Ontologies in a Data-driven World

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Textbook

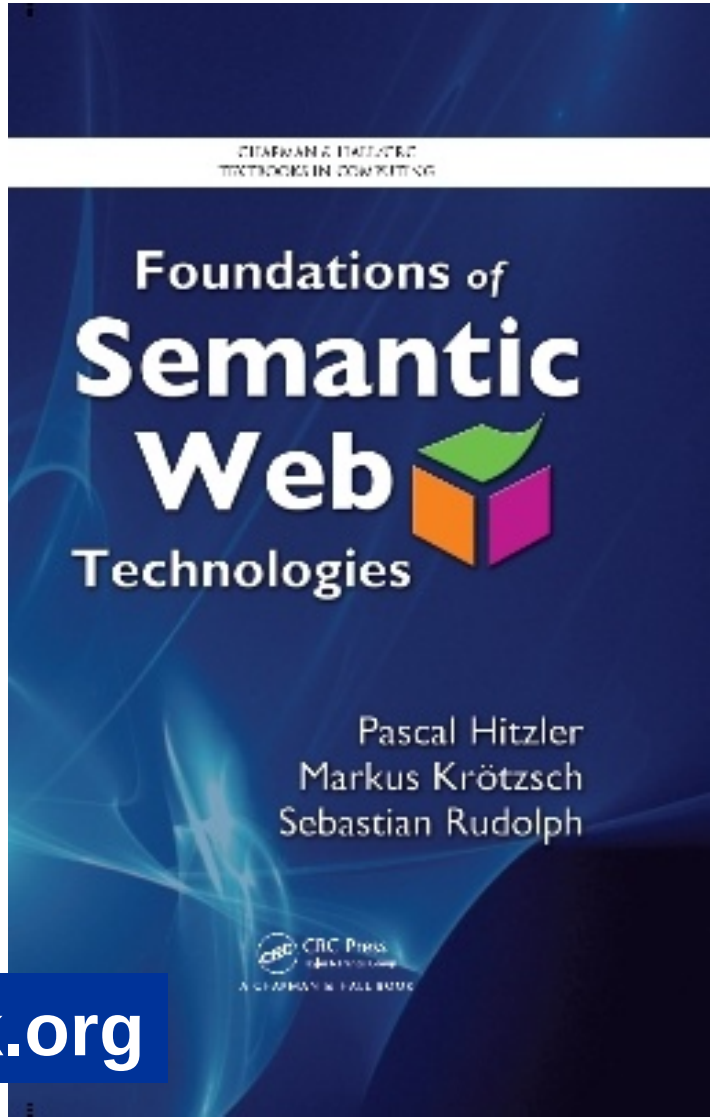
DaSe Lab

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

Semantic Web journal

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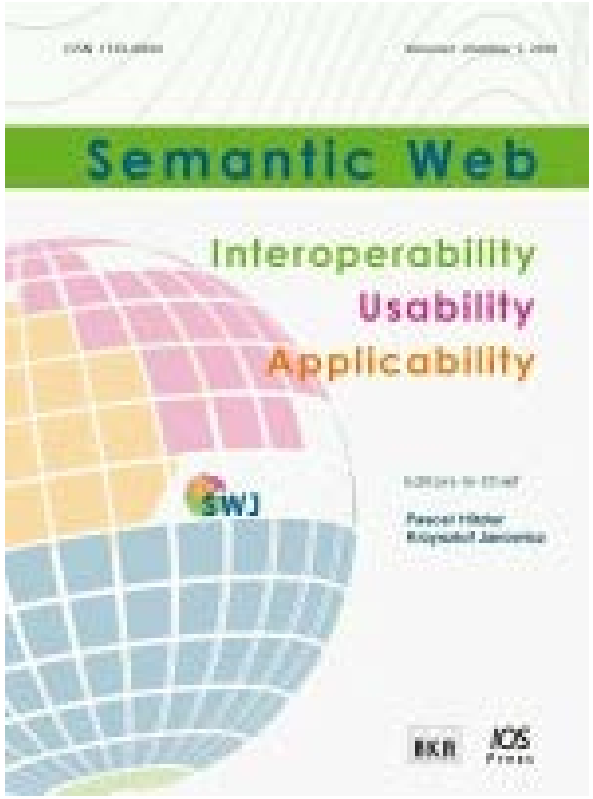
- **EiCs:** **Pascal Hitzler**
  Krzysztof Janowicz

- **New journal with significant initial 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.**

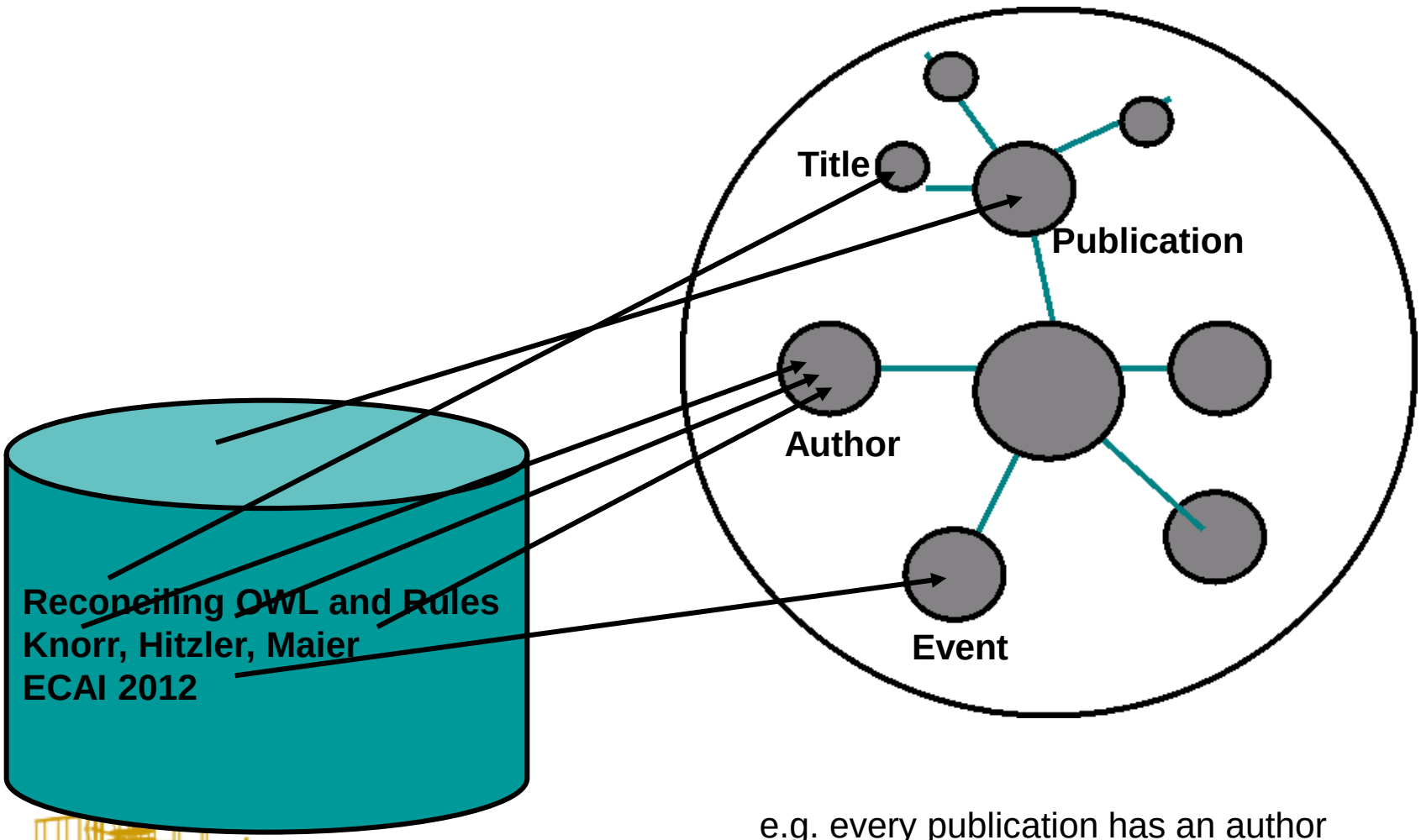
- **Non-standard (open & transparent) review process.**



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

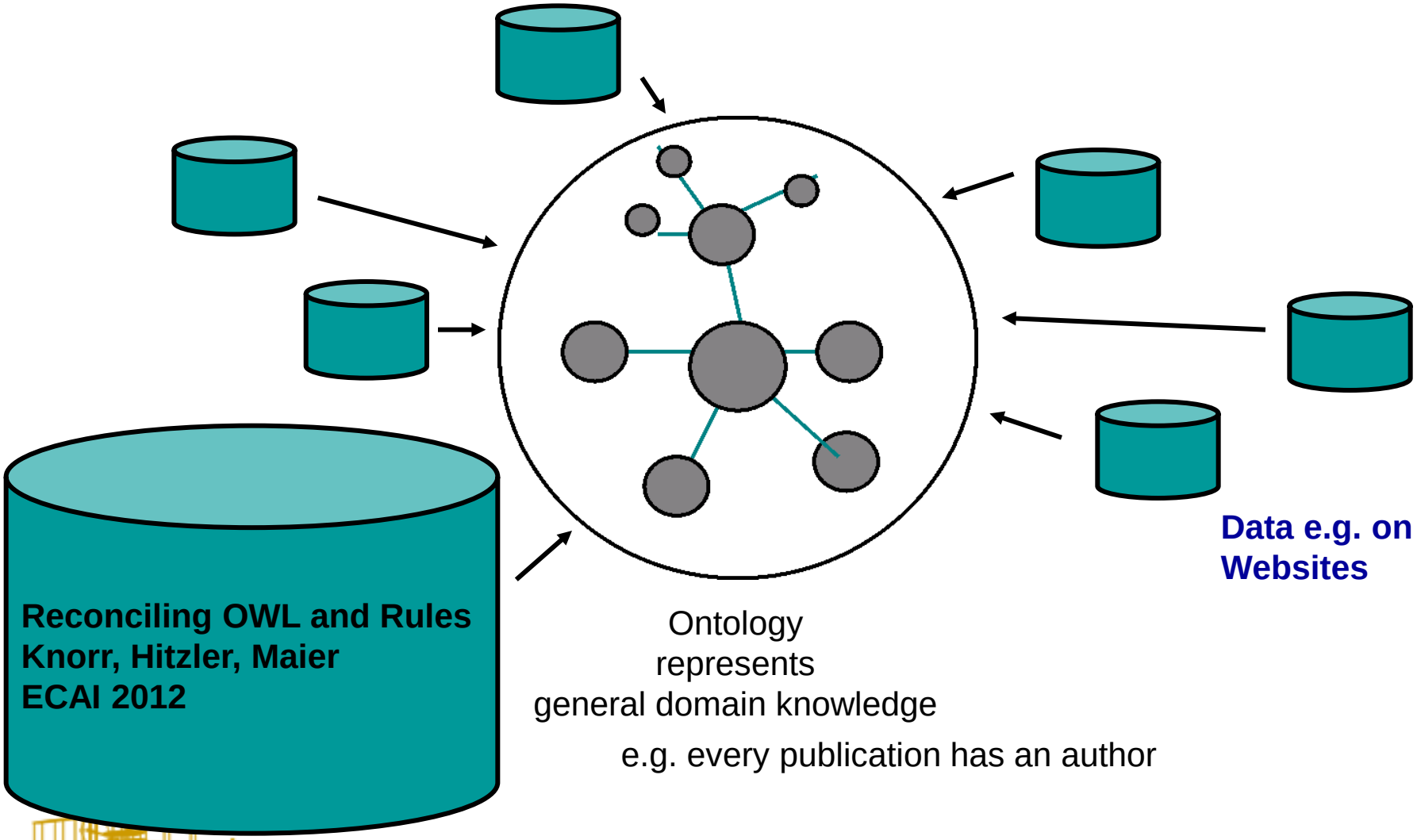
Ontologies?

A Basic Idea of the Semantic Web



e.g. every publication has an author

A Basic Idea of the Semantic Web



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."

  – But 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”.

Multiple perspectives

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$$\text{a:flowsInto} \sqsubseteq \text{a:IsConnected} \quad (1)$$
$$\text{a:IrrigationCanal} \sqsubseteq \text{a:Canal} \quad (2)$$
$$\exists \text{a:flowsInto.a:AgriculturalField} \sqsubseteq \text{a:IrrigationCanal} \quad (3)$$
$$\text{a:Waterbody} \sqcap \text{a:Land} \sqsubseteq \bot \quad (4)$$
$$\text{a:AgriculturalField} \sqsubseteq \text{a:Land} \quad (5)$$

$$\text{b:flowsInto} \sqsubseteq \text{b:IsConnected} \quad (6)$$
$$\text{b:Canal} \sqsubseteq (\geq 2\ \text{b:IsConnected.b:Waterbody}) \quad (7)$$
$$\text{b:IrrigationCanal} \equiv (=1\ \text{b:isConnected.b:Waterbody}) \sqcap (=1\ \text{b:flowsInto.b:AgriculturalField}) \quad (8)$$

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.**

Pre-LOD Semantic Web

- **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.”**

Information as RDF graph

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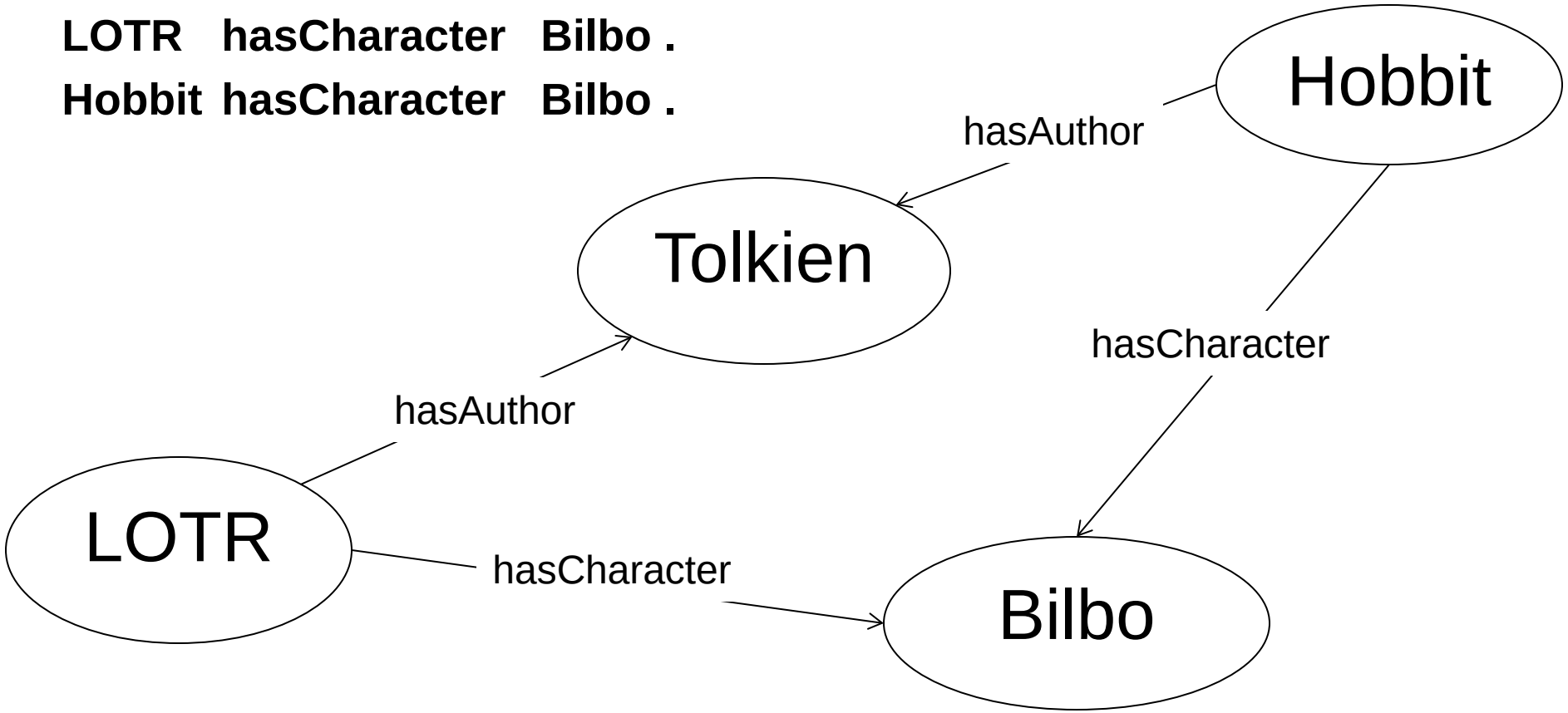
LOTR hasAuthor Tolkien .
Hobbit hasAuthor Tolkien .
LOTR hasCharacter Bilbo .
Hobbit hasCharacter Bilbo .



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

Linked Data: Volume

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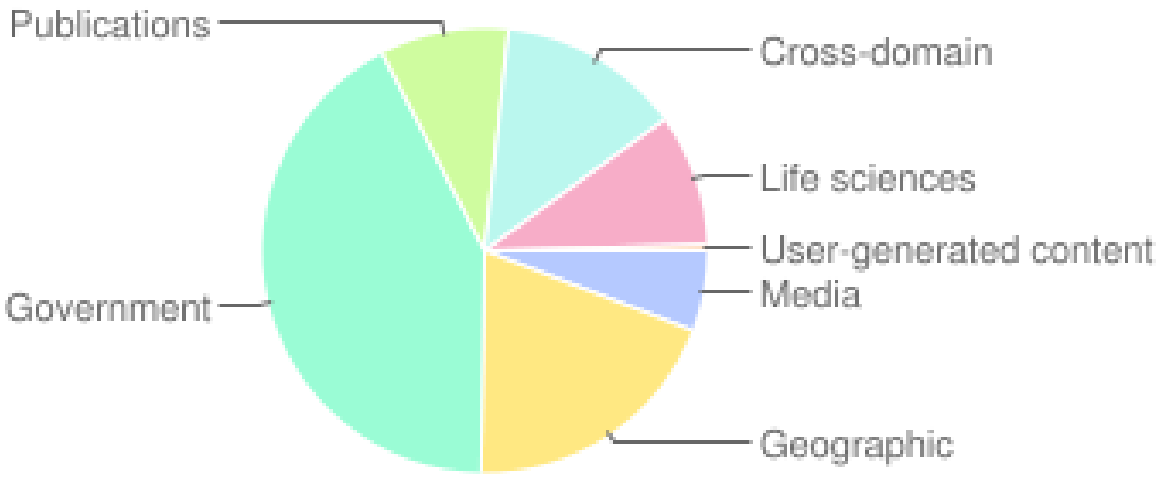
Number of Datasets

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

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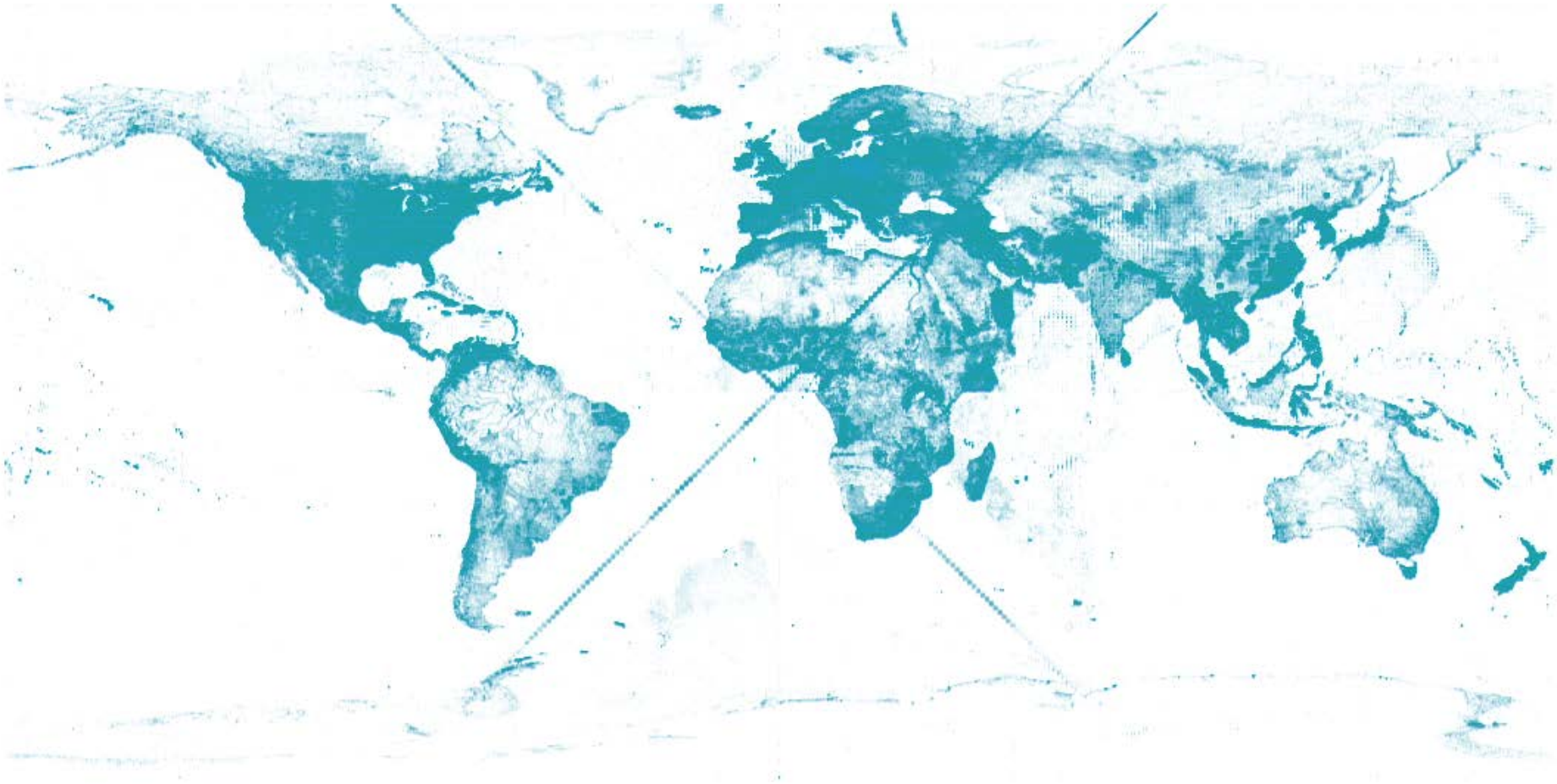
Geoindexed Linked Data – courtesy of Krzysztof Janowicz

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



Linked Data: Volume

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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

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"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

DaSe Lab

"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

DaSe Lab

"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)

Linked Data: Variety

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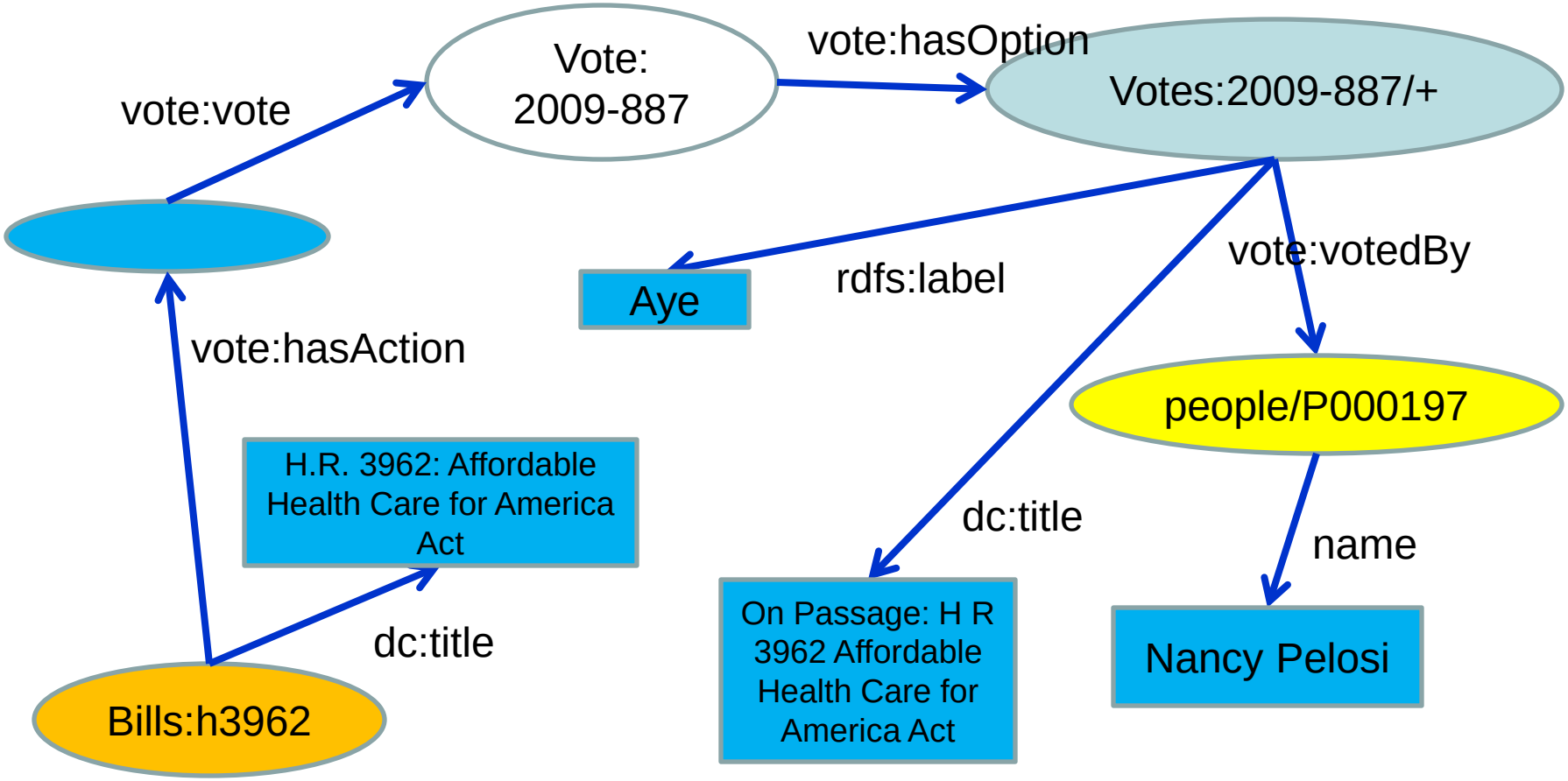
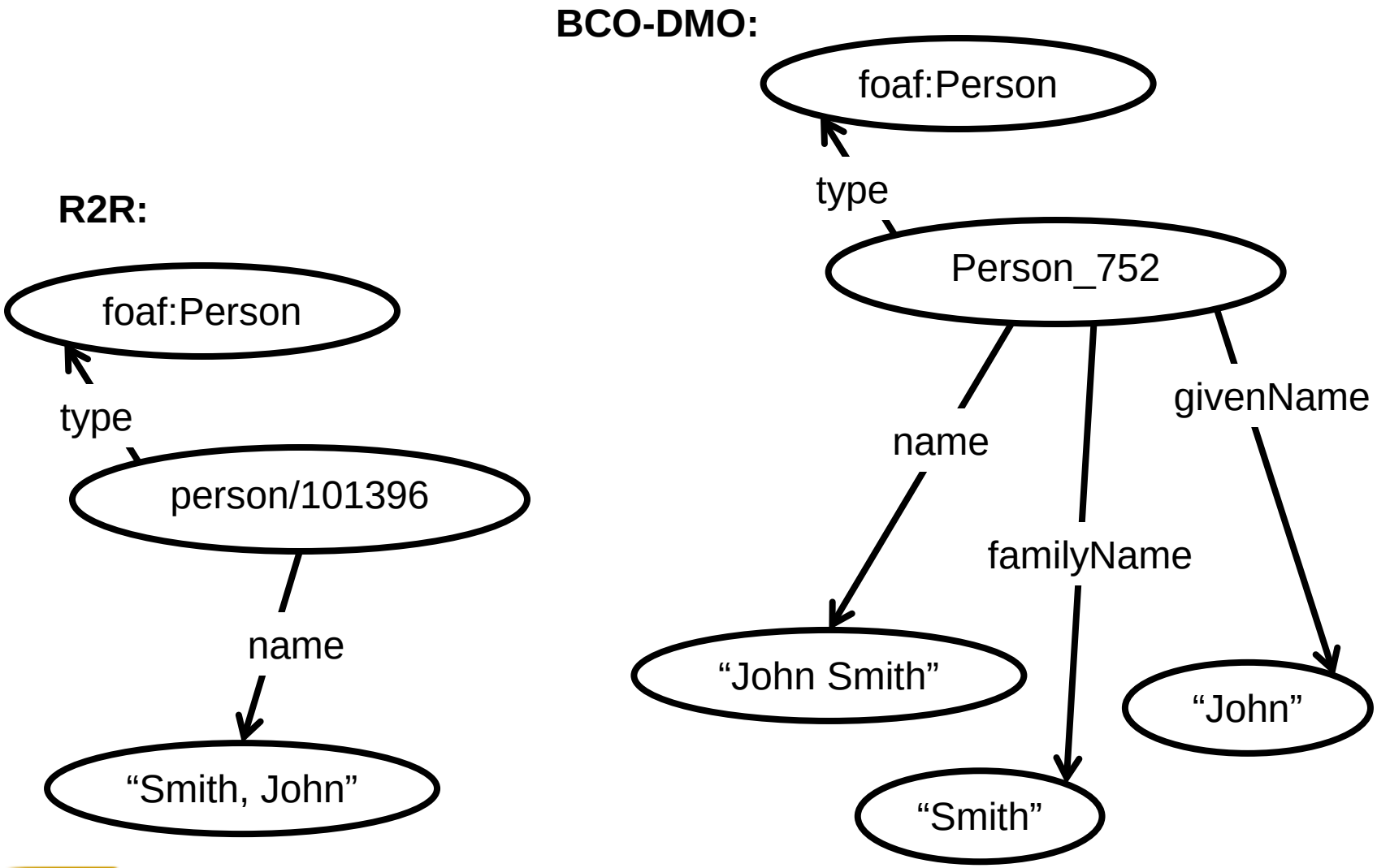
“Nancy Pelosi voted in favor of the Health Care Bill.”



Data Variety



Data Variety

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

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

Data Variety

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

Information Workbench

Print Help Login

Copernicus (lunar crater)

You do not have permission to edit this page. 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

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

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

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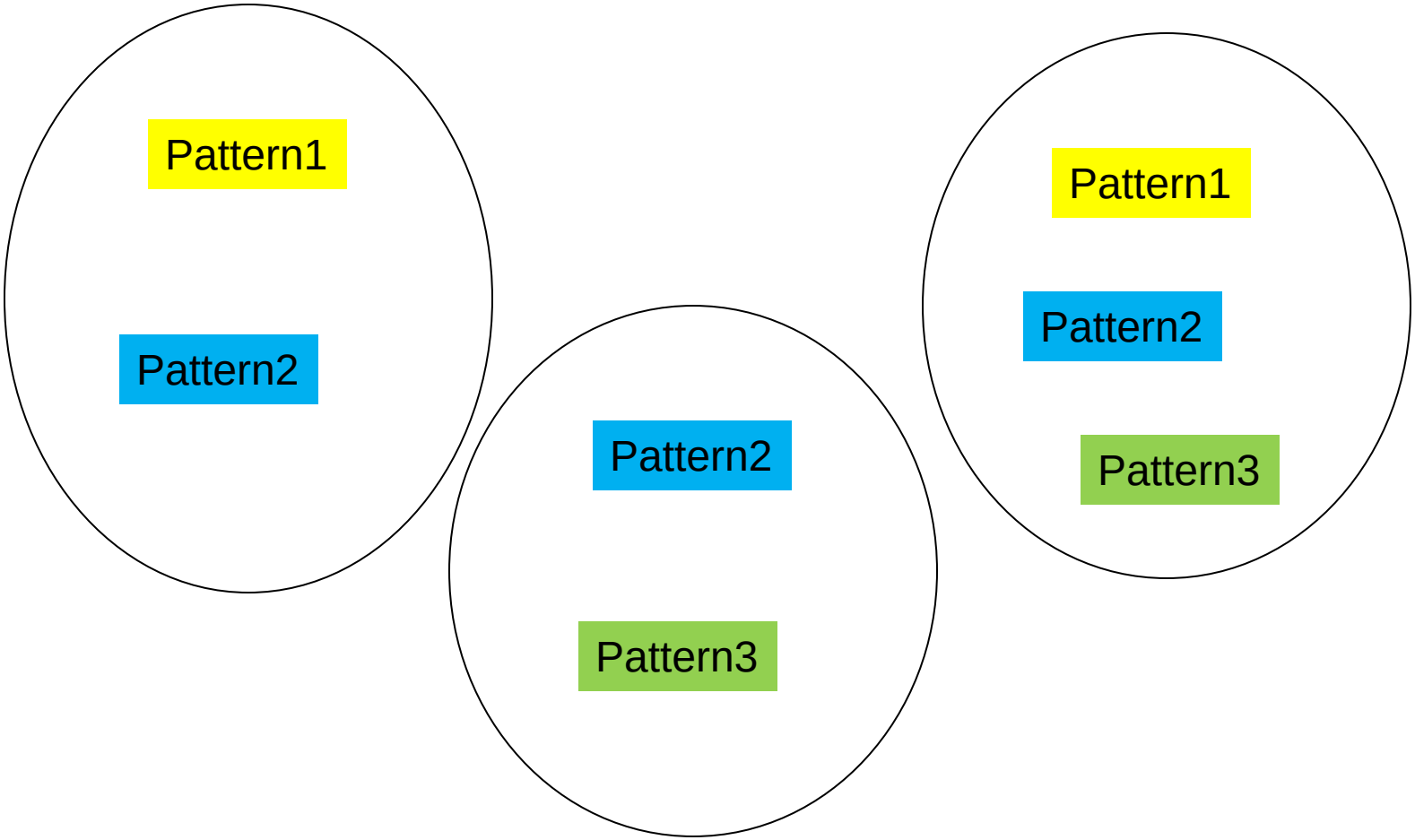
- **Bottom-up homogenization of data representation.**
- **Avoidance of strong ontological commitments.**
- **Avoidance of standardization of specific modeling details.**
- **Well thought-out patterns can be very strong and versatile, thus serve many needs.**

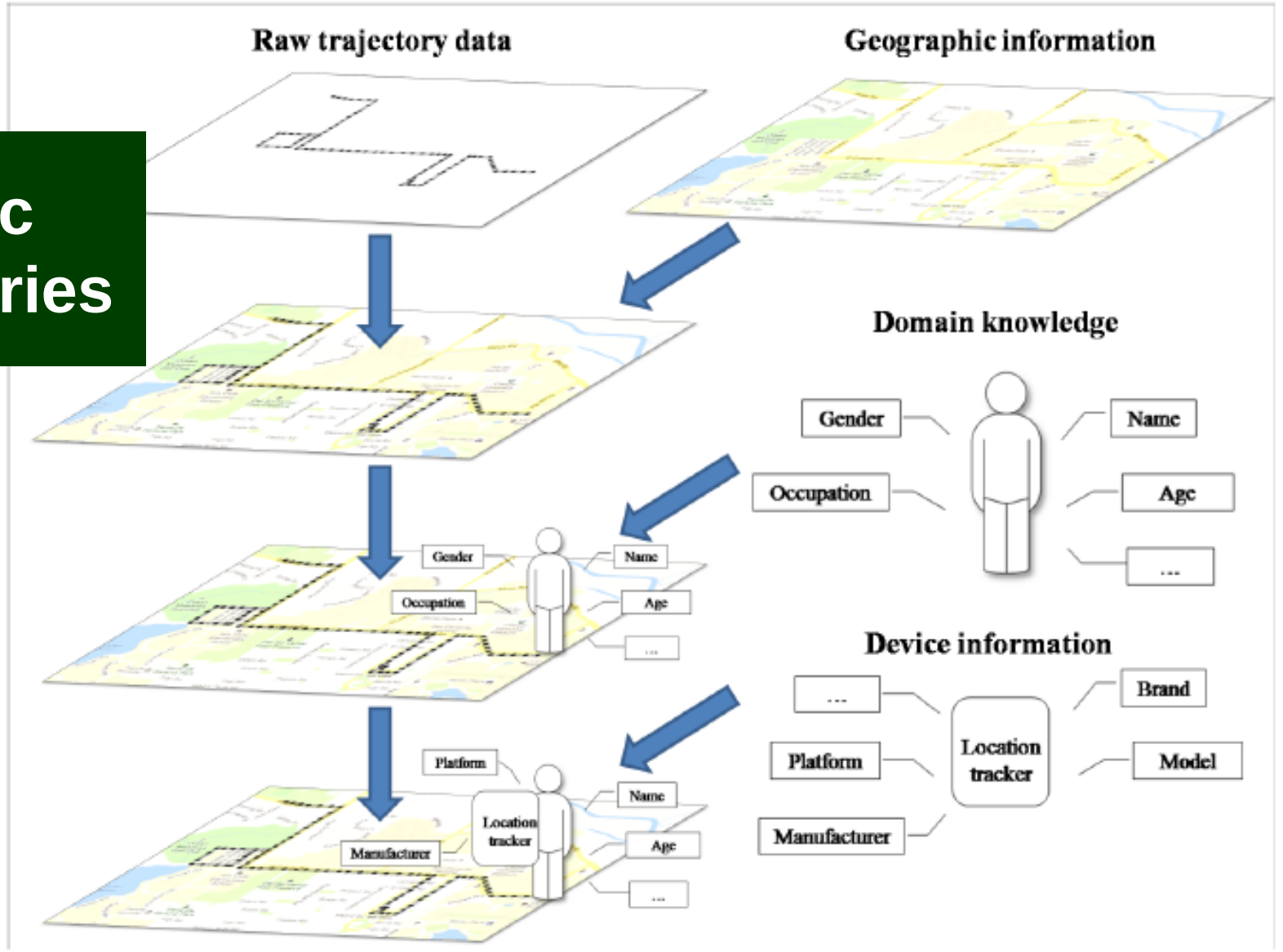
We are currently establishing many geo-patterns in a series of hands-on workshops, the GeoVoCamps, see http://vocamp.org/

Ontology Design Patterns



“Horizontal” alignment via patterns

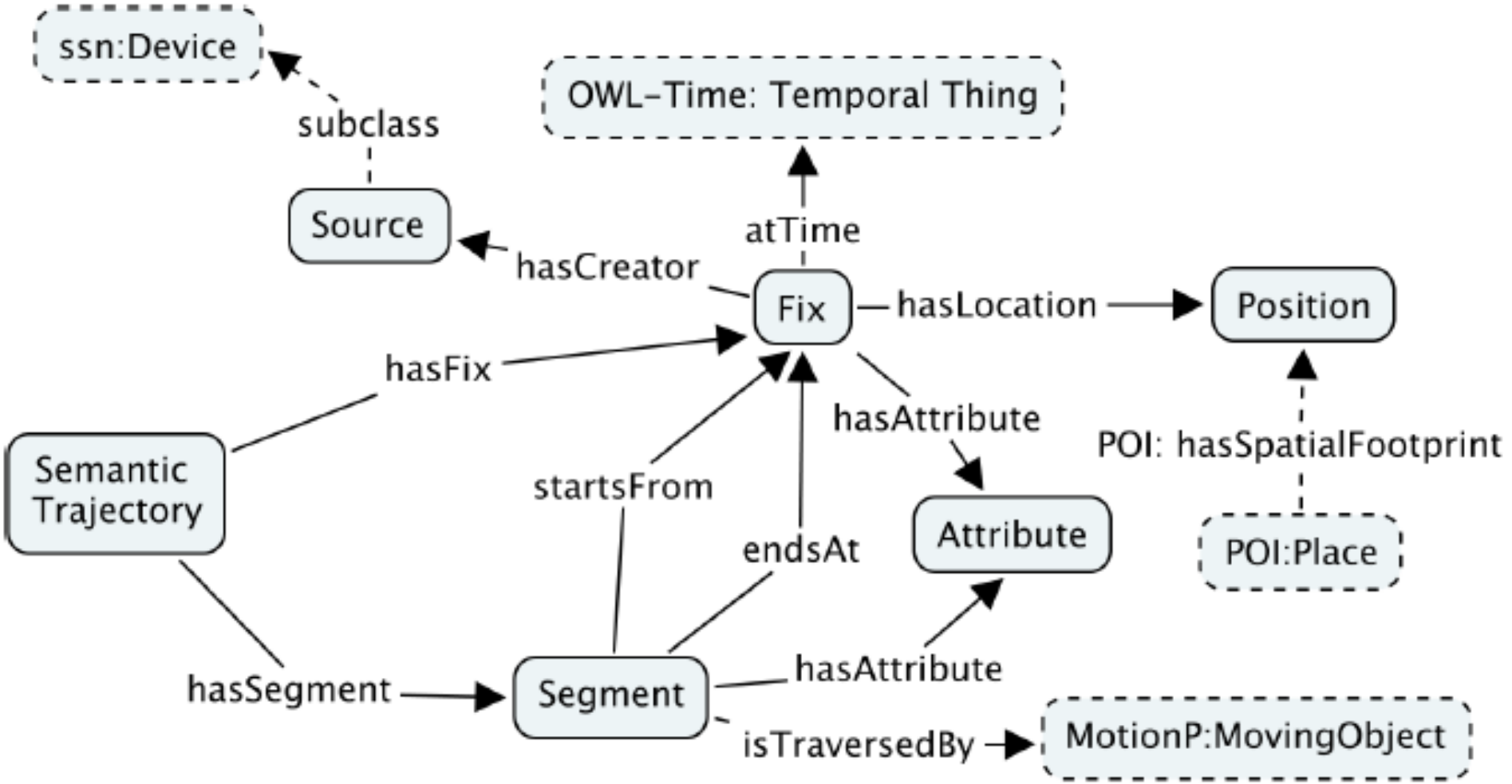
Semantic Trajectories



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

Semantic Trajectories

DaSe Lab



Semantics in OWL

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

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

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

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

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

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

$$hasNext \sqsubseteq hasSuccessor \quad (7)$$

$$hasSuccessor \circ hasSuccessor \sqsubseteq hasSuccessor \quad (8)$$

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

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

Semantics in OWL

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

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

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

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

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

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

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

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

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

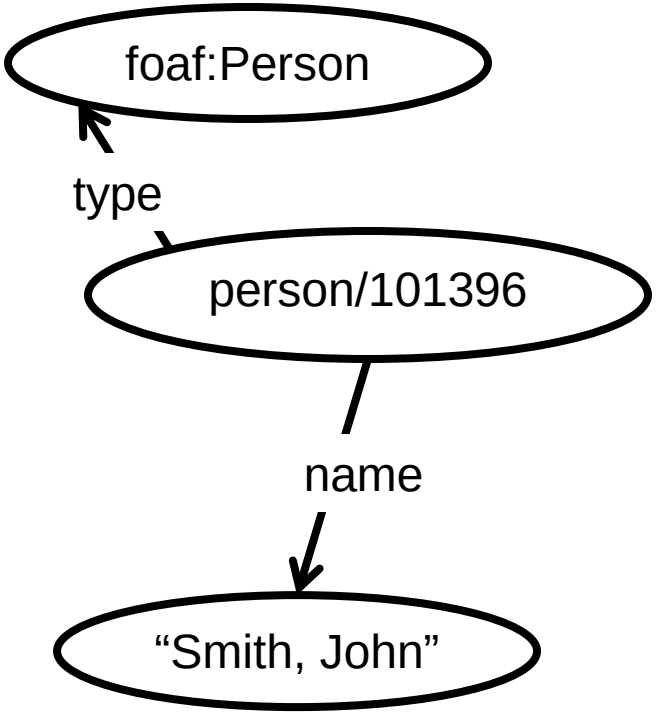
$$\exists hasFix.Segment \sqsubseteq SemanticTrajectory \quad (20)$$

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

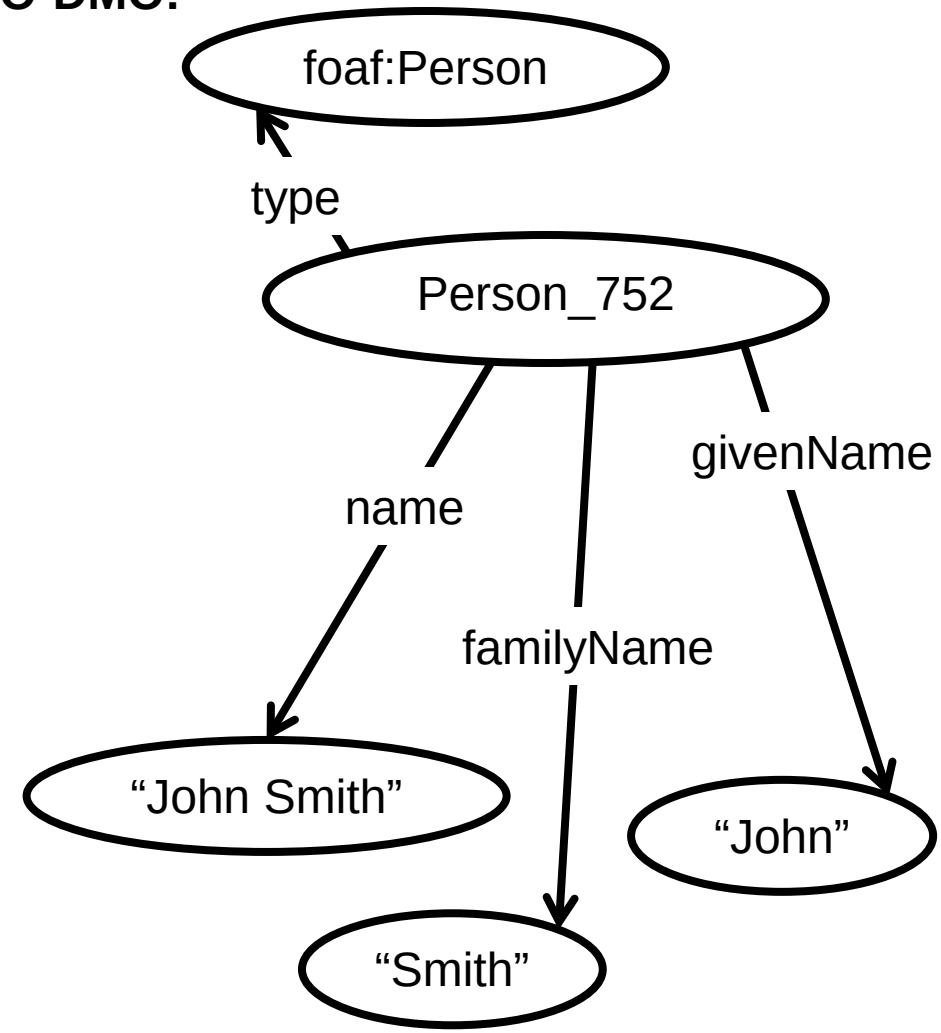
Helpfulness of patterns

Even minimalistic reuse is helpful:

R2R:



BCO-DMO:



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".

Patterns Example

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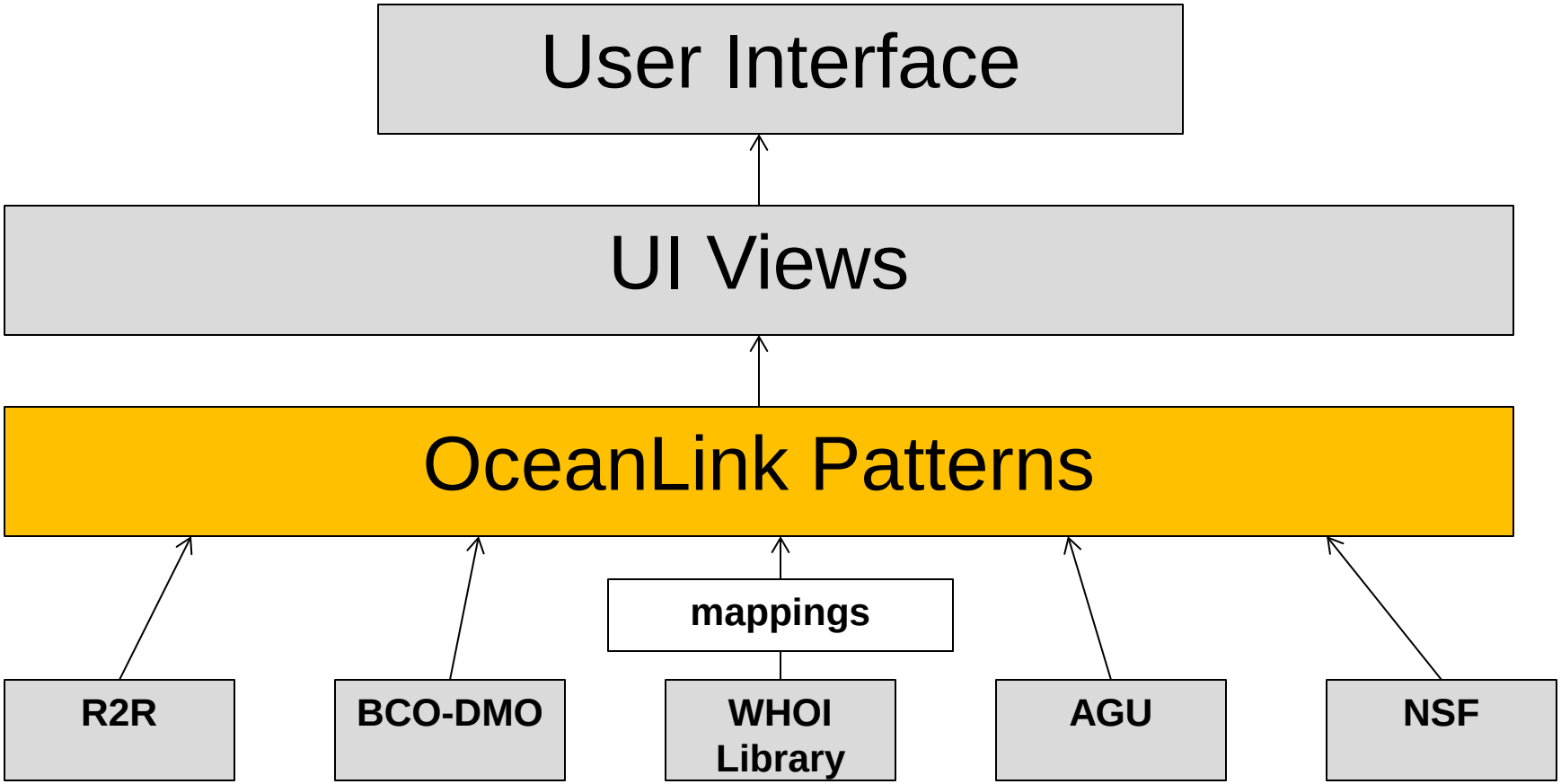
NSF EarthCube project “OceanLink”:

- **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.**

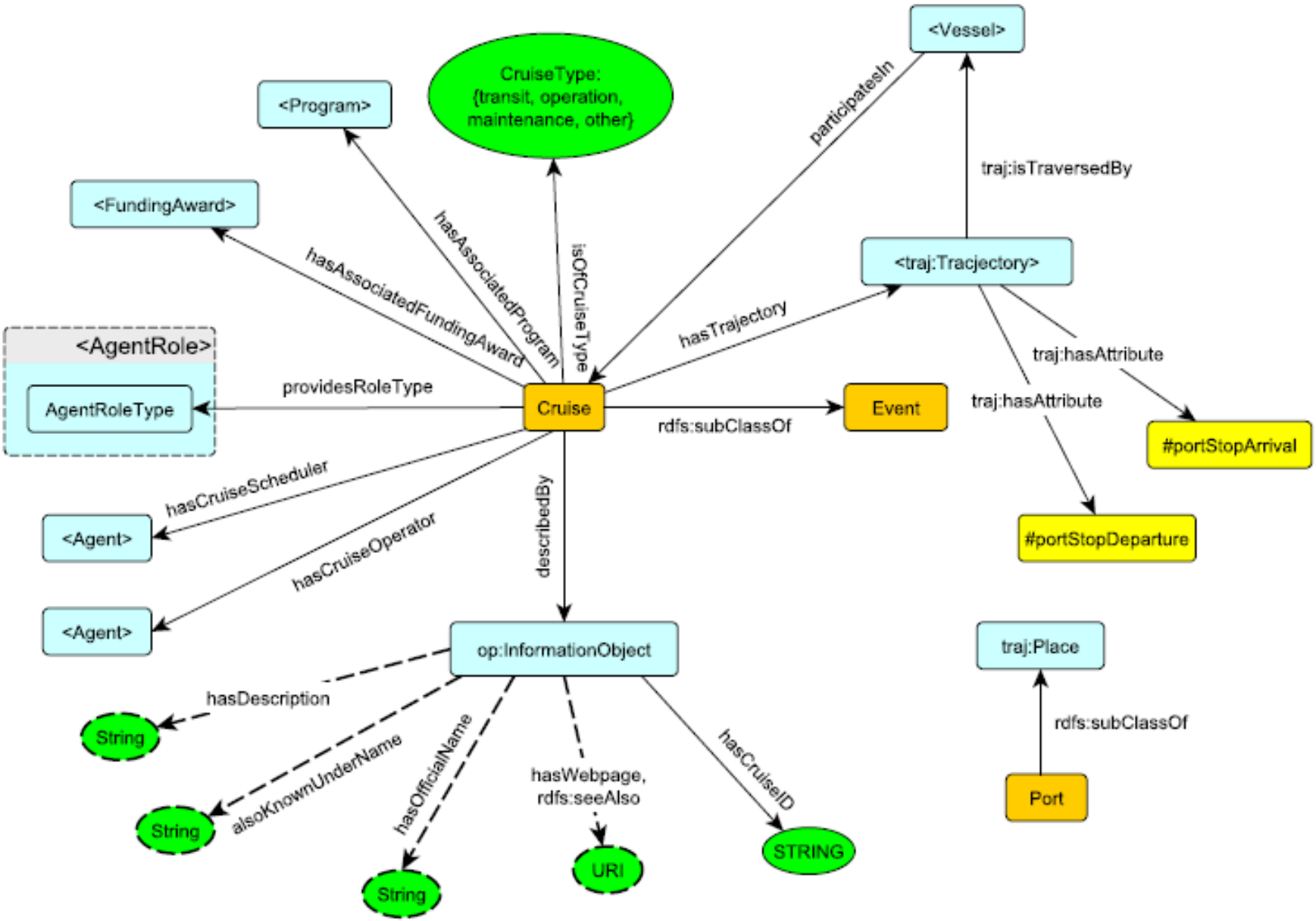
National Science Foundation award 1354778 "EAGER: Collaborative Research: EarthCube Building Blocks, Leveraging Semantics and Linked Data for Geoscience Data Sharing and Discovery."

OceanLink setup



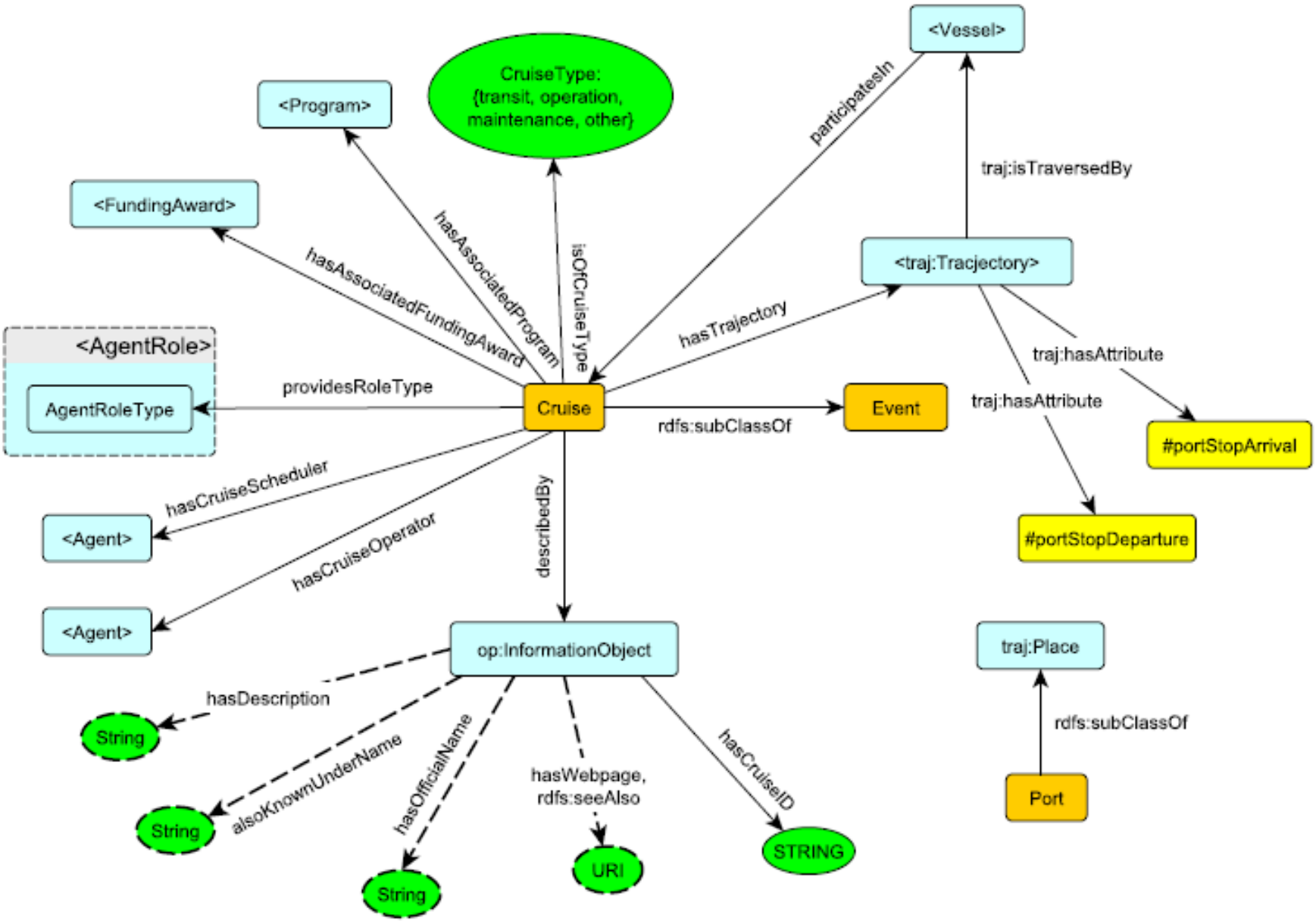
Ocean Science Cruise (draft)

DaSe Lab



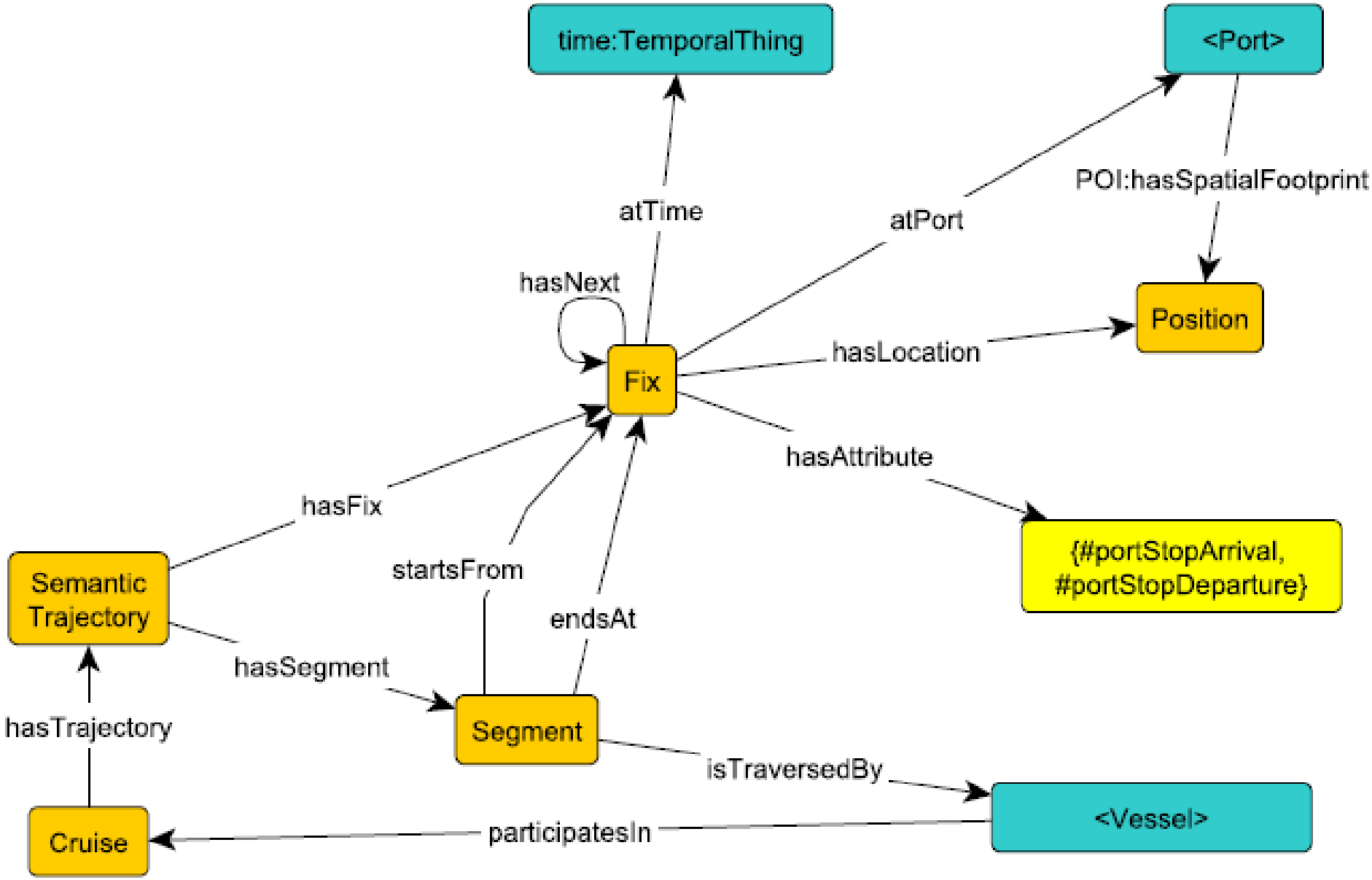
Ocean Science Cruise (draft)

DaSe Lab



Cruise trajectory (draft)

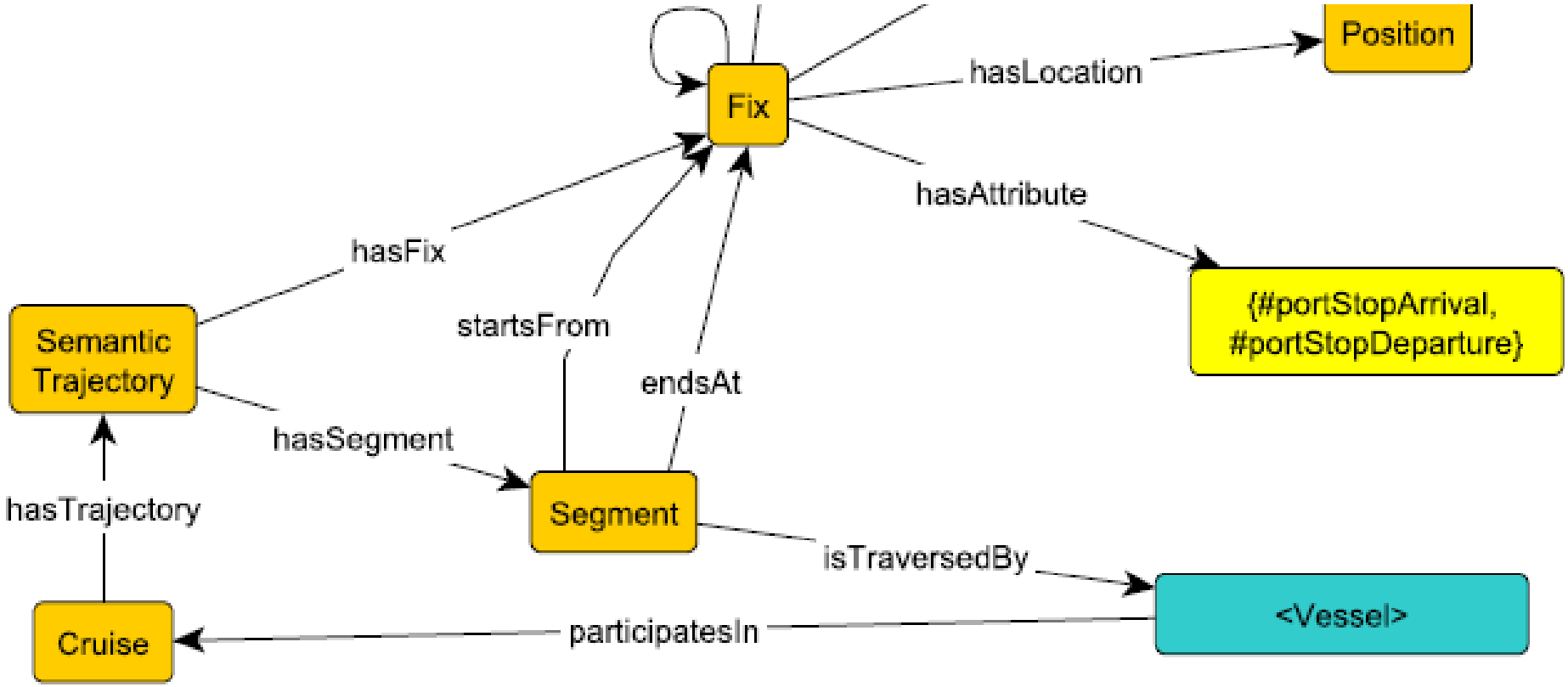
DaSe Lab



Cruise trajectory (draft)

DaSe Lab

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



Cruise trajectory (draft)

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

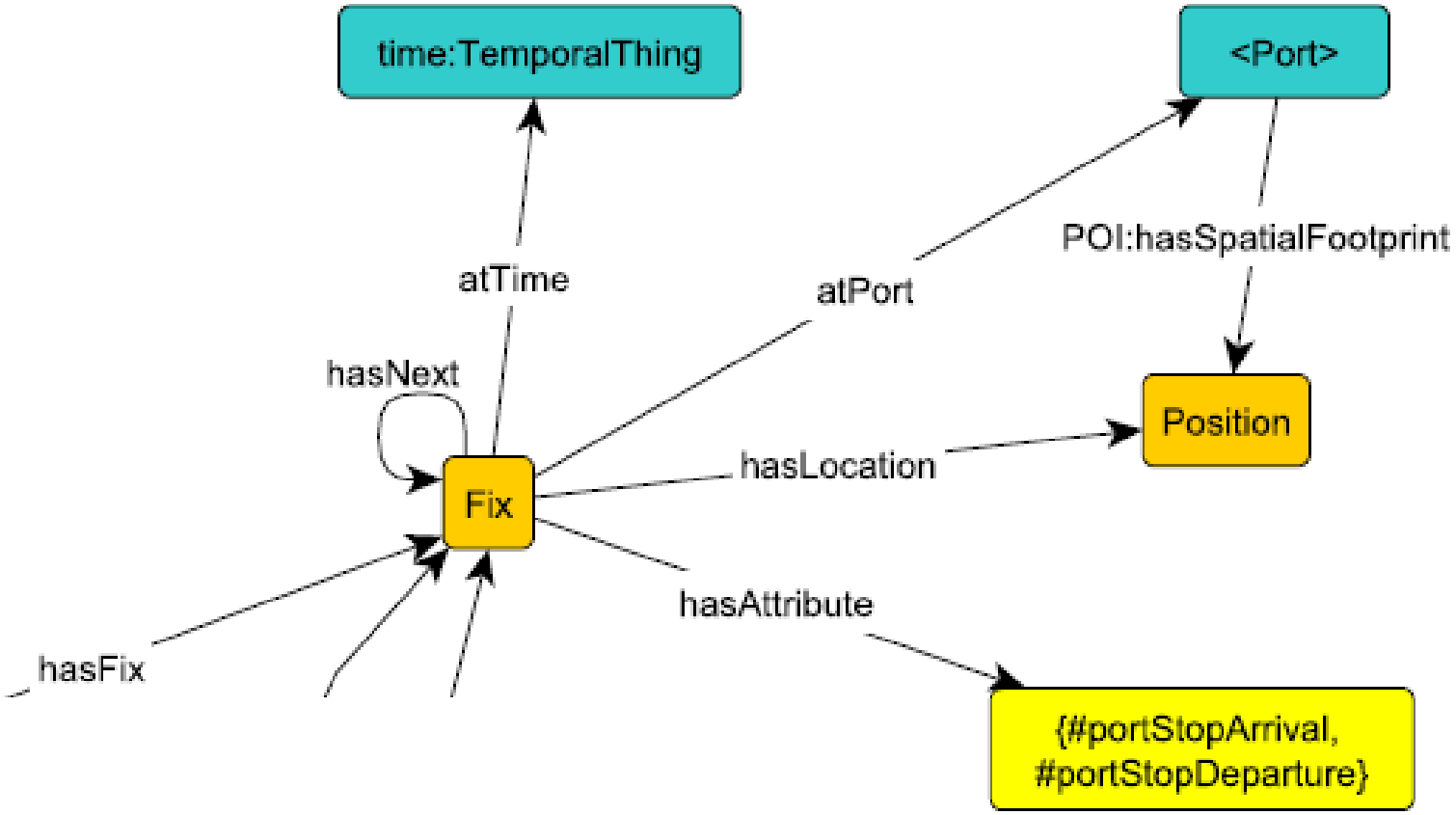
$$\mathrm{Cruise} \equiv \exists \mathrm{cruise}.\mathrm{Self}$$

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

$$\mathrm{hasParticipant} \equiv \mathrm{participatesIn}^{-}$$

Cruise trajectory (draft)

DaSe Lab



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

Cruise trajectory (draft)

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

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

OceanLink patterns

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Some central patterns:

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

We’re not starting from zero of course.

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.

Other things I'm doing

DaSe Lab

- **Automated ontology alignment**
- **Overcoming limitations of ontology languages**
- **Reasoning algorithms for ontologies**
- **Scientometrics (for our journal, but branching out with support from the publisher, IOS Press)**

Thanks!

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