Advances in Semantic Web Technologies

Pascal Hitzler
DaSe Lab for Data Semantics
Wright State University
http://www.pascal-hitzler.de

Textbook

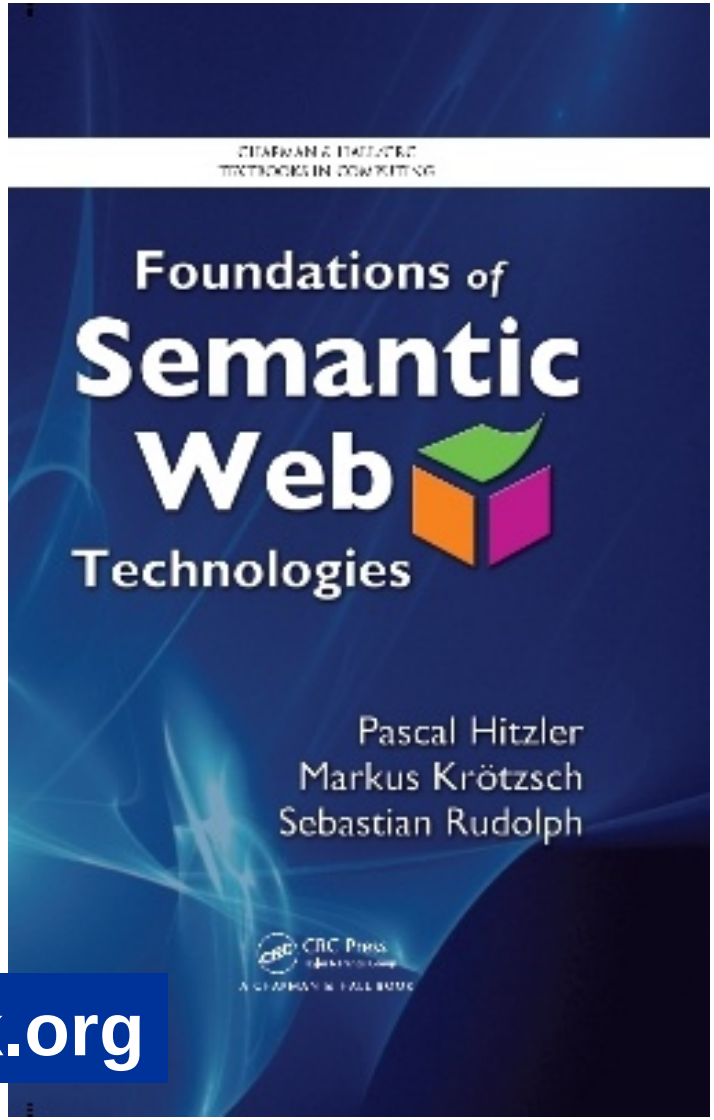
DaSe Lab

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)

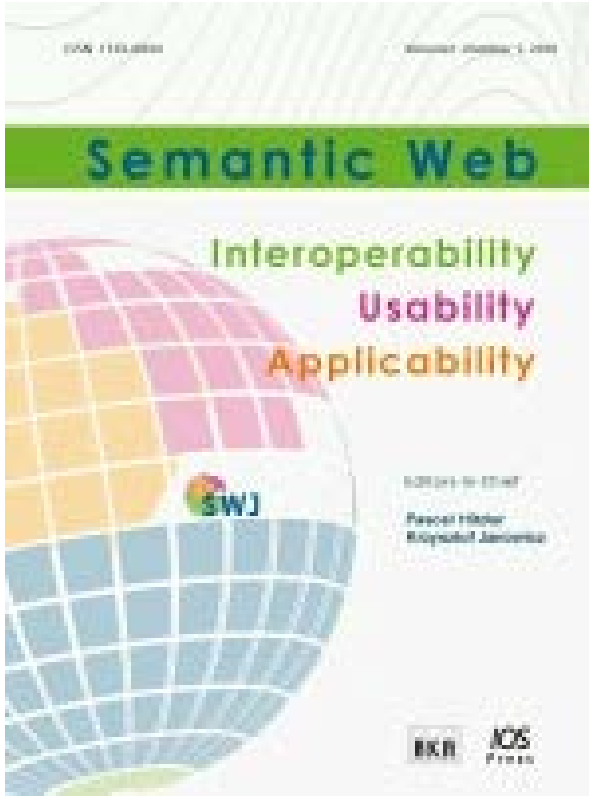


http://www.semantic-web-book.org

Semantic Web journal

DaSe Lab

- EiCs: Pascal Hitzler
  Krzysztof Janowicz
- Funded 2010
- SCImago ranks us 18th worldwide in Computer Science



- 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/**

Our Lab

DaSe Lab

Data Semantics (DaSe) Lab

Wright State University, Dayton, Ohio, USA

Directors: Michelle Cheatham & Pascal Hitzler

PhD students:
- Reihaneh Amini
- David Carral
- Amit Joshi
- Nazifa Karima
- Adila Krisnadhi
- Raghava Mutharaju
- Stella Sam
- Kunal Sengupta
- Cong Wang

Master students:
- Ashley Coleman
- Pawel Grzebala
- Todd Huster
- Kylyn Magee
- Brooke McCurdy

WRIGHT STATE UNIVERSITY

Our Lab

DaSe Lab

Current focus topics:

- ontology modeling
- ontology design patterns
- ontology and data alignment
- data and information integration
- use of formal semantics
- semantic web languages
- logical foundations
- efficient reasoning algorithms
- data security
- applications in the sciences and elsewhere

Part I

Semantic Web

Semantic Web

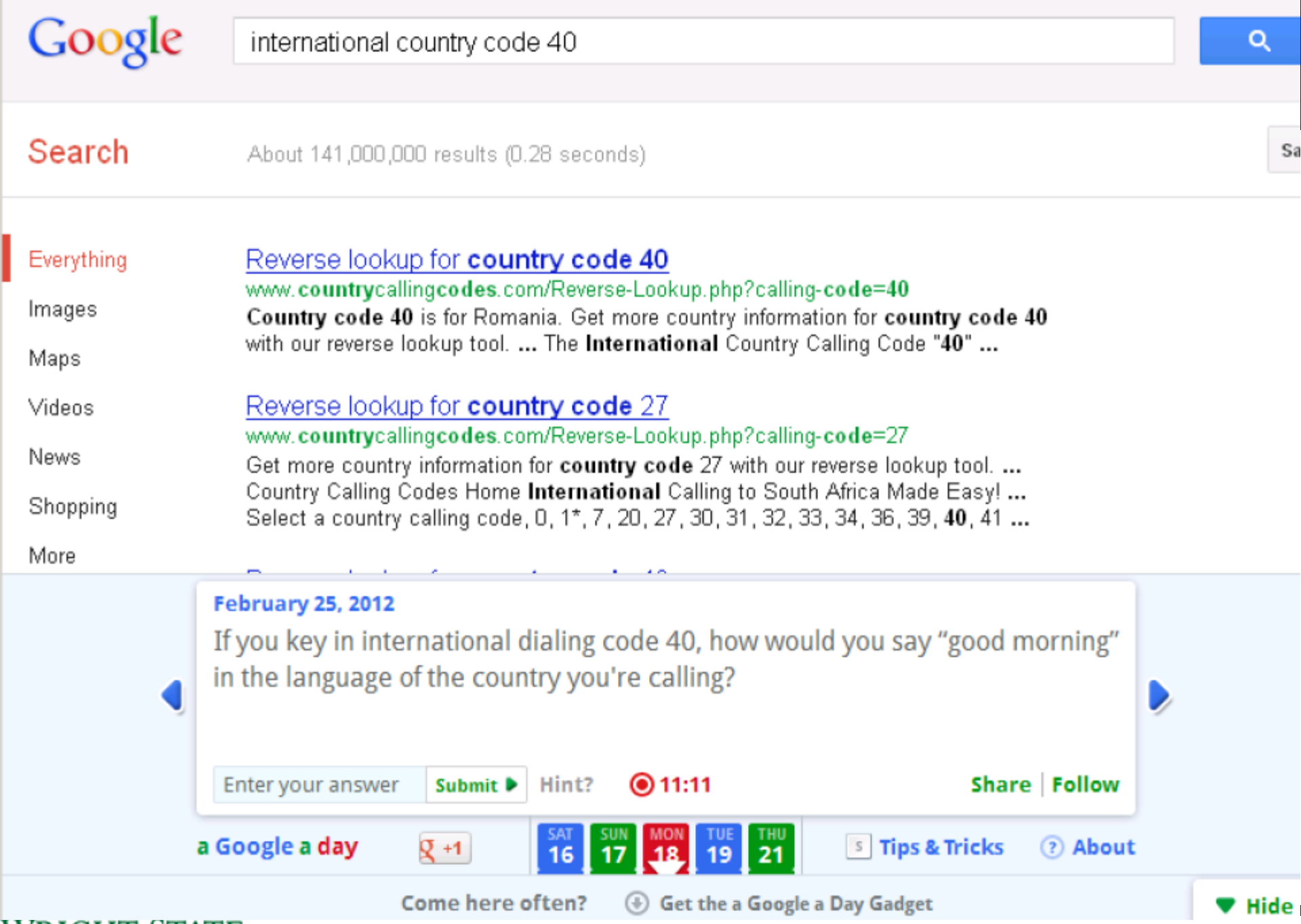
DaSe Lab

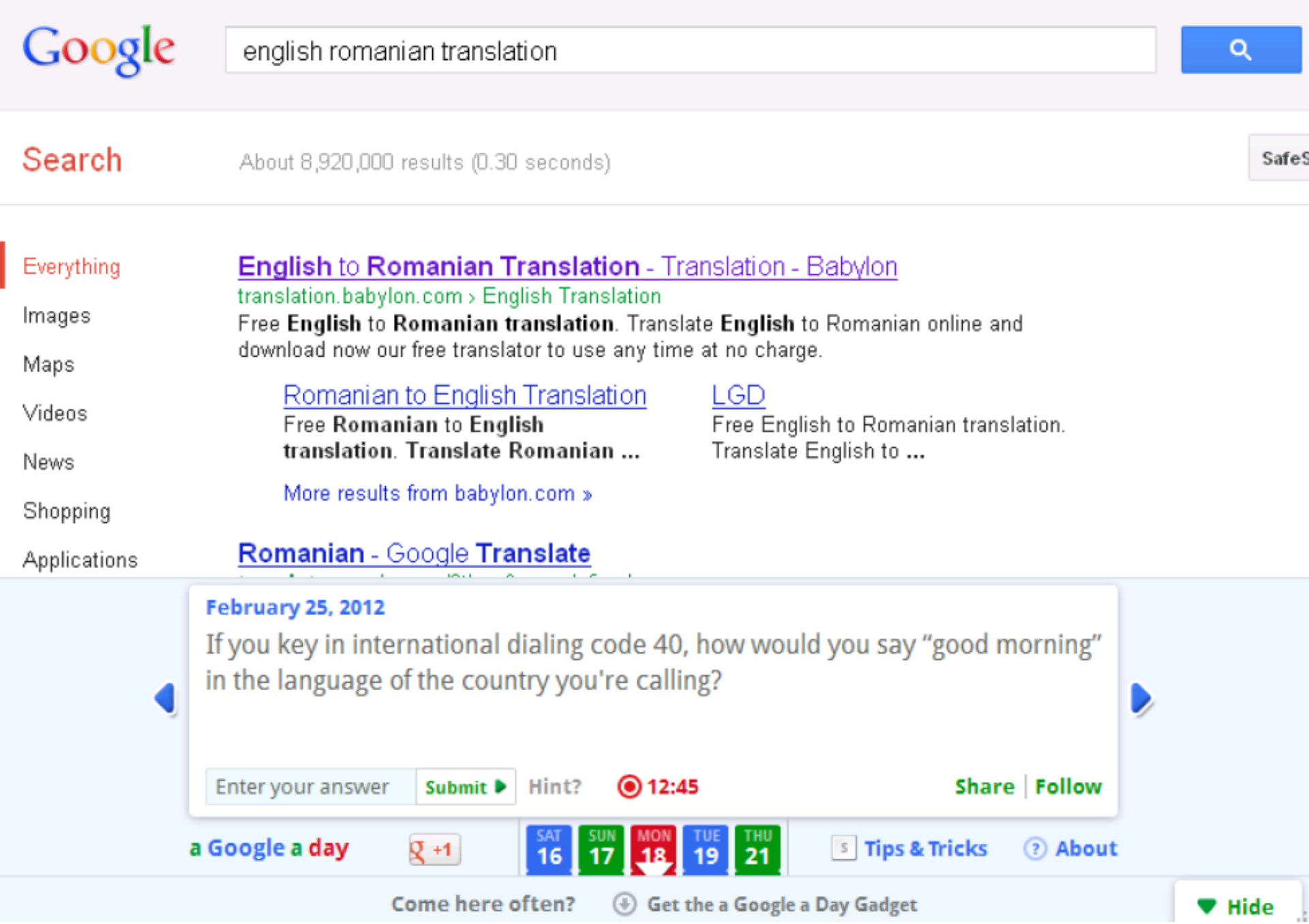
The (in)famous 2001 Scientific American article presented a vision in which data flows seamlessly between all kinds of devices, services, and intelligent agents.

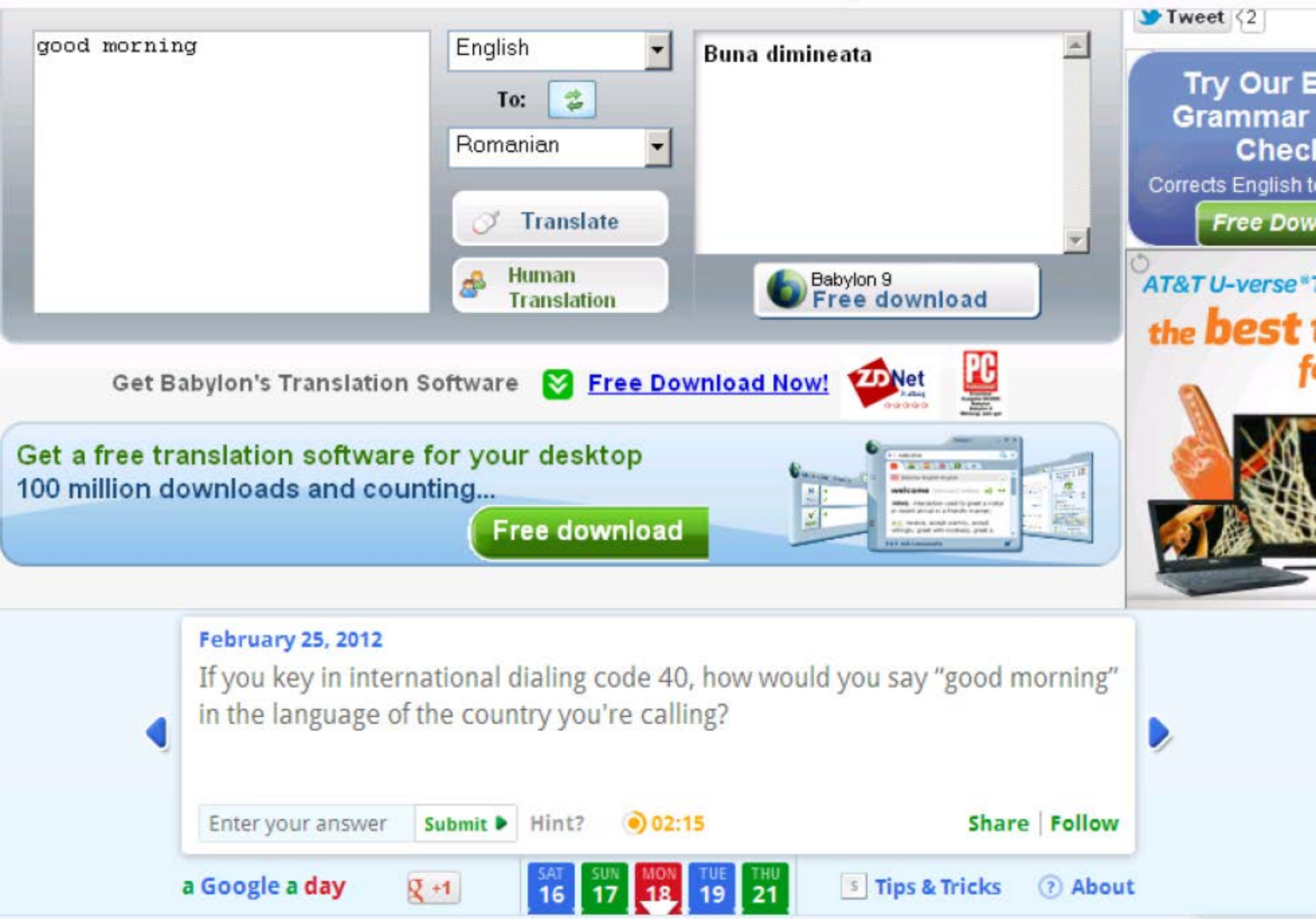
Of course, for the informed researcher it was (or should have been) already clear that the timeline of realizing this vision reached beyond the attention span of funding agencies ...

[Tim Berners-Lee, James Hendler, Ora Lassila, The Semantic Web Scientific American, May 2001, p. 29-37]

A Google a Day - 2012


Google
international country code 40
Search
About 141,000,000 results (0.28 seconds)
Everything
Images
Maps
Videos
News
Shopping
More
Reverse lookup for country code 40
www.countrycallingcodes.com/Reverse-Lookup.php?calling-code=40
Country code 40 is for Romania. Get more country information for country code 40 with our reverse lookup tool. ... The International Country Calling Code "40" ...
Reverse lookup for country code 27
www.countrycallingcodes.com/Reverse-Lookup.php?calling-code=27
Get more country information for country code 27 with our reverse lookup tool. ...
Country Calling Codes Home International Calling to South Africa Made Easy! ...
Select a country calling code, 0, 1*, 7, 20, 27, 30, 31, 32, 33, 34, 36, 39, 40, 41 ...
February 25, 2012
If you key in international dialing code 40, how would you say "good morning" in the language of the country you're calling?
Enter your answer
Submit
Hint?
11:11
Share
Follow
a Google a day
+1
SAT 16
SUN 17
MON 18
TUE 19
THU 21
Tips & Tricks
About
Come here often?
Get the a Google a Day Gadget
Hide


Google
english romanian translation
Search
About 8,920,000 results (0.30 seconds)
Everything
Images
Maps
Videos
News
Shopping
Applications
English to Romanian Translation - Translation - Babylon
translation.babylon.com › English Translation
Free English to Romanian translation. Translate English to Romanian online and download now our free translator to use any time at no charge.
Romanian to English Translation
Free Romanian to English translation. Translate Romanian ...
LGD
Free English to Romanian translation. Translate English to ...
More results from babylon.com »
Romanian - Google Translate
February 25, 2012
If you key in international dialing code 40, how would you say "good morning" in the language of the country you're calling?
Enter your answer
Submit
Hint?
12:45
Share
Follow
a Google a day
+1
SAT 16
SUN 17
MON 18
TUE 19
THU 21
Tips & Tricks
About
Come here often?
Get the a Google a Day Gadget
Hide


good morning
English
To:
Romanian
Translate
Human Translation
Buna dimineata
Babylon 9
Free download
Tweet
Try Our E
Grammar
Checl
Corrects English t
Free Dow
AT&T U-verse
the best
Get Babylon's Translation Software
Free Download Now!
ZDNet
PC
Get a free translation software for your desktop
100 million downloads and counting...
Free download
February 25, 2012
If you key in international dialing code 40, how would you say "good morning" in the language of the country you're calling?
Enter your answer
Submit
Hint?
02:15
Share
Follow
a Google a day
+1
SAT 16
SUN 17
MON 18
TUE 19
THU 21
Tips & Tricks
About

But computers can't do that

DaSe Lab

Question:

美国总统是谁

Answer:

巴拉克•奥巴马

Semantic Web

DaSe Lab

- ideas going back to the early Web days (1989)
- 1990: W3C metadata activity (led to RDF(S))
- W3C semantic web activity: chartered 2001
- USA DAML-Programme 2000-2005
  approx. $90M
- Many large scale EU projects since 2002 and ongoing (FP6/FP7).
- 2004: first version of current Web Ontology Language (OWL)
  W3C standard

More recently ...

Store | Mac | iPod | iPhone | iPad | iTunes | Support

iPhone

Features | Built-in Apps | From the App Store | iOS | iCloud | Tech Specs | Buy iPhone

Siri. Beta

Your wish is its command.

Siri on iPhone 4S lets you use yo
voice to send messages, schedu
meetings, place phone calls, an
more. Ask Siri to do things just
talking the way you talk. Siri

mediabistro | semanticweb.com | SemTechBiz SF | more >>

semanticweb.com™ The Voice of Semantic Web Technology and Linked Data Business

Home | Events | Community | Learning | Industry Verticals | Answers | Search semanticweb.com | SEARCH

Apple Buys Siri: Once Again The Back Story Is About Semantic Web

By Bernard Lunn on April 28, 2010 2:33 PM

According to Robert Scoble who got it from tracking FTC, Apple is buying Siri. (This has yet to be confirmed by Siri or Apple). The front story is mobile, specifically a bruising battle between Apple and Google. But once again the back story is semantic technology. Siri is not some cute iPhone app banged together in a garage over a Red Bull fueled long weekend. Siri has hard core semantic tech that originated from Darpa (just like that little system called the Internet).

Like the Facebook OpenGraph story, this is another example of semantic web going mainstream. The Open Graph front story was all about social media, but the back story was their adoption of RDFa. That has been a big boost to the semantic web community.

Siri looks like a good exit for investors and will give them confidence to invest more in companies

Semanticweb.com Newsletter
Enter your email for updates | and your ZIP | SIGN UP

Semanticweb.com Event Updates
Enter your email for updates | and your ZIP | SIGN UP

Send an anonymous tip | SEND

SemanticWeb.com on Facebook
Like 1,467

Twitter
Mobile
RSS

SEMANTIC TECH & BUSINESS CONFERENCE
June 3-7, 2012 San Francisco
presented by SemanticWeb.com and WebMediaBrands

WRIGHT STATE UNIVERSITY

January 201

IBM

IBM WATSON

The Science Behind an Answer

Watson performs so fast that it can rival the greatest human contestants in understanding a Jeopardy! clue and arriving at a single, precise answer. The significance of this accomplishment can be difficult to comprehend.

Watch the video to see how the computing system designed to play Jeopardy! works.

Possible Answers
bake
balance
ban
bang
bathe
battle
be
beam
bear

The first person mentioned by name
in 'The Man in th
is this hero of a
by the same aut

IBM Watson Solutions and WellPoint, America's largest health benefits company with

The DeepQA hypothesis is that by complementing classic knowledge-based approaches with recent advances in NLP, Information Retrieval, and Machine Learning to interpret and reason over huge volumes of widely accessible naturally encoded knowledge (or "unstructured knowledge") we can build effective and adaptable open-domain QA systems. While they may not be able to formally prove an answer is correct in purely logical terms, they can build confidence based on a combination of reasoning methods that operate directly on a combination of the raw natural language, automatically extracted entities, relations and available structured and semi-structured knowledge available from for example the Semantic Web.

What is Watson?

Implications for analytics, system design and industry transformation ›

Watson for a Smarter Planet™

Join the conversation on IBM Watson Connect

Watson - A System Designed for Answers

Optimize Your Growing

Google Wright State University Sign in

Web Maps Images Shopping News More Search tools

About 78,900,000 results (0.40 seconds)

Wright State University
www.wright.edu/ Wright State University

Wright State University's annual Diversity in the Multicultural Millennium Conference tackles issues such as race relations, gender equality, minority rights, and ...

4.4 ★★★★½ 31 Google reviews · Write a review

3640 Colonel Glenn Hwy, Dayton, OH 45435
(937) 775-3333

Results from wright.edu

Wings
Get a WINGS username and password. Alternative Login for ...

Graduate School
Programs - Apply - Admissions - Academics - Check Status - ...

Admissions
Welcome to Admissions at Wright State University! Our diverse ...

Pilot
Sign Into Pilot. Username: Password: Help Desk · System ...

Academics
Programs - College of Engineering - Academic Calendar - Catalog

Boonshoft School of Medicine
Admissions - Departments - Current Students - Education

Wright State University - Wikipedia, the free encyclopedia
en.wikipedia.org/wiki/Wright_State_University Wikipedia

Wright State University is a public research university in Fairborn, Ohio, located just

Wright State University

University in Dayton, Ohio

Directions Write a review

Wright State University is a public research university in Fairborn, Ohio, located just outside of Dayton near Wright-Patterson Air Force Base and Beavercreek. Wikipedia

Address: 3640 Colonel Glenn Hwy, Dayton, OH 45435

Mascot: Rowdy Raider

Colors: Green, Gold

schema.org

Search

Home Schemas Documentation

What is Schema.org?

This site provides a collection of schemas that webmasters can use to markup HTML pages in ways recognized by major search providers, and that can also be used for structured data interoperability (e.g. in JSON). Search engines including Bing, Google, Yahoo! and Yandex rely on this markup to improve the display of search results, making it easier for people to find the right Web pages.

Many sites are generated from structured data, which is often stored in databases. When this data is formatted into HTML, it becomes very difficult to recover the original structured data. Many applications, especially search engines, can benefit greatly from direct access to this structured data. On-page markup enables search engines to understand the information on web pages and provide richer search results in order to make it easier for users to find relevant information on the web. Markup can also enable new tools and applications that make use of the structure.

A shared markup vocabulary makes it easier for webmasters to decide on a markup schema and get the maximum benefit for their efforts. So, in the spirit of sitemaps.org, search engines have come together to provide a shared collection of schemas that webmasters can use.

Wikidata

The online encyclopedia Wikipedia is being supplemented by user-edited structured data, available for free to anyone.

BY DENNY VRANDEČIĆ AND MARKUS KRÖTZSCH

Wikidata: A Free Collaborative Knowledge Base

[Denny Vrandecic, Markus Krötzsch: Wikidata: a free collaborative knowledgebase. Commun. ACM 57(10): 78-85 (2014)]

UNNOTICED BY MOST of its readers, Wikipedia is currently undergoing dramatic changes, as its sister project Wikidata introduces a new multilingual 'Wikipedia for data' to manage the factual information of the popular online encyclopedia. With Wikipedia's data becoming cleaned and integrated in a single location, opportunities arise for many new applications.

Freebase

Shared publicly - Dec 16, 2014

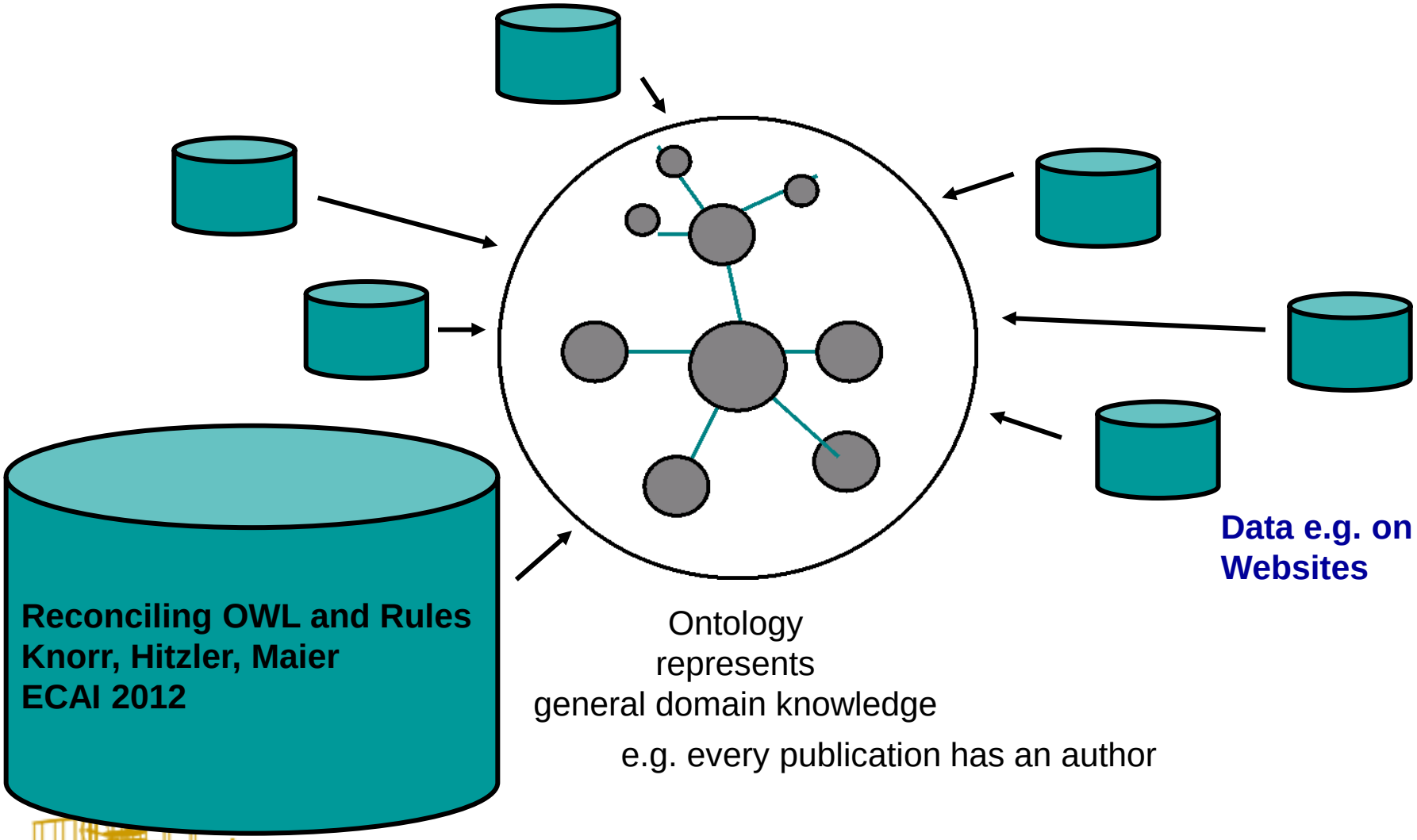
When we publicly launched Freebase back in 2007, we thought of it as a "Wikipedia for structured data." So it shouldn't be surprising that we've been closely watching the Wikimedia Foundation's project Wikidata[1] since it launched about two years ago. We believe strongly in a robust community-driven effort to collect and curate structured knowledge about the world, but we now think we can serve that goal best by supporting Wikidata -- they're growing fast, have an active community, and are better-suited to lead an open collaborative knowledge base.

So we've decided to help transfer the data in Freebase to Wikidata, and in mid-2015 we'll wind down the Freebase service as a standalone project. Freebase has also supported developer access to the data, so before we retire it, we'll launch a new API for entity search powered by Google's Knowledge Graph.

Part II

Ontologies

A Basic Idea of the Semantic Web



The ontology hype

- **Large, well-thought-out ontologies (foundational/domain/etc).**
- **“You just have to get your formal definitions right, and a lot of the rest will just fall into place.”**

The ontology hype

- **“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

DaSe Lab

- 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

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

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

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.
- Need a lot of manpower to create.

The First Semantic Web Hype

- **Large, monolithic 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 ☺

Part III

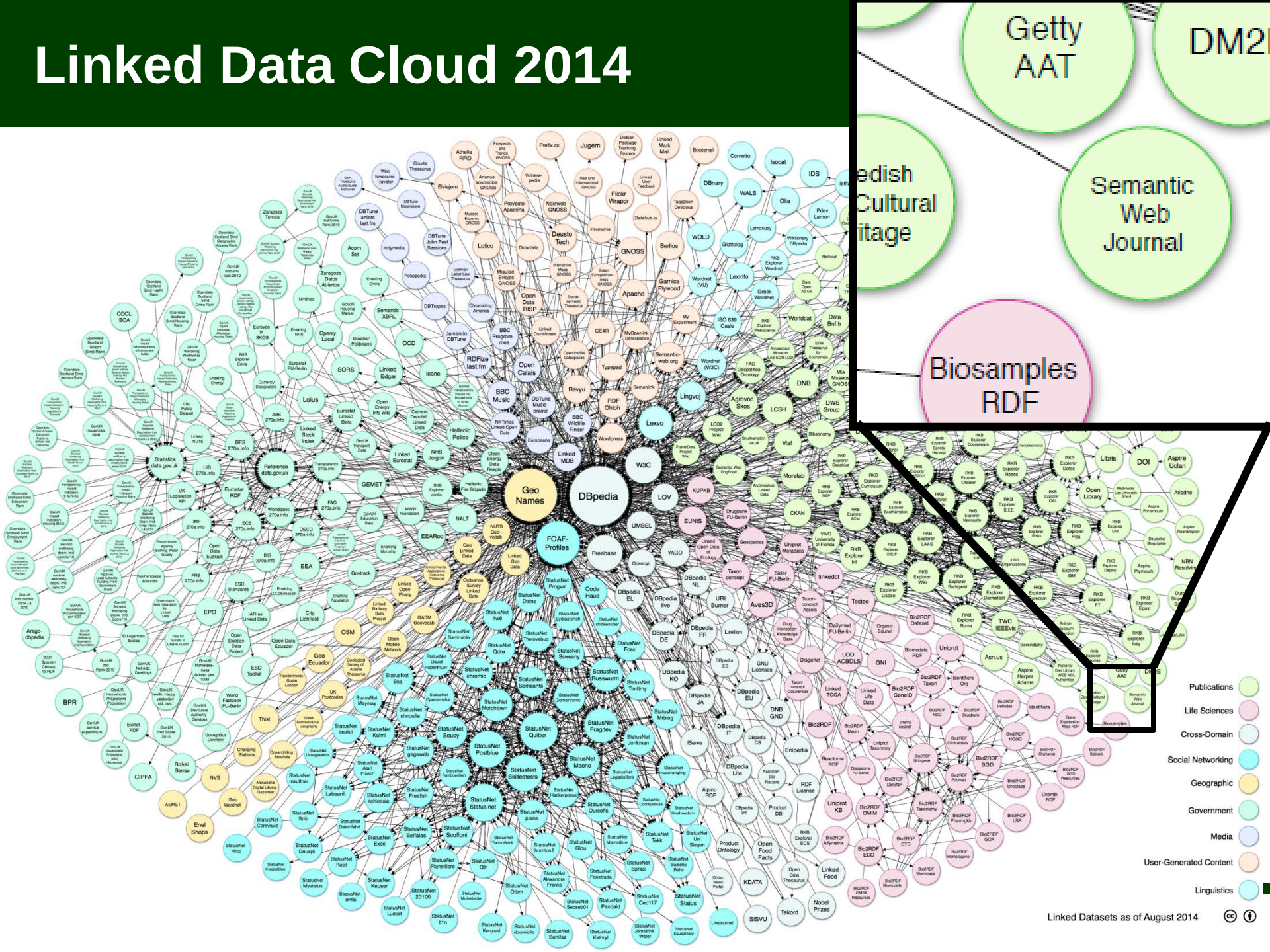
Linked Data

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.”**

Linked Data started in 2006, and took off in 2007.

Linked Data Cloud 2014

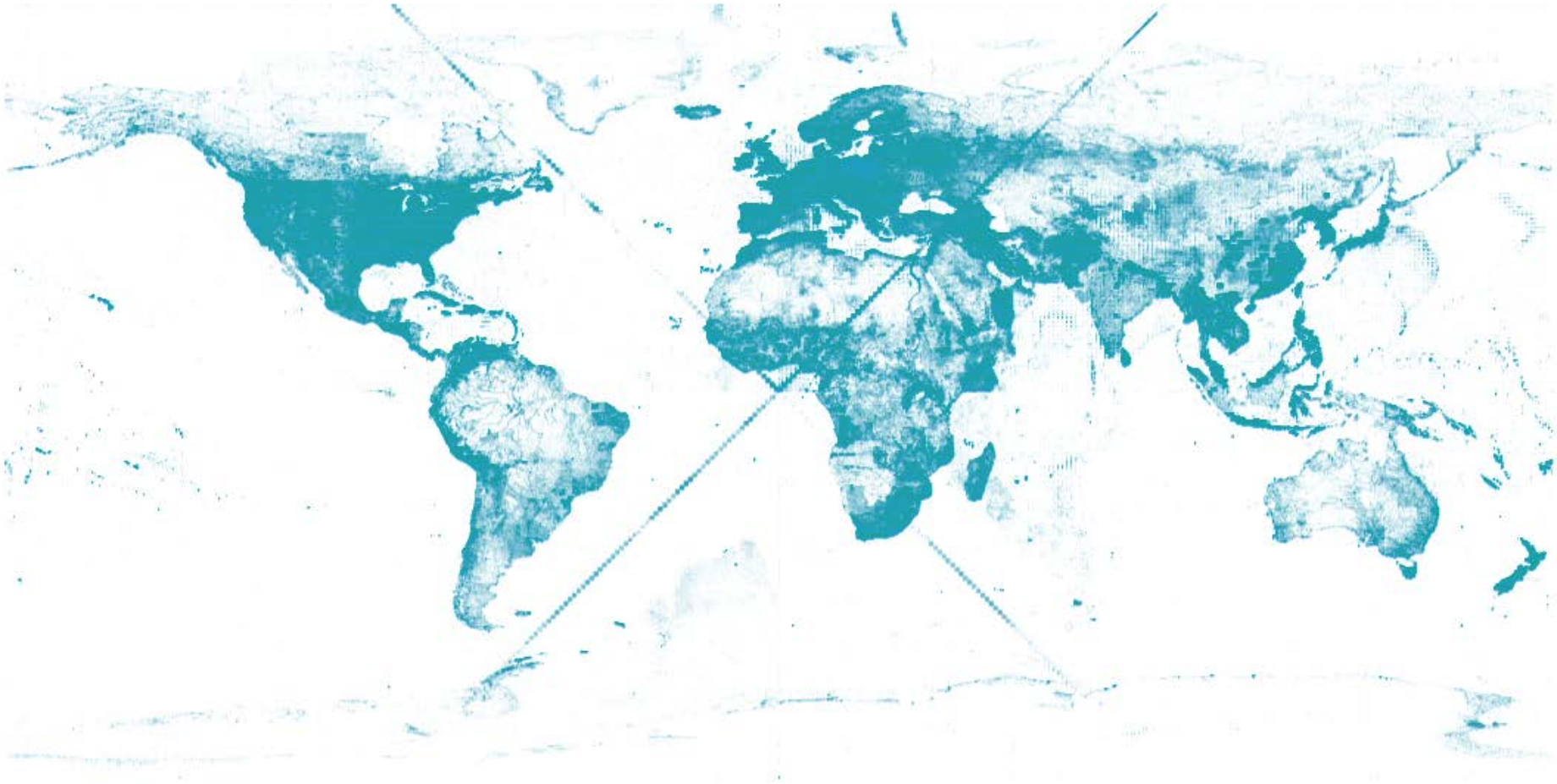


Linked Data: Volume

DaSe Lab

Geoindexed Linked Data – courtesy of Krzysztof Janowicz

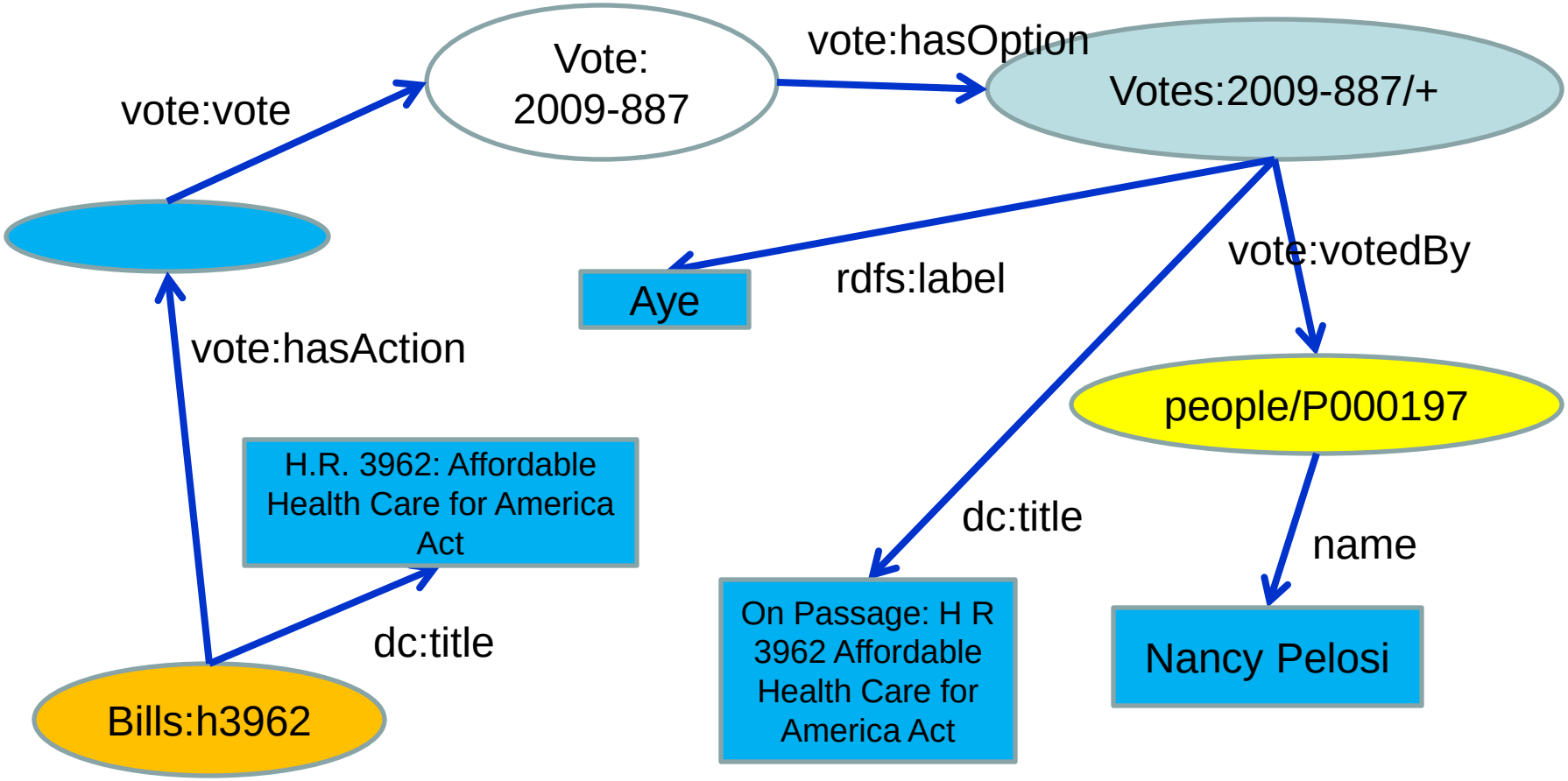
http://stko.geog.ucsb.edu/location_linked_data



Using Linked Data is tricky

DaSe Lab

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



Absence of schema?

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
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

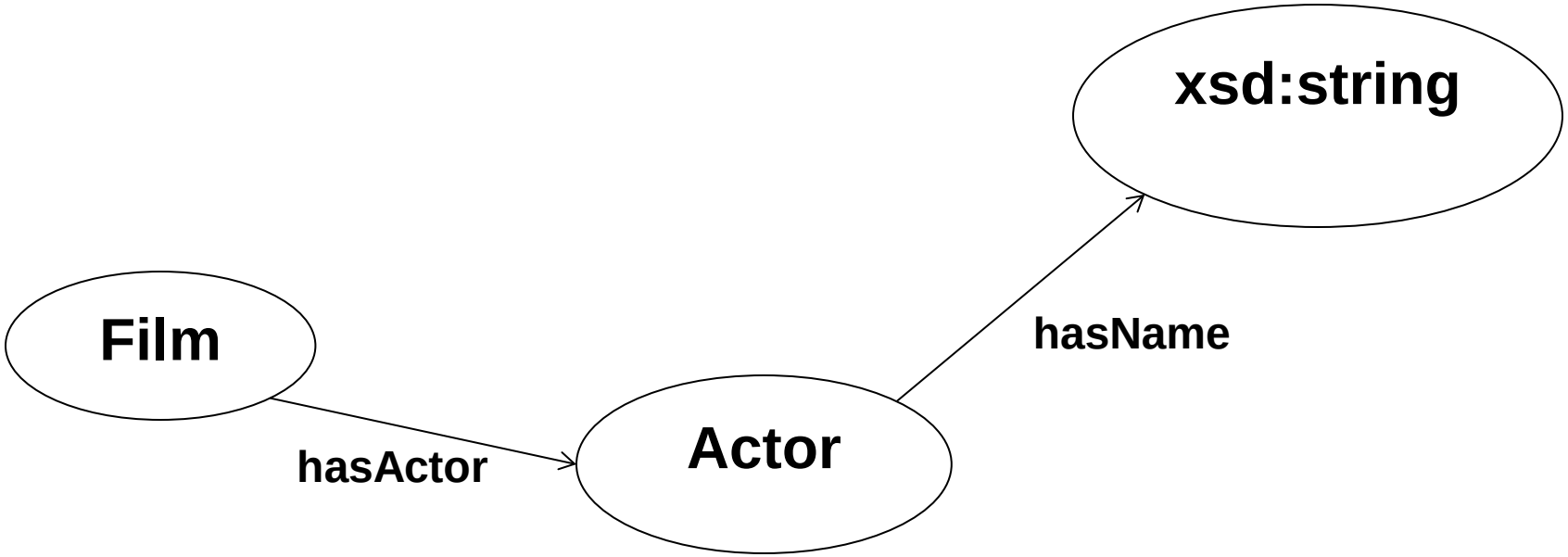
5 LOD Schema Stars

DaSe Lab

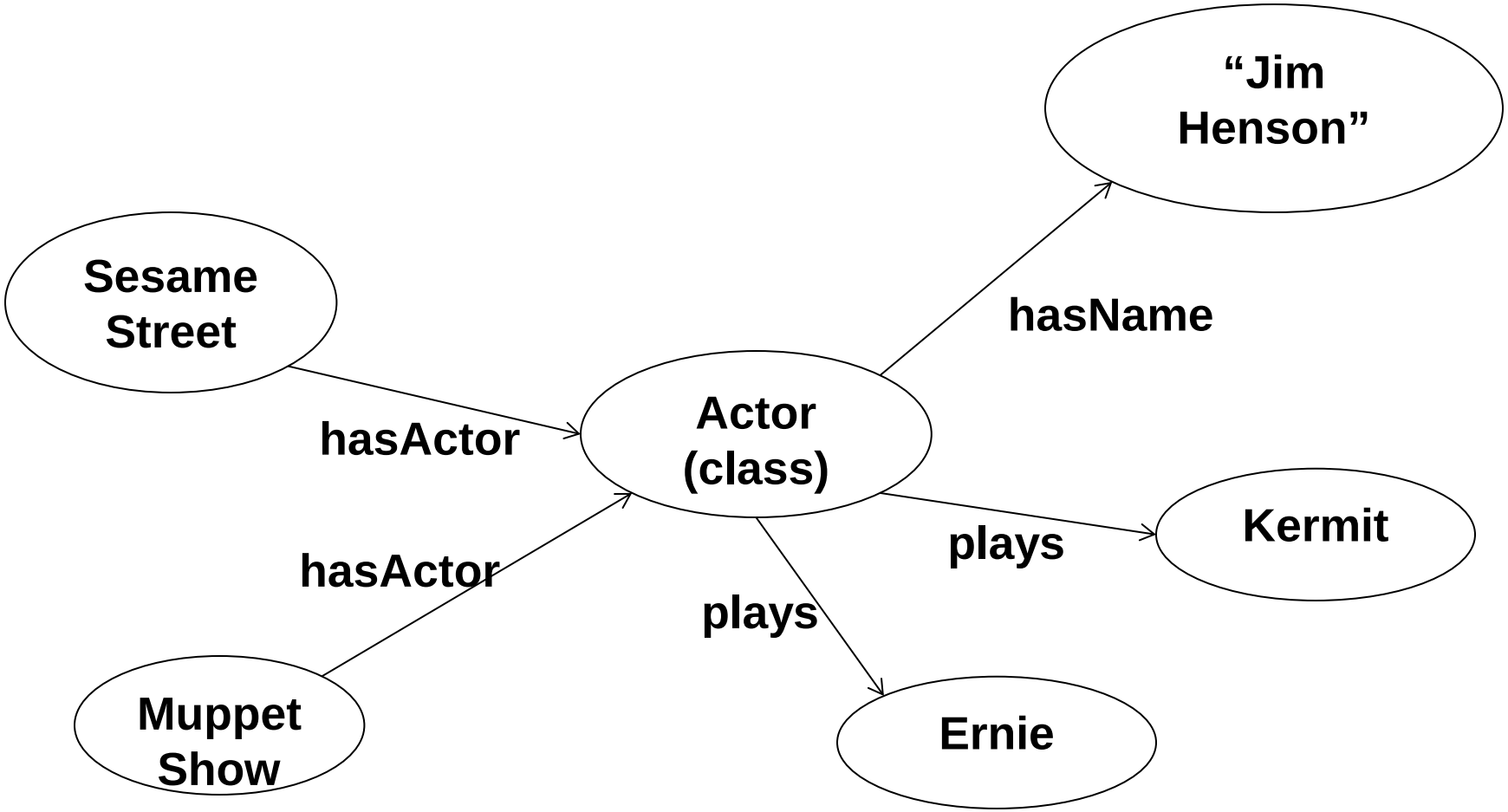
Krzysztof Janowicz, Pascal Hitzler, Benjamin Adams, Dave Kolas, Charles Vardeman II, Five Stars of Linked Data Vocabulary Use. Semantic Web 5 (3), 2014, 173-176.

- **Quality of schema and documentation.**
- **Level of reuseability.**

Example from Linked MDB



Problem!


"Jim Henson"
Sesame Street
hasName
hasActor
Actor (class)
Kermit
plays
hasActor
plays
Muppet Show
Ernie

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?**

Part IV

Towards Synthesis

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.

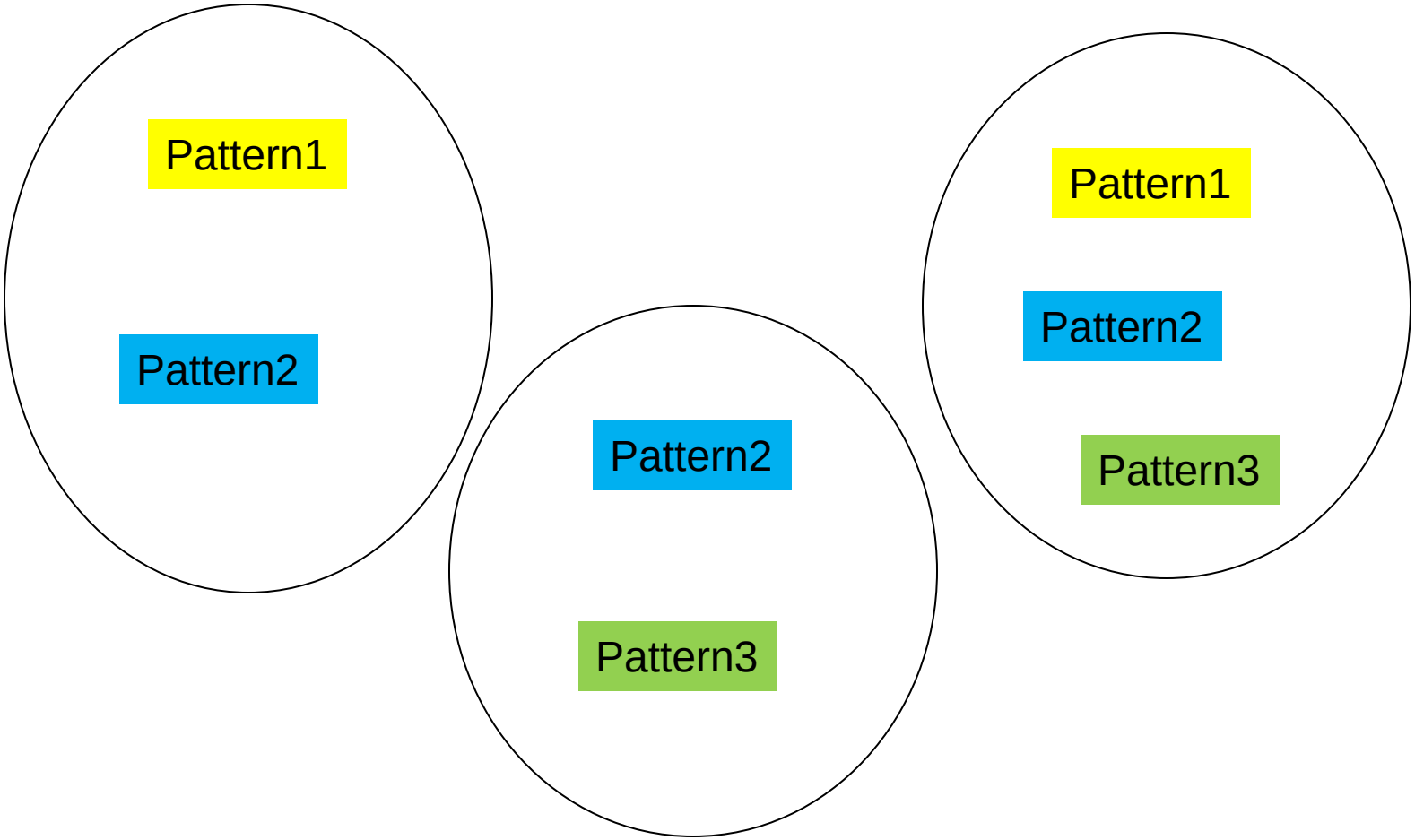
Ontology Design Patterns

DaSe Lab

- **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

Example: The NSF GeoLink Project

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.”

EarthCube GeoLink project

DaSe Lab

Targeting data sharing and discovery in the Earth Sciences.

LDEO: Robert Arko, Suzanne Carbotte, Kerstin Lehnert, Peng Ji

WHOI: Cynthia Chandler, Peter Wiebe, Lisa Raymond, Adam Shepherd, Audrey Mickle

UCSB: Mark Schildhauer, Krzysztof Janowicz, Matt Jones, Yingjie Hu

Ocean Leadership: Douglas Fils

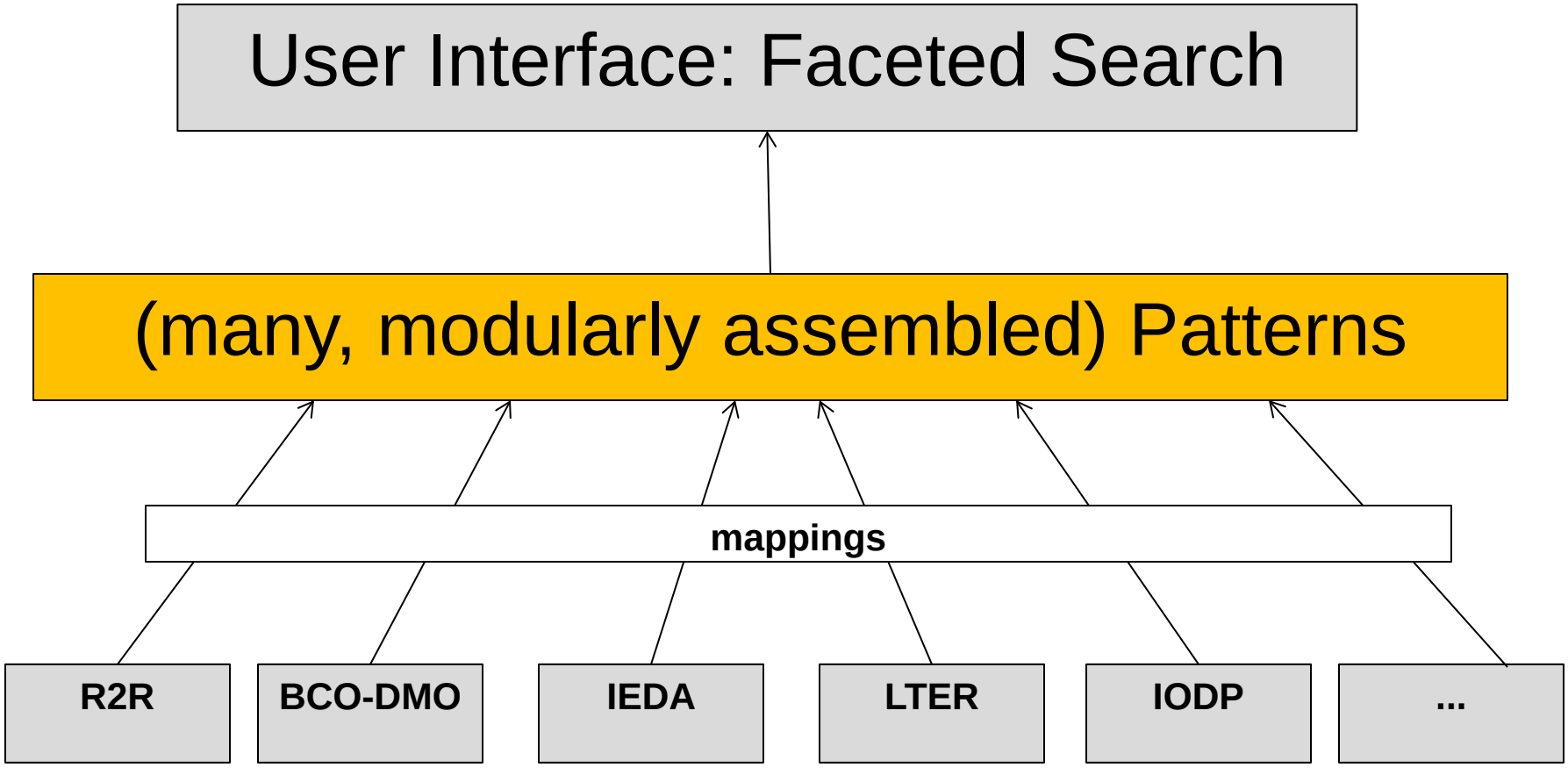
Marymount Univ: Thomas Narock

WSU: Pascal Hitzler, Michelle Cheatham, Adila Krisnadhi, Nazifa Karima, Brooke McCurdy

UMBC: Tim Finin

Featured in a January 2015 *Science* article.

GeoLink setup



Ontology Design Patterns

DaSe Lab

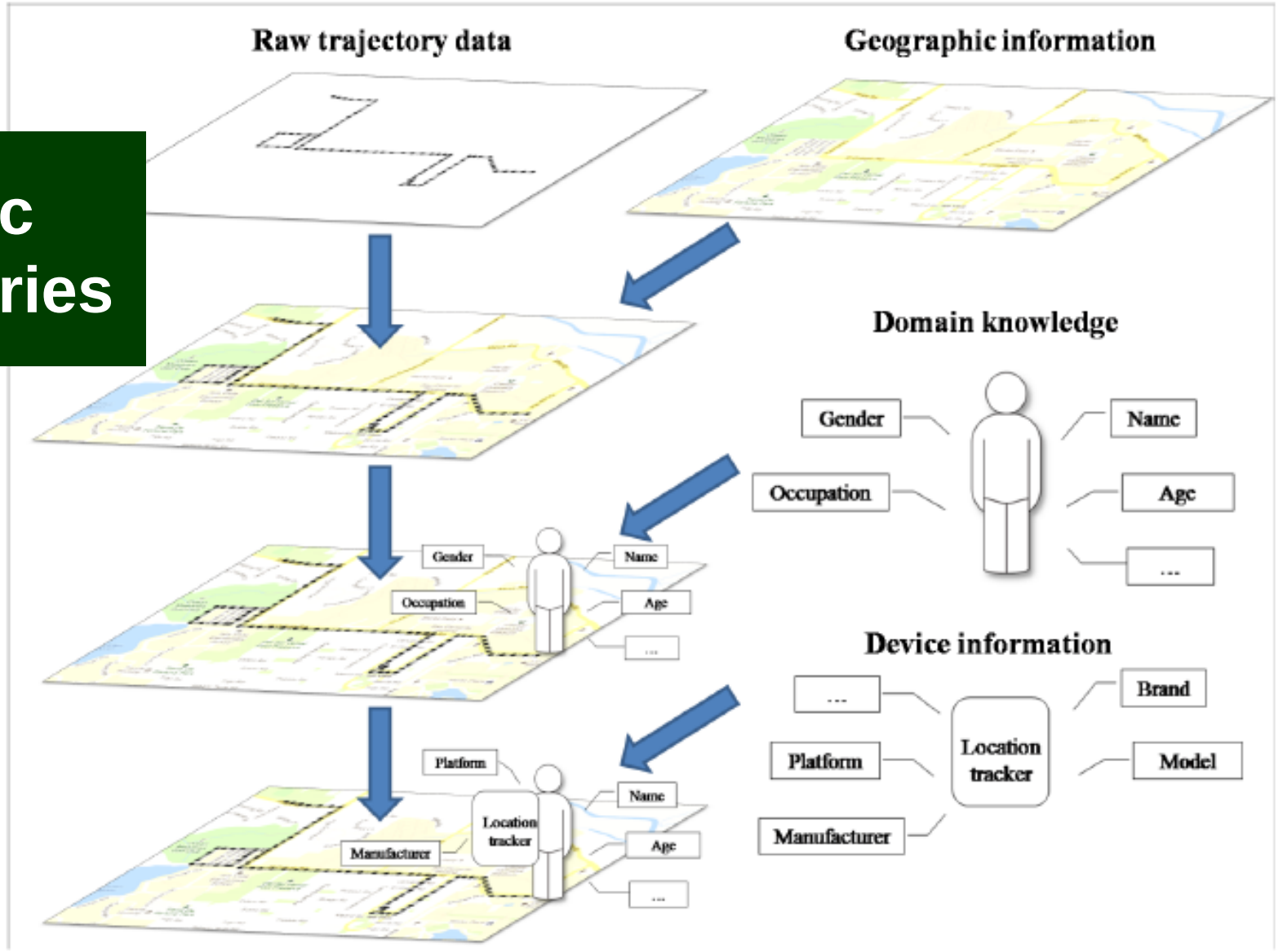
“An ontology design pattern is a reusable successful solution to a recurrent modeling problem.”

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

Patterns provide modular, reusable, replaceable, pieces.

By agreeing on reuse of generic patterns (but leaving the relationships between the patterns to a specific assembly for a special purpose), we can have reuse while preserving heterogeneity.

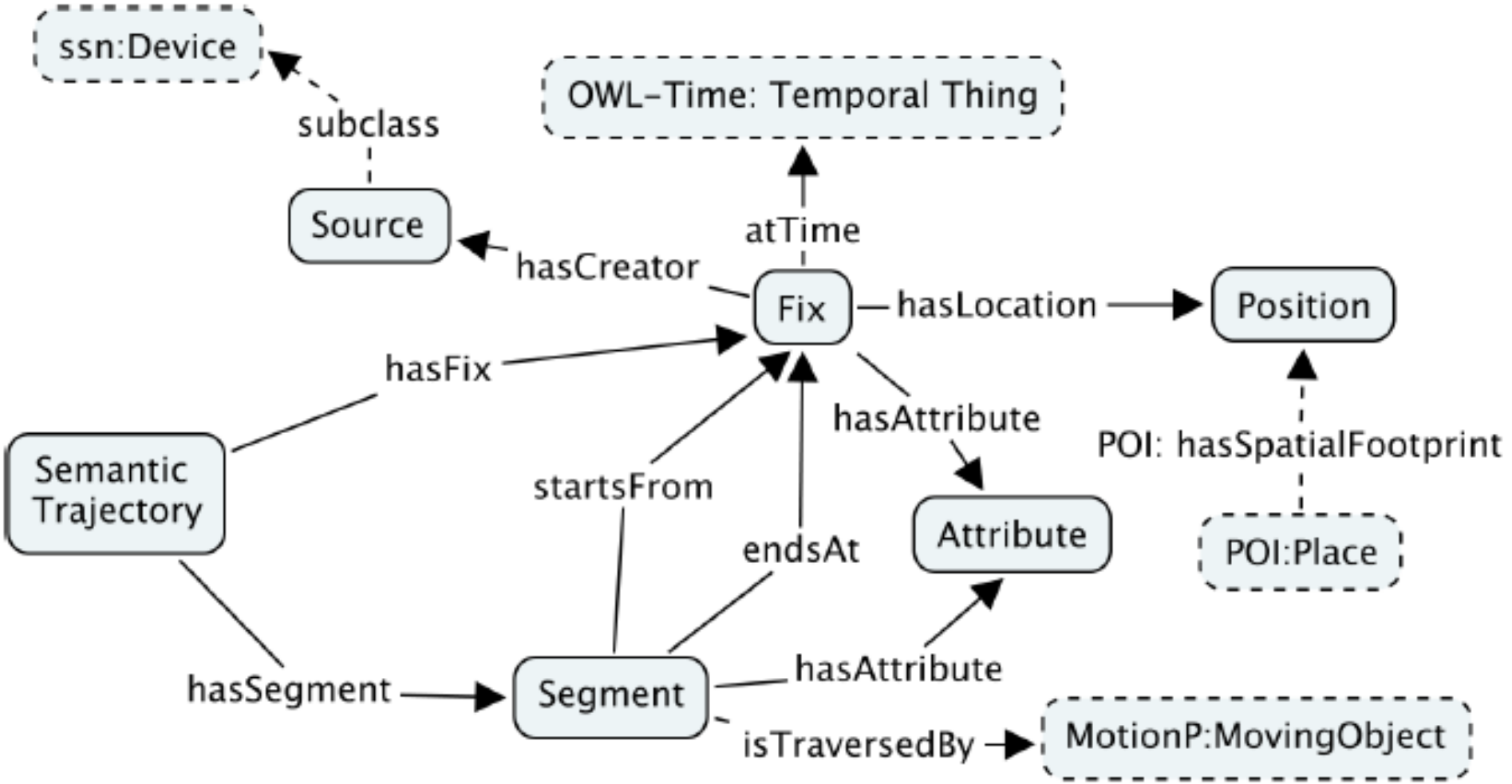
Semantic Trajectories



[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

DaSe Lab

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

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

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

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

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

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

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

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

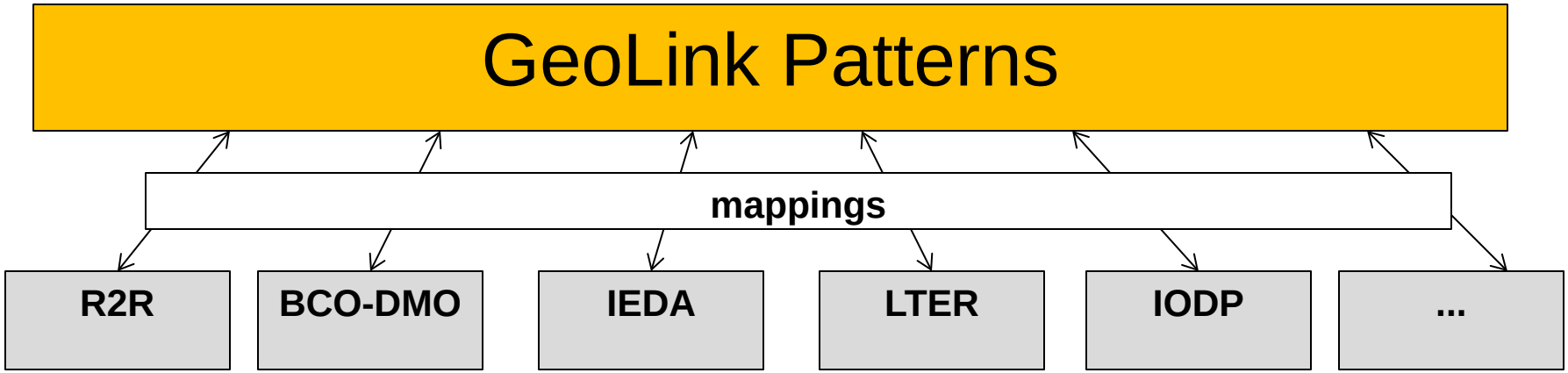
$$\exists hasSegment^{-}.SemanticTrajectory \sqsubseteq Segment \quad (19)$$

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

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

Patterns as interchange format

- **Aggregated data can be “pulled back” along the same mappings, if desired.**
- **Since the patterns are very generic, there is no loss of information by using them as interchange format.**



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.

Some central questions

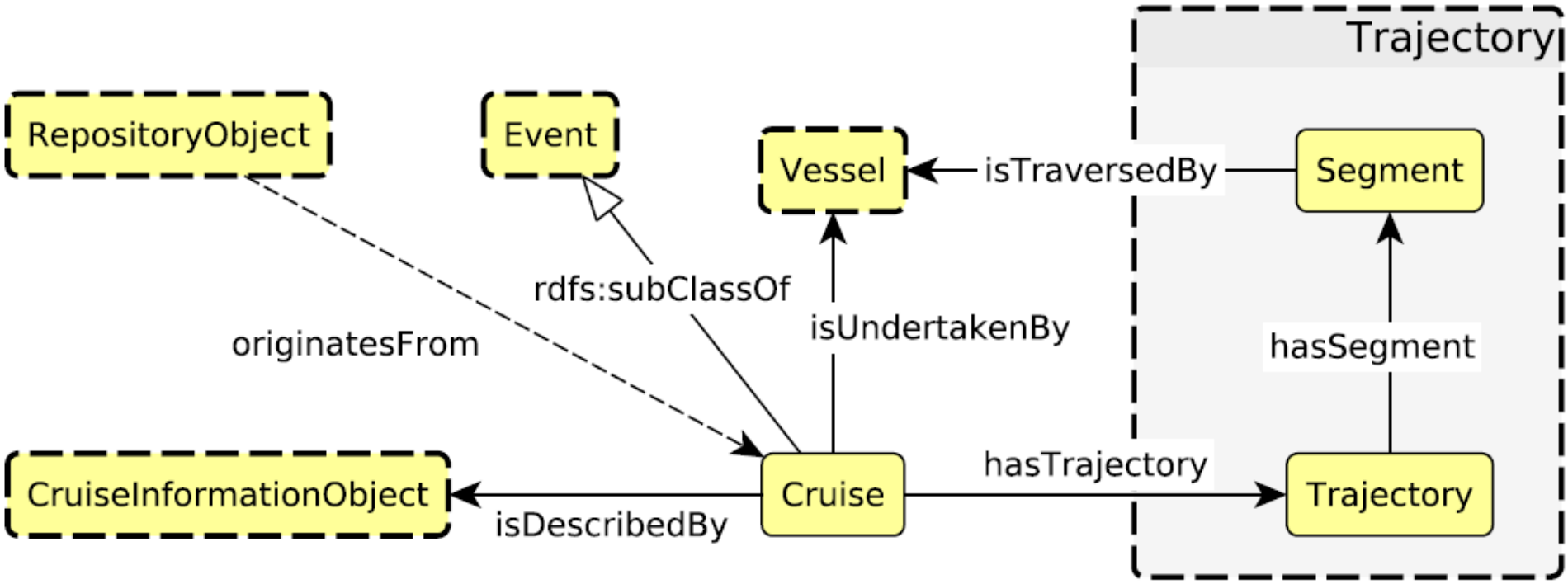
- **ODPs as subject of study**
- **Understanding generic versus specific modeling in patterns.**
- **Developing pattern languages and tools**
- **Understanding and formalizing relationships between patterns, and making systematic use of it: ecosystems of patterns**
- **Evaluating the added value of patterns for ontology-based tasks or applications, e.g. ontology alignment, linked data visualization, information integration, ...**

Thanks!

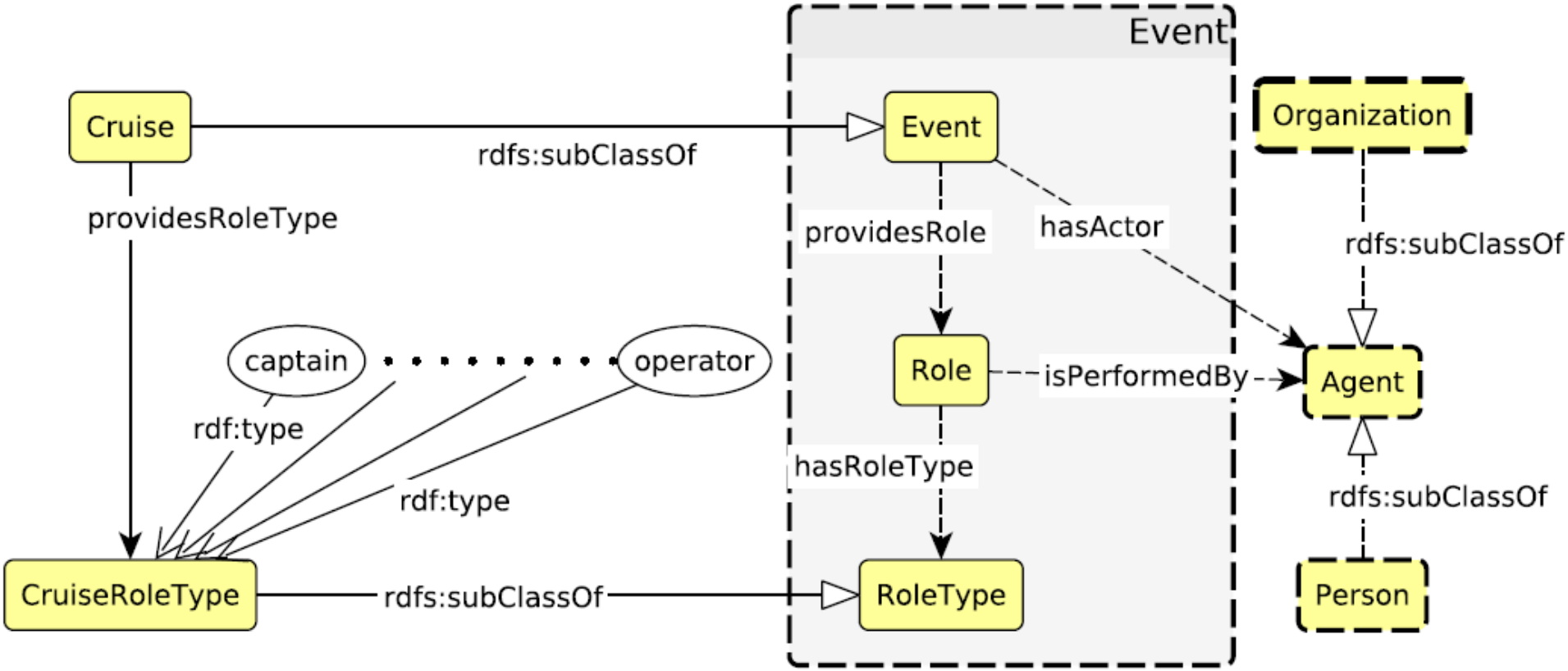
www.oceanlink.org

www.geo-link.org

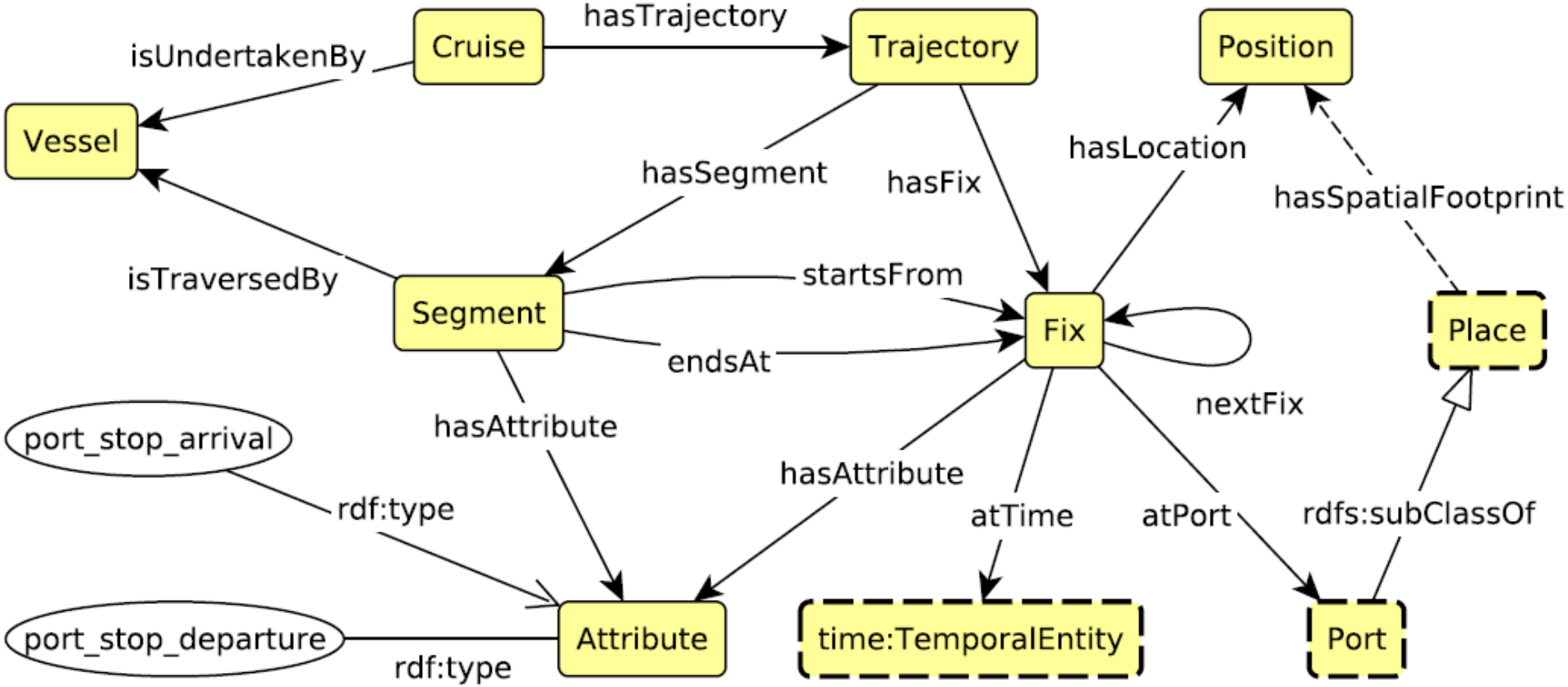
Oceanographic Cruise



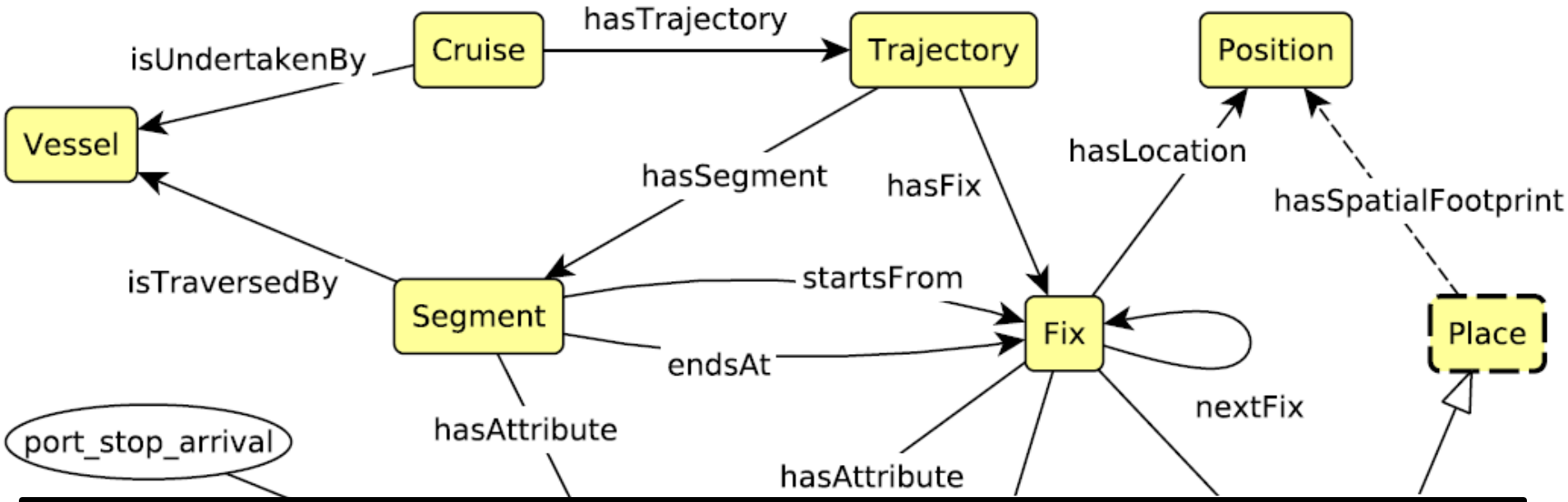
Roles (Cruise as Event)



Cruise Trajectories



Cruise Trajectories



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

Cruise trajectory

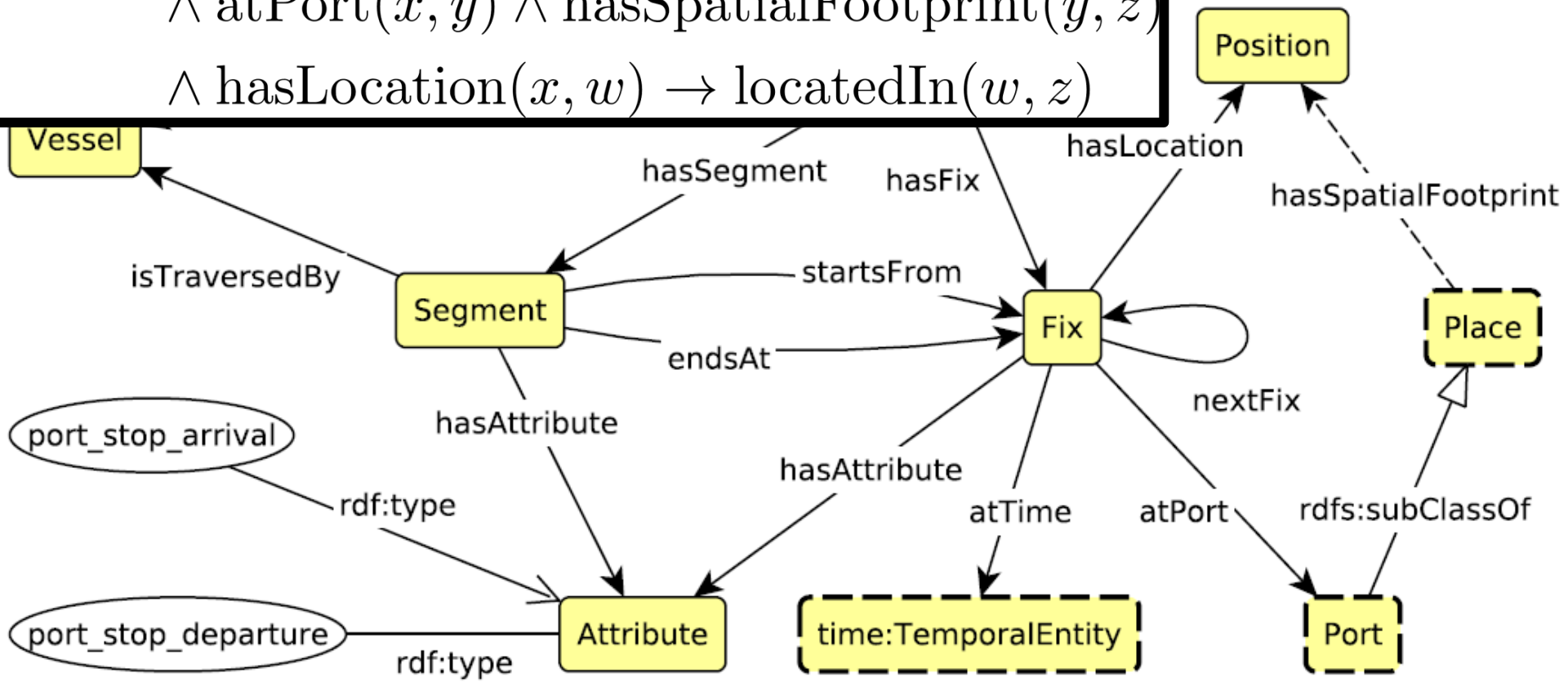
$$\mathrm{Cruise}(x) \wedge \mathrm{hasTrajectory}(x, y) \wedge \mathrm{hasSegment}(y, z) \wedge \mathrm{isTraversedBy}(z, v) \rightarrow \mathrm{isUndertakenBy}(x, v)$$

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

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

Cruise Trajectories

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

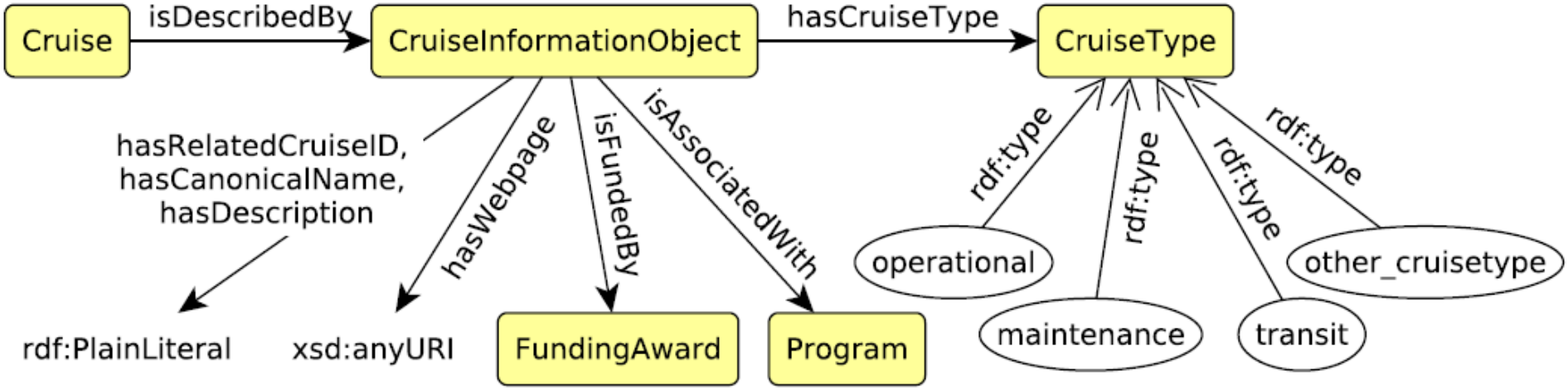


Cruise trajectory

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

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

Information Objects



References

- Pascal Hitzler, Frank van Harmelen, A reasonable Semantic Web. Semantic Web 1 (1-2), 39-44, 2010.
- Prateek Jain, Pascal Hitzler, Peter Z. Yeh, Kunal Verma, Amit P. Sheth, Linked Data is Merely More Data. In: Dan Brickley, Vinay K. Chaudhri, Harry Halpin, Deborah McGuinness: Linked Data Meets Artificial Intelligence. Technical Report SS-10-07, AAAI Press, Menlo Park, California, 2010, pp. 82-86. ISBN 978-1-57735-461-1. Proceedings of LinkedAI at the AAAI Spring Symposium, March 2010.
- Pascal Hitzler, Krzysztof Janowicz, *What's Wrong with Linked Data?* http://blog.semantic-web.at/2012/08/09/whats-wrong-with-linked-data/ , August 2012.
- Krzysztof Janowicz, Pascal Hitzler, Benjamin Adams, Dave Kolas, Charles Vardeman II, Five Stars of Linked Data Vocabulary Use. Semantic Web 5 (3), 2014, 173-176.

References

- Yingjie Hu, Krzysztof Janowicz, David Carral, Simon Scheider, Werner Kuhn, Gary Berg-Cross, Pascal Hitzler, Mike Dean, Dave Kolas, A Geo-Ontology Design Pattern for Semantic Trajectories. In: Thora Tenbrink, John G. Stell, Antony Galton, Zena Wood (Eds.): Spatial Information Theory - 11th International Conference, COSIT 2013, Scarborough, UK, September 2-6, 2013. Proceedings. Lecture Notes in Computer Science Vol. 8116, Springer, 2013, pp. 438-456.
- Pascal Hitzler, Markus Krötzsch, Sebastian Rudolph, *Foundations of Semantic Web Technologies*. Chapman and Hall/CRC Press, 2010.
- Adila Alfa Krisnadhi, Frederick Maier, Pascal Hitzler, OWL and Rules. In: A. Polleres, C. d'Amato, M. Arenas, S. Handschuh, P. Kroner, S. Ossowski, P.F. Patel-Schneider (eds.), Reasoning Web. Semantic Technologies for the Web of Data. 7th International Summer School 2011, Galway, Ireland, August 23-27, 2011, Tutorial Lectures. Lecture Notes in Computer Science Vol. 6848, Springer, Heidelberg, 2011, pp. 382-415.

References

- Pascal Hitzler, Krzysztof Janowicz, Linked Data, Big Data, and the 4th Paradigm. Semantic Web 4 (3), 2013, 233-235.
- Krzysztof Janowicz, Pascal Hitzler, The Digital Earth as Knowledge Engine. Semantic Web 3 (3), 213-221, 2012.
- Gary Berg-Cross, Isabel Cruz, Mike Dean, Tim Finin, Mark Gahegan, Pascal Hitzler, Hook Hua, Krzysztof Janowicz, Naicong Li, Philip Murphy, Bryce Nordgren, Leo Obrst, Mark Schildhauer, Amit Sheth, Krishna Sinha, Anne Thessen, Nancy Wiegand, Ilya Zaslavsky, Semantics and Ontologies for EarthCube. In: K. Janowicz, C. Kessler, T. Kauppinen, D. Kolas, S. Scheider (eds.), Workshop on GIScience in the Big Data Age, In conjunction with the seventh International Conference on Geographic Information Science 2012 (GIScience 2012), Columbus, Ohio, USA. September 18th, 2012. Proceedings.
- Krzysztof Janowicz, Pascal Hitzler, Thoughts on the Complex Relation Between Linked Data, Semantic Annotations, and Ontologies. In: Paul N. Bennett, Evgeniy Gabrilovich, Jaap Kamps, Jussi Karlgren (eds.), Proceedings of the 6th International Workshop on Exploiting Semantic Annotation in Information Retrieval, ESAIR 2013, ACM, San Francisco, 2013, pp. 41-44.

References

- Prateek Jain, Pascal Hitzler, Amit P. Sheth, Kunal Verma, Peter Z. Yeh, Ontology Alignment for Linked Open Data. In P. Patel-Schneider, Y. Pan, P. Hitzler, P. Mika, L. Zhang, J. Pan, I. Horrocks, B. Glimm (eds.), The Semantic Web - ISWC 2010. 9th International Semantic Web Conference, ISWC 2010, Shanghai, China, November 7-11, 2010, Revised Selected Papers, Part I. Lecture Notes in Computer Science Vol. 6496. Springer, Berlin, 2010, pp. 402-417.
- Amit Krishna Joshi, Prateek Jain, Pascal Hitzler, Peter Z. Yeh, Kunal Verma, Amit P. Sheth, Mariana Damova, Alignment-based Querying of Linked Open Data. In: Meersman, R.; Panetto, H.; Dillon, T.; Rinderle-Ma, S.; Dadam, P.; Zhou, X.; Pearson, S.; Ferscha, A.; Bergamaschi, S.; Cruz, I.F. (eds.), On the Move to Meaningful Internet Systems: OTM 2012, Confederated International Conferences: CoopIS, DOA-SVI, and ODBASE 2012, Rome, Italy, September 10-14, 2012, Proceedings, Part II. Lecture Notes in Computer Science Vol. 7566, Springer, Heidelberg, 2012, pp. 807-824.
- Yingjie Hu, Krzysztof Janowicz, David Carral, Simon Scheider, Werner Kuhn, Gary Berg-Cross, Pascal Hitzler, Mike Dean, Dave Kolas, A Geo-Ontology Design Pattern for Semantic Trajectories. In: Thora Tenbrink, John G. Stell, Antony Galton, Zena Wood (Eds.): Spatial Information Theory - 11th International Conference, COSIT 2013, Scarborough, UK, September 2-6, 2013. Proceedings. Lecture Notes in Computer Science Vol. 8116, Springer, 2013, pp. 438-456.

References

- Prateek Jain, Peter Z. Yeh, Kunal Verma, Reymonrod G. Vasquez, Mariana Damova, Pascal Hitzler, Amit P. Sheth, Contextual Ontology Alignment of LOD with an Upper Ontology: A Case Study with Proton. In: Grigoris Antoniou, Marko Grobelnik, Elena Paslaru Bontas Simperl, Bijan Parsia, Dimitris Plexousakis, Pieter De Leenheer, Jeff Pan (Eds.): The Semantic Web: Research and Applications - 8th Extended Semantic Web Conference, ESWC 2011, Heraklion, Crete, Greece, May 29-June 2, 2011, Proceedings, Part I. Lecture Notes in Computer Science 6643, Springer, 2011, pp. 80-92.
- Prateek Jain, Pascal Hitzler, Kunal Verma, Peter Yeh, Amit Sheth, Moving beyond sameAs with PLATO: Partonomy detection for Linked Data. In: Ethan V. Munson, Markus Strohmaier (Eds.): 23rd ACM Conference on Hypertext and Social Media, HT '12, Milwaukee, WI, USA, June 25-28, 2012. ACM, 2012, pp. 33-42.