarrow \text{participatesIn}(v, z) \end{aligned}$$


$$\begin{aligned} & \text{Cruise}(x) \wedge \text{hasTrajectory}(x, y) \\ & \quad \wedge \text{hasSegment}(y, z) \wedge \text{isTraversedBy}(z, v) \\ & \quad \rightarrow \text{participatesIn}(v, z) \end{aligned}$$
$$\text{Cruise} \equiv \exists \text{cruise}.\text{Self}$$
$$\begin{aligned} & \text{cruise} \circ \text{hasTrajectory} \circ \text{hasSegment} \circ \text{isTraversedBy} \\ & \quad \sqsubseteq \text{hasParticipant} \\ & \text{hasParticipant} \equiv \text{participatesIn}^- \end{aligned}$$



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



$$\begin{aligned} & \text{Fix}(x) \wedge \text{hasAttribute}(x, \#\text{portStopArrival}) \\ & \wedge \text{atPort}(x, y) \wedge \text{hasSpatialFootprint}(y, z) \\ & \wedge \text{hasLocation}(x, w) \rightarrow \text{locatedIn}(w, z) \end{aligned}$$
$$\begin{aligned} \text{Fix} \wedge \exists \text{hasTrajectory}.\{\#\text{portStopArrival}\} & \equiv \exists \text{fixps}.\text{Self} \\ & \text{hasLocation}^- \circ \text{fixps} \circ \text{atPort} \circ \text{hasSpatialFootprint} \\ & \sqsubseteq \text{locatedIn} \end{aligned}$$

- **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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