



# A Brief Introduction to Semantic Web – and a Contribution to Explainable Artificial Intelligence

## **Pascal Hitzler**

Data Semantics Laboratory (DaSe Lab)  
Data Science and Security Cluster (DSSC)  
Wright State University  
<http://www.pascal-hitzler.de>



Pascal Hitzler, Markus Krötzsch,  
Sebastian Rudolph

Foundations of Semantic Web  
Technologies

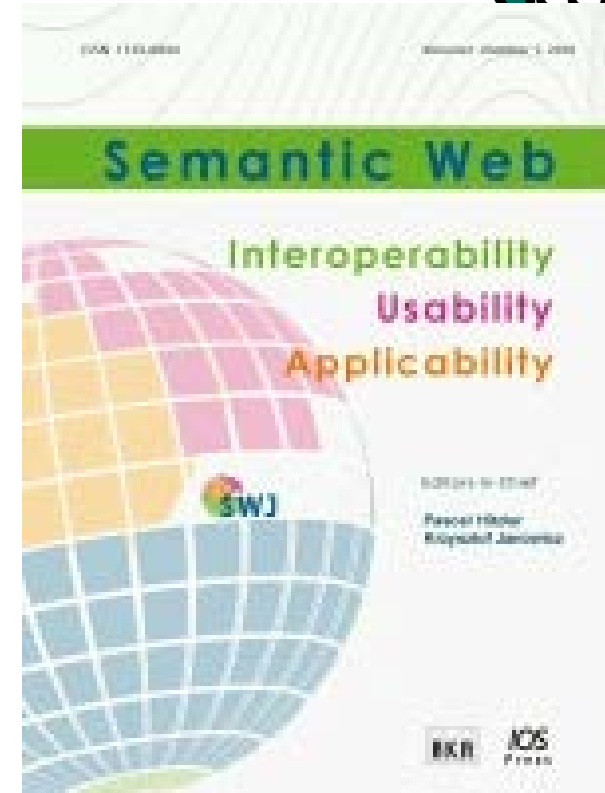
Chapman & Hall/CRC, 2010

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

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



- **EiCs:** Pascal Hitzler  
Krzysztof Janowicz
- **Funded 2010**
- **2017 Impact factor of 2.889, top (with 1.3 distance) of all journals with “Web” in the title**
- **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/>**



# U.S. Semantic Technologies Symposium

March 1-2, 2018, at Wright State University, Dayton, Ohio

## Confirmed speakers/panelists/coordinators:

**Achille Fukoue**

**Karl Grossner**

**Jim Hender**

**Chris Mungall**

**Dan Brickley**

**David Booth**

**Tim Finin**

**Peter Fox**

**Michael Grüninger**

**Melissa Haendel**

**Eric Kansa**

**Craig Knoblock**

**Werner Kuhn**

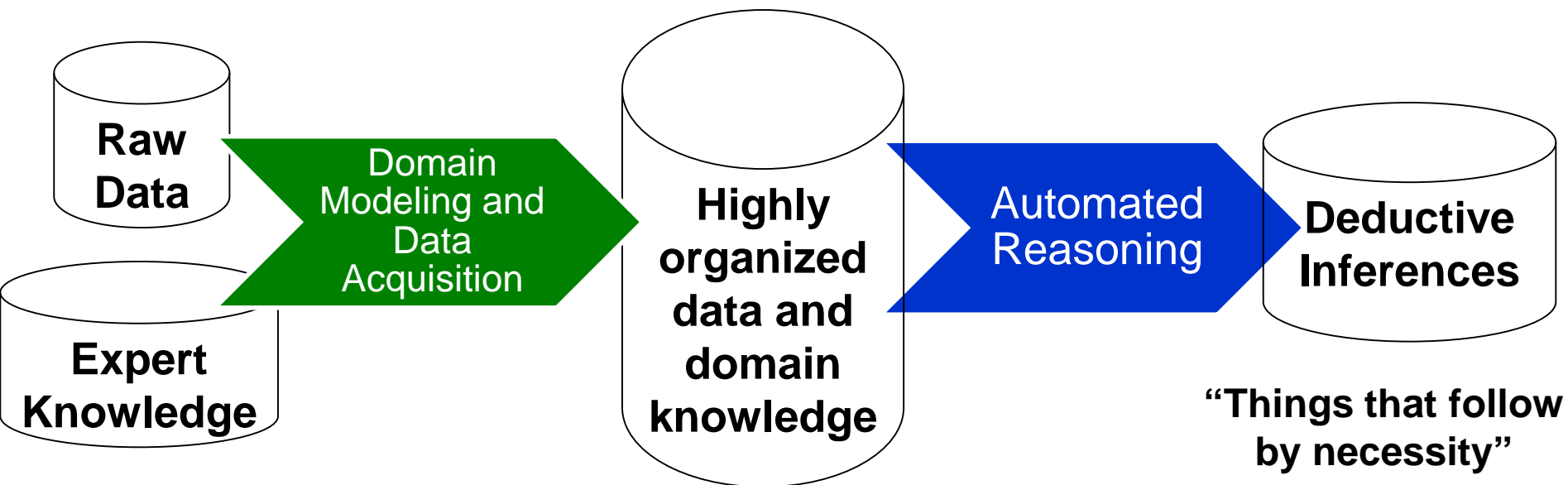
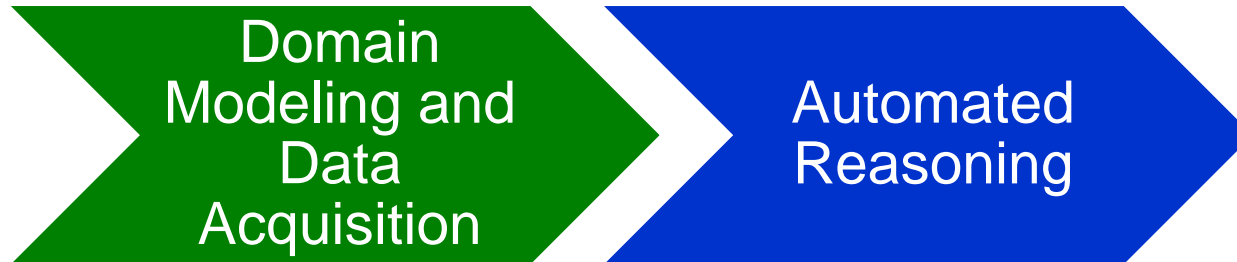
**Matt Lange**

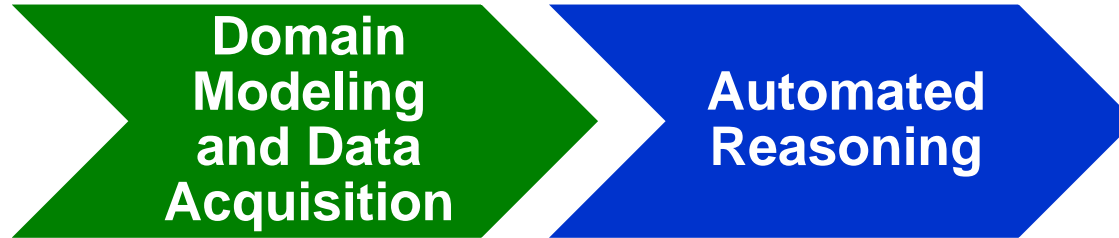
**Rob Sanderson**

**Philip Schreur**

**Ryan Shaw**

**Brian Ulicny**





**“Expert Systems” traditionally based on the logic programming paradigm.**

**In the wake of Semantic Web Technologies, Description Logics have emerged as alternative dominant paradigm.**

**Description logics underlie the W3C standard “Web Ontology Language” (OWL).**



**Semantic Web technologies provides efficient methods for**

- data sharing**
- data reuse**
- data integration**
- data discovery**

**for all kinds of application scenarios.**

**Key idea: A good data model (schema) makes a lot of a difference!**

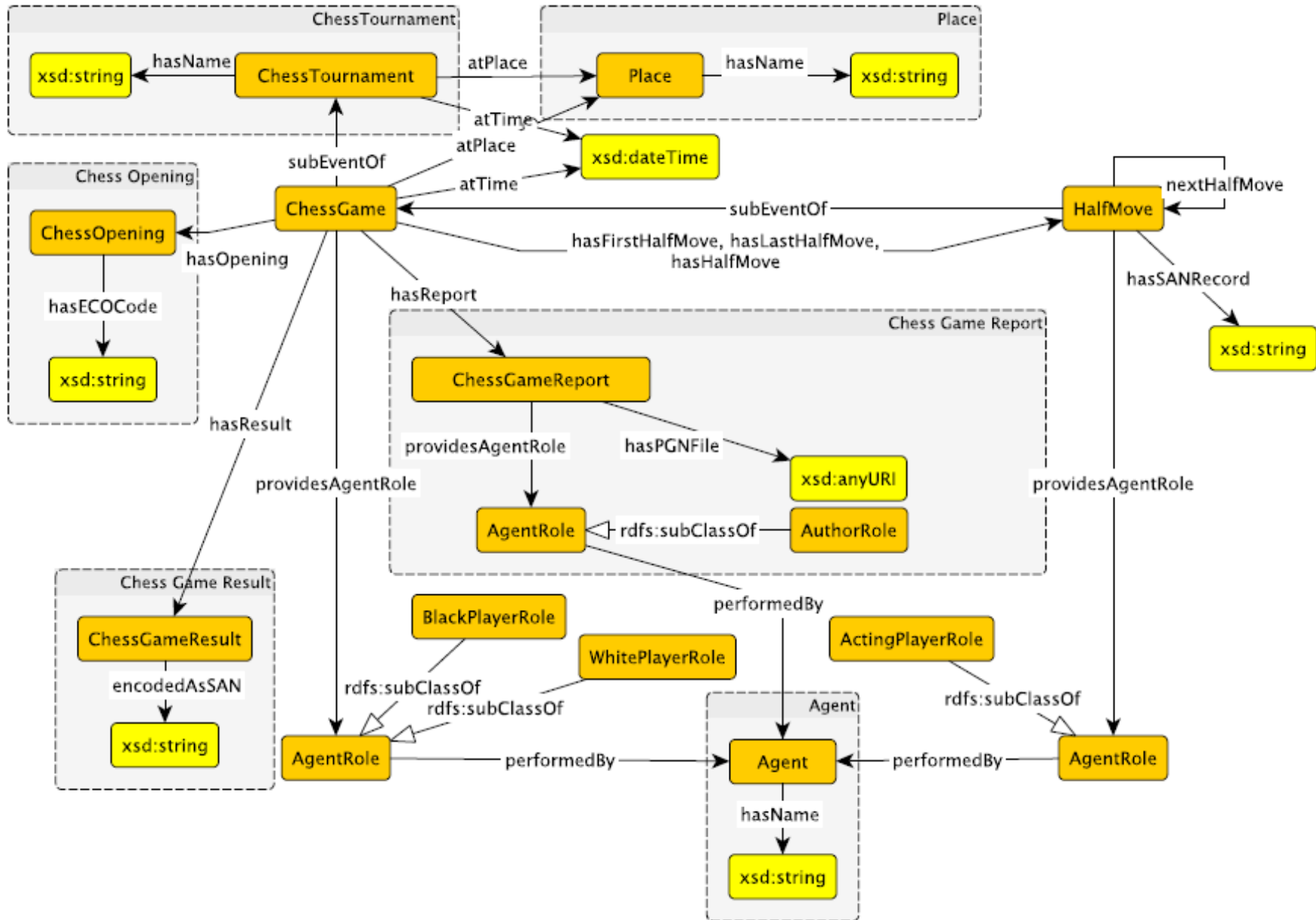
- **Unary and binary predicates only (classes = concepts  
properties = roles)**
- **Conjunction, disjunction, negation and restricted quantifiers to form complex class expressions**
- **SubClass relationships (i.e., implications between complex classes)**
- **Role chains (concatenation of binary predicates)**
- **Variable bindings are severely restricted.**



## **Result:**

- **Decidable logics, with complexities known.**
- **Variable-free notation.**
- **Some are P-complete; some are 2NExpTime**
- **Very efficient reasoners available.**





AgentRole  $\sqsubseteq$  ( $=1$  performedBy.Agent)  $\sqcap$   $\forall$ performedBy.Agent (10.1)

$\exists$ performedBy.Agent  $\sqsubseteq$  AgentRole (10.2)

$\top$   $\sqsubseteq$   $\forall$ pAR.AgentRole (10.3)

ChessGame  $\sqsubseteq$   $\exists$ atPlace.Place  $\sqcap$   $\forall$ atPlace.Place (10.4)

ChessGame  $\sqsubseteq$   $\exists$ atTime.xsd:dateTime  $\sqcap$   $\forall$ atTime.xsd:dateTime (10.5)

ChessGame  $\sqsubseteq$   $\exists$ pAR.BlackPlayerRole  $\sqcap$   $\exists$ pAR.WhitePlayerRole (10.6)

$\exists$ subEventOf.ChessTournament  $\sqcup$   $\exists$ hasOpening.ChessOpening  $\sqsubseteq$  ChessGame (10.7)

$\exists$ hasResult.ChessGameResult  $\sqcup$   $\exists$ hasReport.ChessGameReport  $\sqsubseteq$  ChessGame (10.8)

ChessGame  $\sqsubseteq$   $\forall$ subEventOf.ChessTournament  $\sqcap$   $\forall$ hasOpening.ChessOpening (10.9)

ChessGame  $\sqsubseteq$   $\forall$ hasResult.ChessGameResult  $\sqcap$   $\forall$ hasReport.ChessGameReport (10.10)

BlackPlayerRole  $\sqcup$  WhitePlayerRole  $\sqsubseteq$  AgentRole  $\sqcap$  ( $=1$  pAR<sup>-</sup>.ChessGame) (10.11)

ChessGame  $\sqsubseteq$  ( $=1$  hasFirstHalfMove.HalfMove)  $\sqcap$  ( $=1$  hasLastHalfMove.HalfMove) (10.12)

ChessGame  $\sqsubseteq$  ( $=1$  hasLastHalfMove.HalfMove) (10.13)

hasHalfMove  $\sqsubseteq$  subEventOf<sup>-</sup> (10.14)

hasFirstHalfMove  $\sqsubseteq$  hasHalfMove (10.15)

hasLastHalfMove  $\sqsubseteq$  hasHalfMove (10.16)

HalfMove  $\sqsubseteq$  Event  $\sqcap$   $\exists$ pAR.ActingPlayerRole  $\sqcap$  ( $=1$  hasHalfMove<sup>-</sup>.ChessGame) (10.17)

ActingPlayerRole  $\sqsubseteq$  AgentRole  $\sqcap$  ( $=1$  pAR<sup>-</sup>.HalfMove) (10.18)

HalfMove  $\sqsubseteq$  ( $\leq 1$  nextHalfMove.HalfMove)  $\sqcap$   $\neg \exists$ nextHalfMove.Self (10.19)

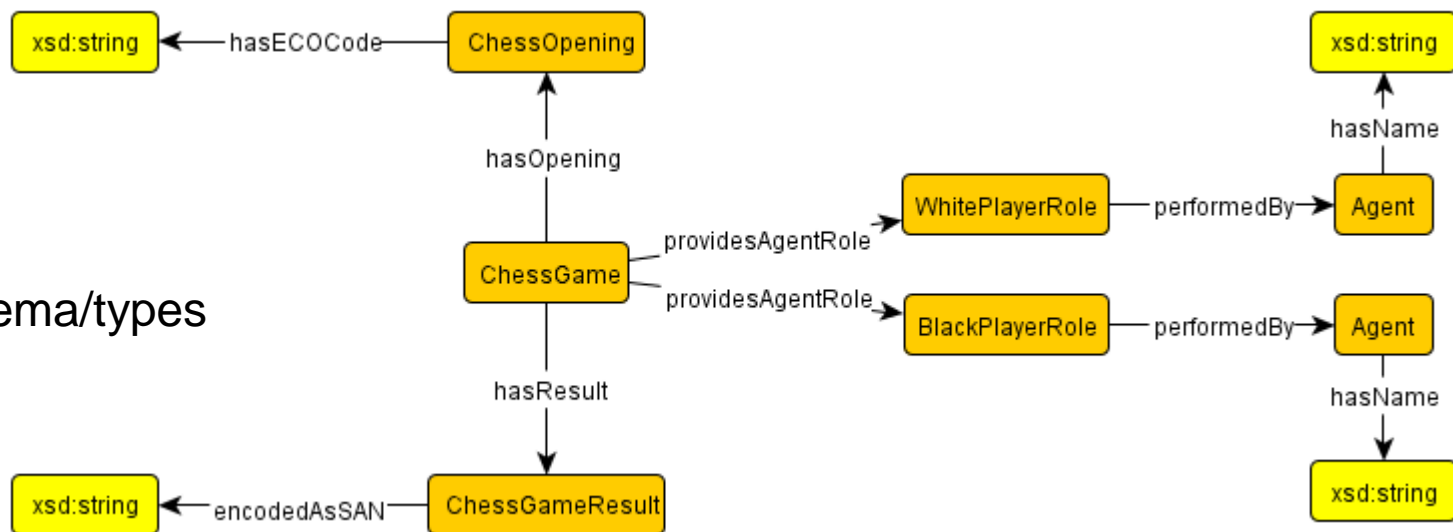
$\exists$ subEventOf.ChessGame  $\sqcup$   $\exists$ nextHalfMove.HalfMove  $\sqsubseteq$  HalfMove (10.20)

$\exists$ hasSANRecord.xsd:string  $\sqsubseteq$  HalfMove (10.21)

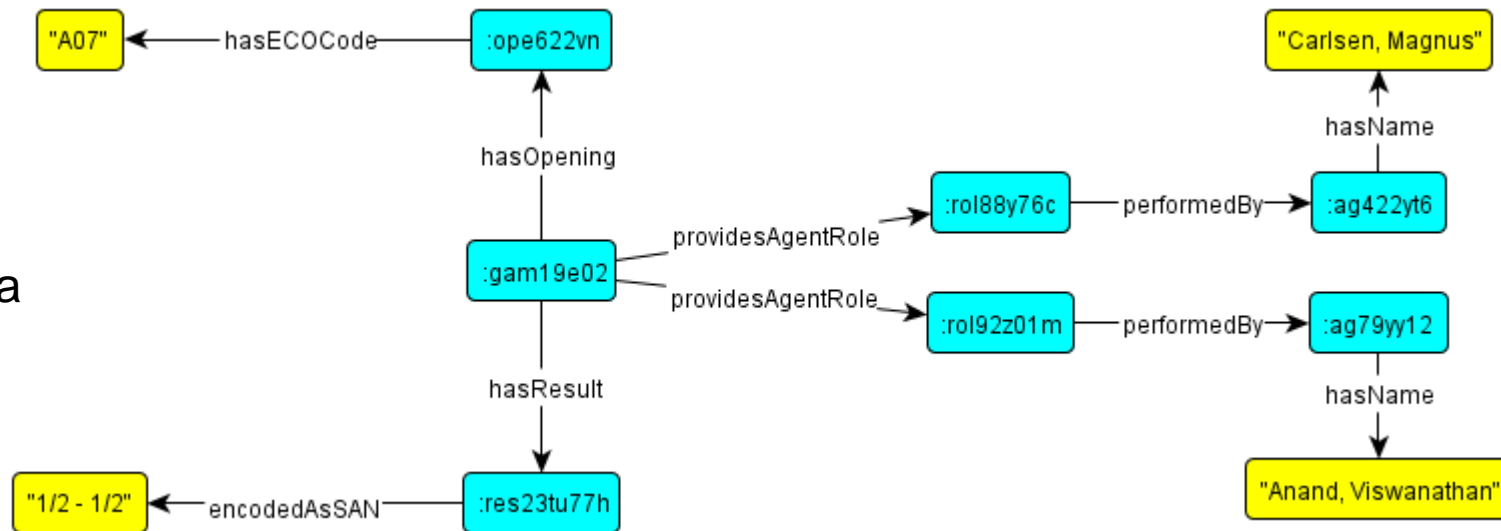
HalfMove  $\sqcap$   $\forall$ subEventOf.ChessGame  $\sqcap$   $\forall$ nextHalfMove.HalfMove (10.22)



## Schema/types



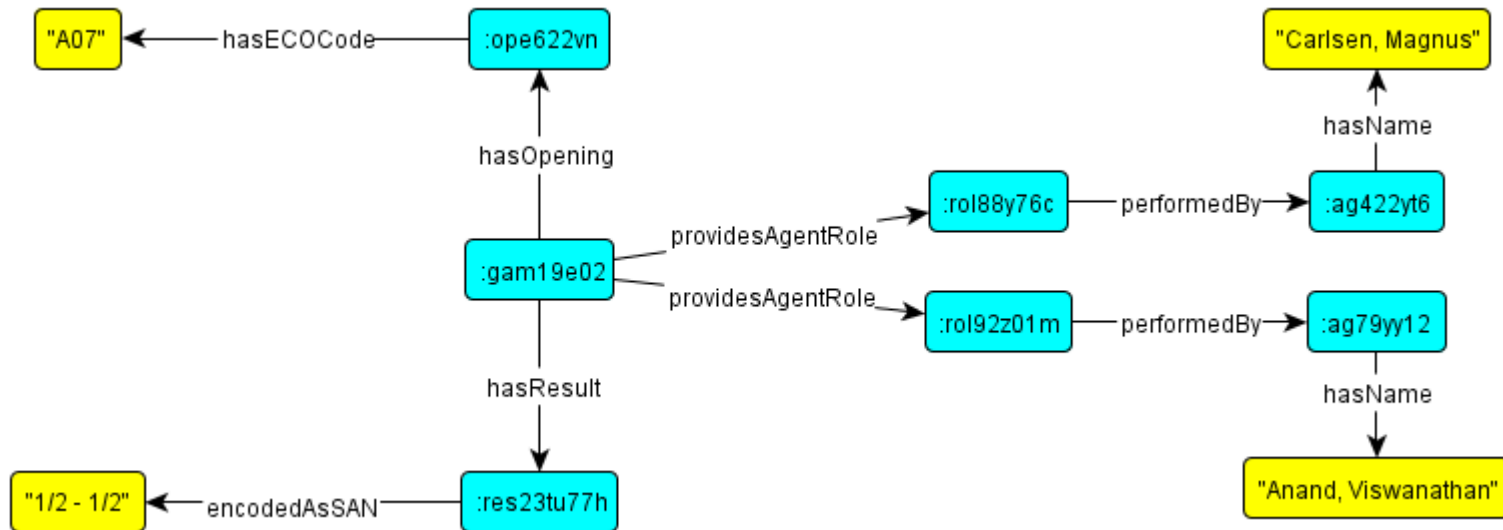
## Data





RDF uses Web-referencable identifiers.

E.g., `:ag422yt6` expands to a full URI (for Magnus Carlsen).  
Under best practices, it even dereferences.



Knowledge Graph

RDF Graph

Labelled Graph

Abox

Facts

Schema

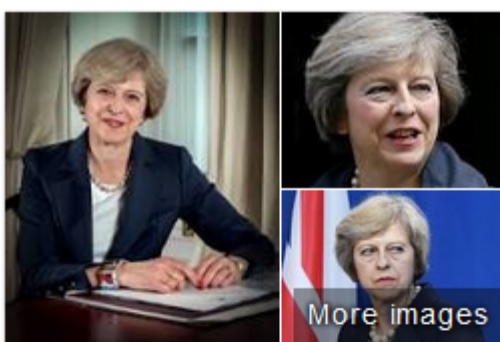
Ontology

Type Logic

Tbox

Logical Theory





More images

# Theresa May



British Prime Minister



tmay.co.uk

Theresa Mary May is a British politician who has served as Prime Minister of the United Kingdom and Leader of the Conservative Party since July 2016, the second woman to hold both positions. [Wikipedia](#)

**Born:** October 1, 1956 (age 60), Eastbourne, United Kingdom

**Height:** 5' 8"

**Party:** Conservative Party

**Spouse:** Philip May (m. 1980)

**Education:** St Hugh's College, Oxford (1974–1977)

**Previous offices:** Home Secretary (2010–2016), [MORE](#) ▾

## Profiles



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# St Hugh's College, Oxford

College in Oxford, England

[Website](#)

[Directions](#)

St Hugh's College is one of the constituent colleges of the University of Oxford. It is located on a 14.5-acre site on St Margaret's Road, to the north of the city centre. [Wikipedia](#)

**Address:** St Margaret's Rd, Oxford OX2 6LE, UK

**Principal:** Elish Angiolini

**Phone:** +44 1865 274900

**Founder:** Elizabeth Wordsworth

**Founded:** 1886

**Named for:** Hugh of Lincoln

**Undergraduates:** 432 (2011–2012)

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## Reviews from the web

4.1/5 [University Rooms](#) · 2,310 votes

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## Notable alumni

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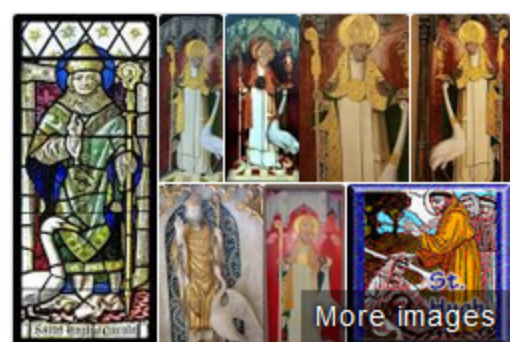
Theresa May



Aung San Suu Kyi



Barbara Castle



More images

# Hugh of Lincoln



Saint

Hugh of Lincoln, also known as Hugh of Avalon, was a French noble, Benedictine and Carthusian monk, bishop of Lincoln in the Kingdom of England, and Catholic saint. [Wikipedia](#)

**Born:** 1140, Avalon, France

**Died:** November 16, 1200, London, United Kingdom

**Feast:** 16 November (R.C.C.); 17 November (Anglican)

**Major shrine:** Lincoln Cathedral

**Attributes:** a white swan

**Patronage:** sick children, sick people, shoemakers and swans

## People also search for



Little Saint Hugh of Lincoln



Thomas More



William Howard, 1st Visco...

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, KY, U

# Schema.org



- Collaboratively launched in 2011 by Google, Microsoft, Yahoo, Yandex.  
2011: 297 classes, 187 relations  
2015: 638 classes, 965 relations
- Simple schema, request to web site providers to annotate their content with schema.org markup. Promise: They will make better searches based on this.
- 2015: 31.3% of Web pages have schema.org markup, on average 26 assertions per page.

Ramanathan V. Guha, Dan Brickley, Steve Macbeth:  
Schema.org: Evolution of Structured Data on the  
Web. ACM Queue 13(9): 10 (2015)

- TrainTrip
- Organization
  - Airline
  - Corporation
  - EducationalOrganization
    - CollegeOrUniversity
    - ElementarySchool
    - HighSchool
    - MiddleSchool
    - Preschool
    - School
  - GovernmentOrganization
  - LocalBusiness
    - AnimalShelter
    - AutomotiveBusiness
      - AutoBodyShop
      - AutoDealer
      - AutoPartsStore
      - AutoRental
      - AutoRepair
      - AutoWash
      - GasStation
      - MotorcycleDealer
      - MotorcycleRepair
    - ChildCare
    - Dentist
    - DryCleaningOrLaundry
    - EmergencyService
      - FireStation
      - Hospital
      - PoliceStation
    - EmploymentAgency
    - EntertainmentBusiness
      - AdultEntertainment
      - AmusementPark
      - ArtGallery
      - Casino
      - ComedyClub
      - MovieTheater
      - NightClub
    - FinancialService
      - AccountingService
      - AutomatedTeller
      - BankOrCreditUnion
      - InsuranceAgency
    - FoodEstablishment
      - Bakery
      - BarOrPub
      - Brewery
      - CafeOrCoffeeShop
      - FastFoodRestaurant



- Main page
- Community portal
- Project chat
- Create a new item
- Recent changes
- Random item
- Query Service
- Nearby
- Help
- Donate

Print/export

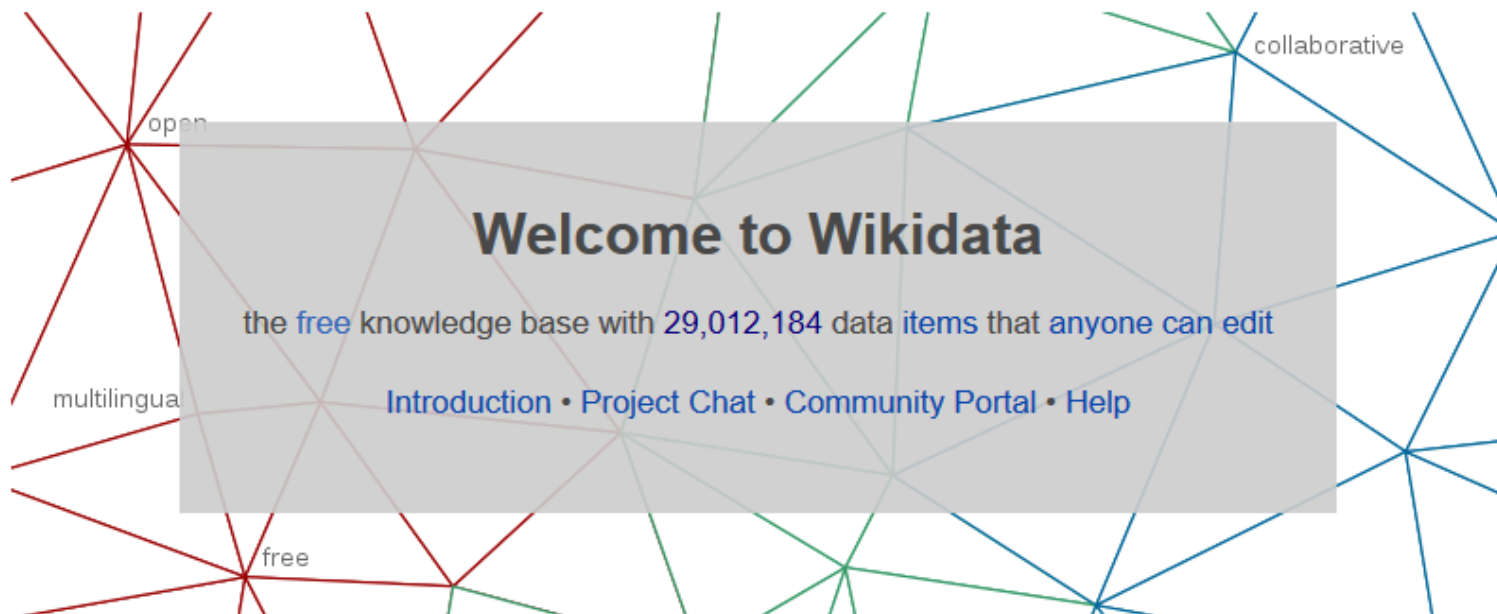
- Create a book
- Download as PDF
- Printable version

In other projects

- Wikimedia Commons
- MediaWiki
- Meta-Wiki
- Wikispecies
- Wikibooks
- Wikinews
- Wikipedia
- Wikiquote
- Wikisource
- Wikiversity
- Wikivoyage
- Wiktionary

Tools

What links here



## Welcome!

Wikidata is a free and open knowledge base that can be read and edited by both humans and machines.

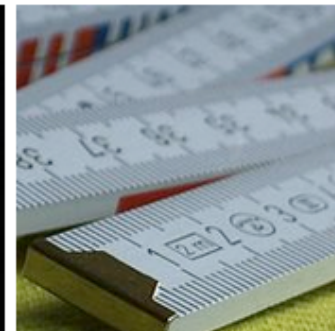
Wikidata acts as central storage for the **structured data** of its Wikimedia sister projects including Wikipedia, Wikivoyage, Wikisource, and others.

Wikidata also provides support to many other sites and services beyond just Wikimedia projects! The content of Wikidata is [available under a free license](#), [exported using standard formats](#), and [can be interlinked to other open data sets](#) on the linked data web.



## Learn about data

New to the wonderful world of data? [Develop and improve your data literacy through content](#) designed to get you up to speed and feeling comfortable with the fundamentals in no time.





A bit older but somewhat more expressive: Linked Data on the Web



<b>Number of Datasets</b>	<b>2017-01-26</b>	<b>1,146</b>
	2014-08-30	570
	2011-09-19	295
	2010-09-22	203
	2009-07-14	95
	2008-09-18	45
	2007-10-08	25
	2007-05-01	12

38.606.408.854 triples and counting!



LOD Laundromat

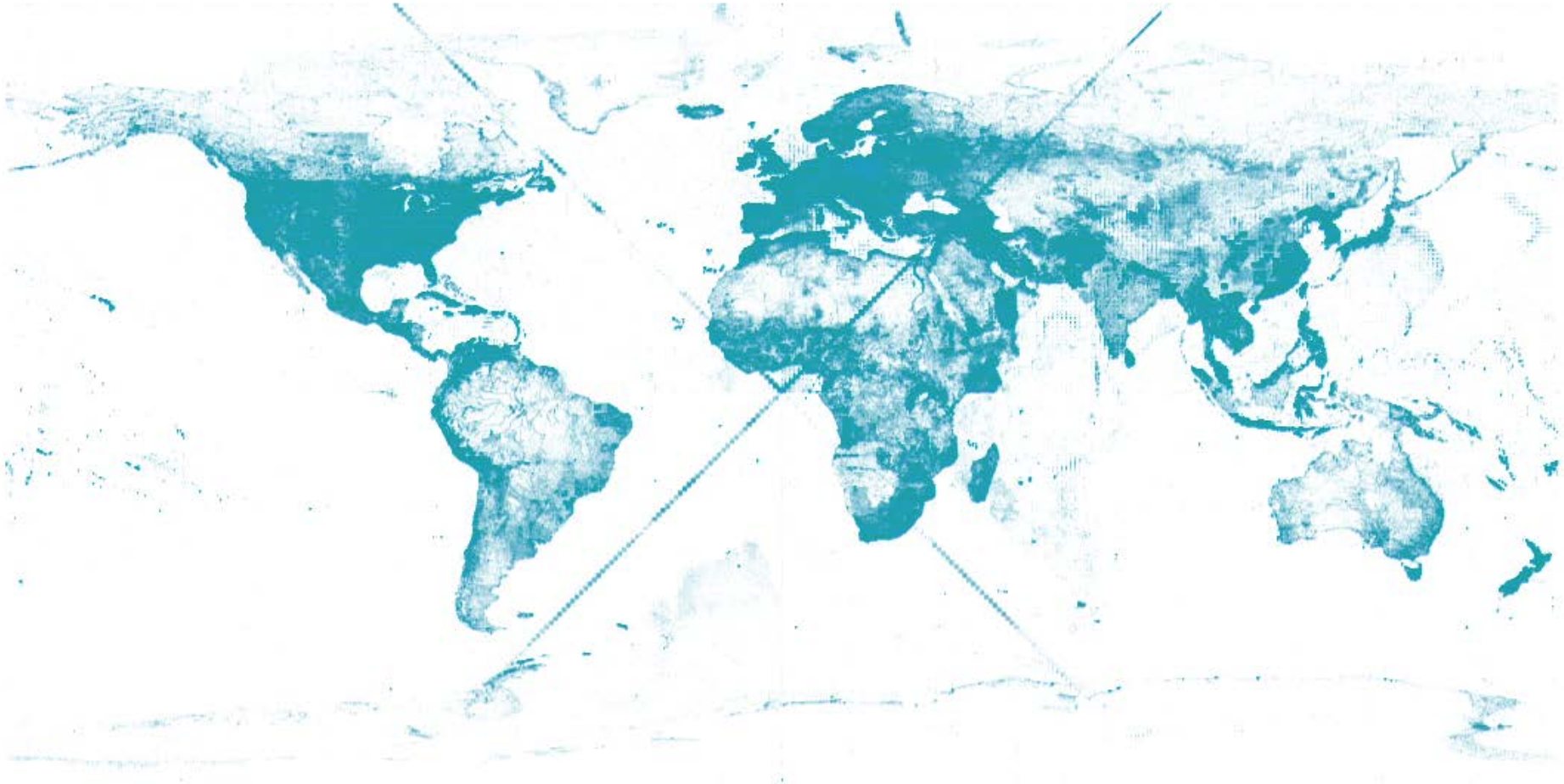
# DBpedia: LOTR page

dbpedia-owl:thumbnail	<ul style="list-style-type: none"><li>▪ <a href="http://upload.wikimedia.org/wikipedia/commons/thumb/6/62/Jrrt_lotr_cover_design.jpg/200px-Jrrt_lotr_cover_design.jpg">http://upload.wikimedia.org/wikipedia/commons/thumb/6/62/Jrrt_lotr_cover_design.jpg/200px-Jrrt_lotr_cover_design.jpg</a></li></ul>
dbpedia-owl:wikiPageExternalLink	<ul style="list-style-type: none"><li>▪ <a href="http://lotr.wikia.com">http://lotr.wikia.com</a></li><li>▪ <a href="http://www.glyphweb.com/arda/">http://www.glyphweb.com/arda/</a></li><li>▪ <a href="http://www.tolkienlibrary.com/">http://www.tolkienlibrary.com/</a></li><li>▪ <a href="http://www.tolkien.co.uk/">http://www.tolkien.co.uk/</a></li><li>▪ <a href="http://www.houghtonmifflinbooks.com/features/lordoftheringstrilogy/">http://www.houghtonmifflinbooks.com/features/lordoftheringstrilogy/</a></li></ul>
dbpprop:author	<ul style="list-style-type: none"><li>▪ dbpedia:J._R._R._Tolkien</li></ul>
dbpprop:books	<ul style="list-style-type: none"><li>▪ dbpedia:The_Two_Towers</li><li>▪ dbpedia:The_Return_of_the_King</li><li>▪ dbpedia:The_Fellowship_of_the_Ring</li><li>▪ "Volumes:"</li></ul>
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dbpprop:expiry	<ul style="list-style-type: none"><li>▪ 20 (xsd:integer)</li></ul>
dbpprop:genre	<ul style="list-style-type: none"><li>▪ dbpedia:Adventure_novel</li><li>▪ dbpedia:High_fantasy</li></ul>
dbpprop:hasPhotoCollection	<ul style="list-style-type: none"><li>▪ <a href="http://www4.wiwiss.fu-berlin.de/flickrwrappr/photos/The_Lord_of_the_Rings">http://www4.wiwiss.fu-berlin.de/flickrwrappr/photos/The_Lord_of_the_Rings</a></li></ul>
dbpprop:imageCaption	<ul style="list-style-type: none"><li>▪ Tolkien's own cover designs for the three volumes</li></ul>
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dbpprop:mediaType	<ul style="list-style-type: none"><li>▪ Print</li></ul>
dbpprop:name	<ul style="list-style-type: none"><li>▪ The Lord of the Rings</li></ul>
dbpprop:pages	<ul style="list-style-type: none"><li>▪ 1216 (xsd:integer)</li></ul>
dbpprop:precededBy	<ul style="list-style-type: none"><li>▪ dbpedia:The_Hobbit</li></ul>
dbpprop:pubDate	<ul style="list-style-type: none"><li>▪ 21 (xsd:integer)</li></ul>
dbpprop:publisher	<ul style="list-style-type: none"><li>▪ dbpedia:Allen_&amp;_Unwin</li></ul>
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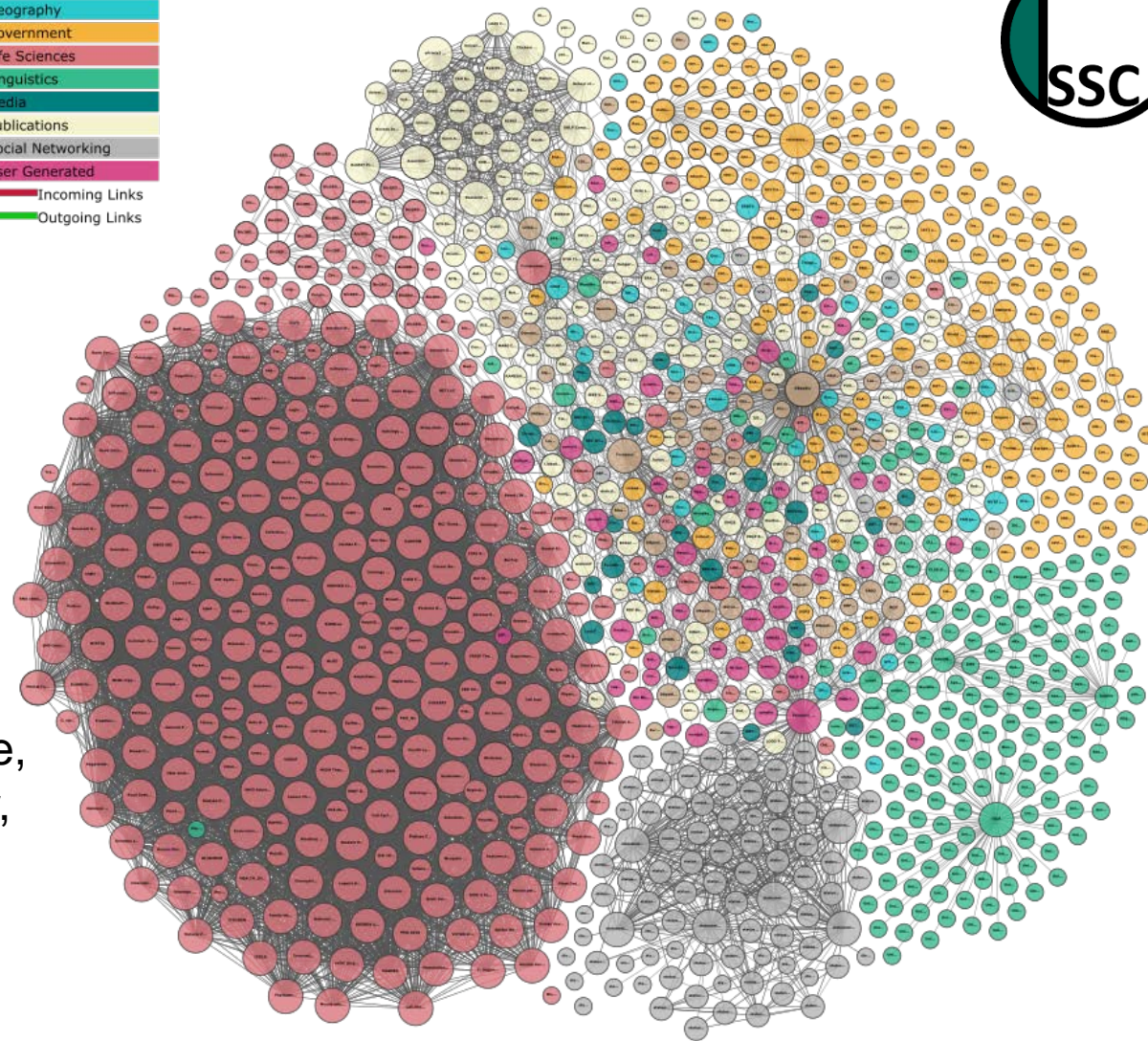
# Linked Data: Volume

Geoindexed Linked Data – courtesy of Krzysztof Janowicz, 2012

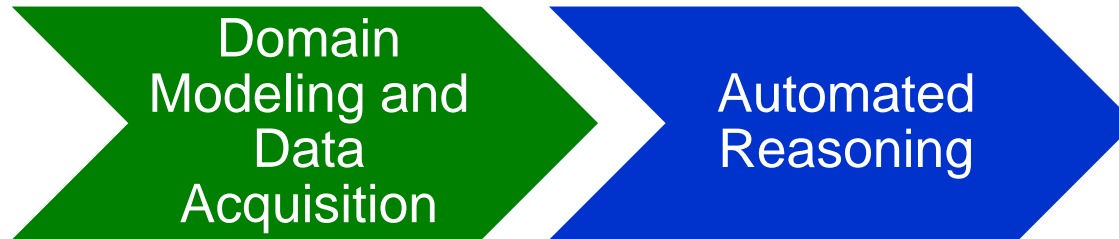
[http://stko.geog.ucsb.edu/location\\_linked\\_data](http://stko.geog.ucsb.edu/location_linked_data)



# Some Linked Datasets 2017

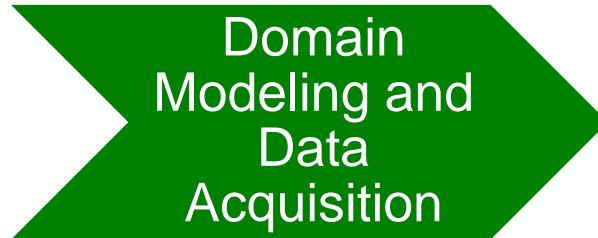


Linking Open Data cloud  
diagram 2017, by Andrejs Abele,  
John P. McCrae, Paul Buitelaar,  
Anja Jentzsch and Richard  
Cyganiak. <http://lod-cloud.net/>



**Phylogenetic tree: Reconstructed evolutionary history/lines of descent using organismal traits etc.**

**“Phyloreferencing” uses ontological representations and automated reasoning for this purpose.**



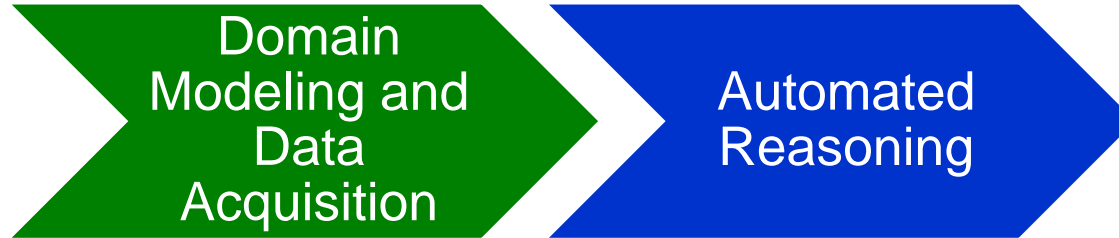
**Data \*management\*: SWT promises:**

**If information is structured \*well\*, then this significantly reduces data management cost (discovery, reuse, repurposing, integration, revision).**

**Use of standards.**

**Best practices.**

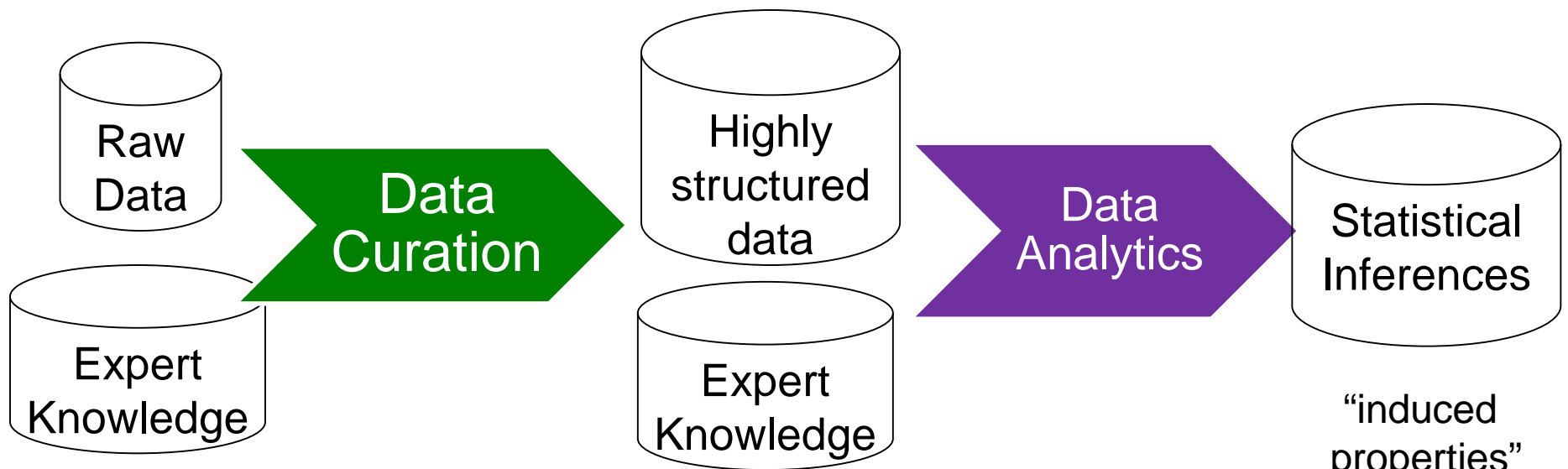
**Data and ontology quality principles.**



## Reasoning as a tool for Data Management:

Data Curation by identifying e.g.

- inconsistencies
- violations of schema/model







**Semantic Web Technologies simplify the data curation part.**

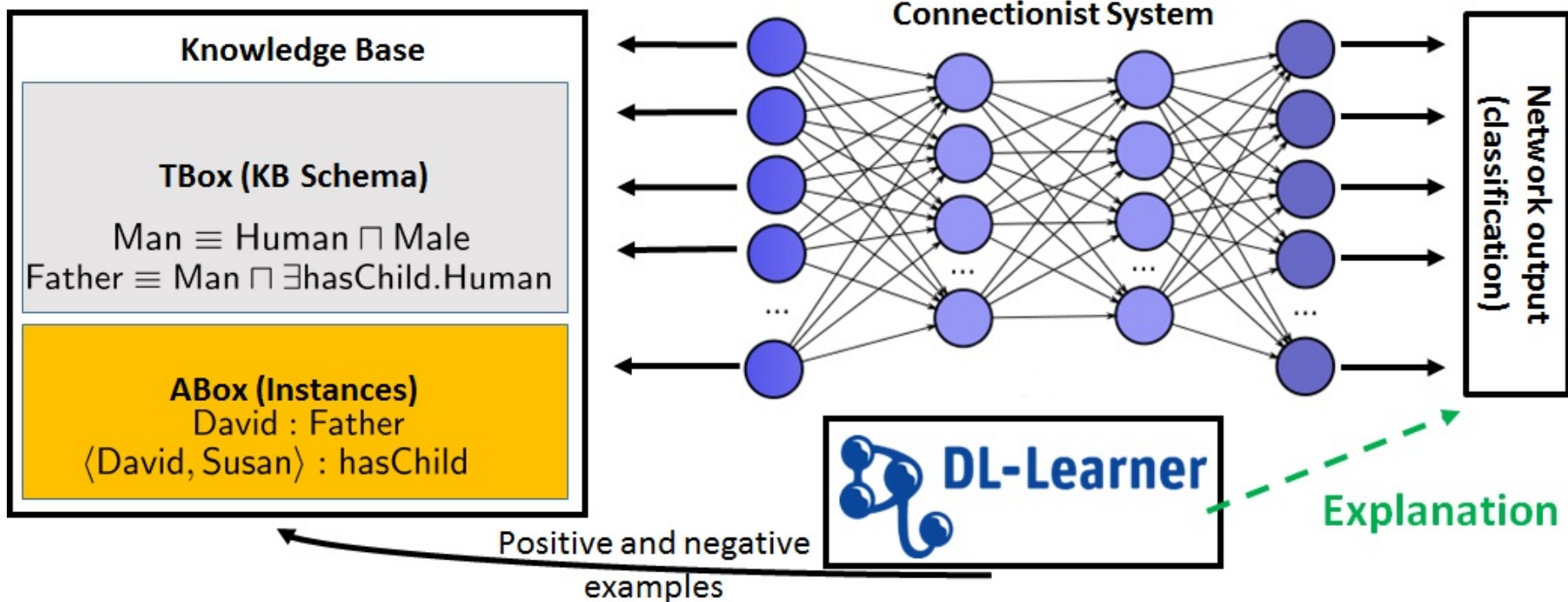
- **Easier integration of different sources.**
- **Clearer relationship between data organization and expert knowledge (i.e., data easier to understand).**
- **Easier discovery of relevant data.**

Joint work with  
Md Kamruzzaman Sarker, Derek Doran, Ning Xie, Mike Raymer





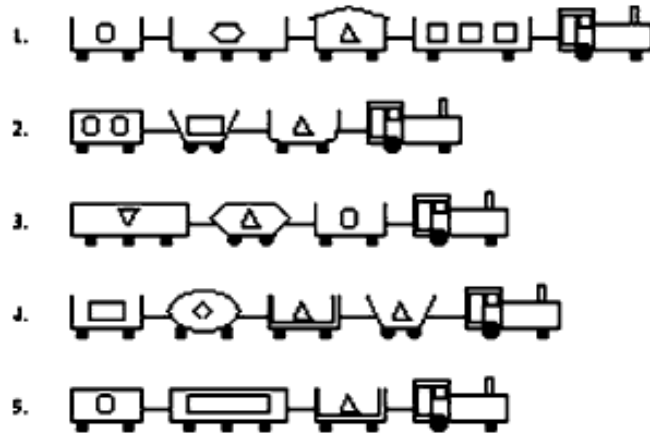
- Explain input-output behavior of trained (deep) NNs.
- Idea:
  - Use background knowledge in the form of linked data and ontologies to help explain.
  - Link inputs and outputs to background knowledge.
  - Use a symbolic learning system (e.g., DL-Learner) to generate an explanatory theory.
- We're just starting on this, I report on very first experiments.



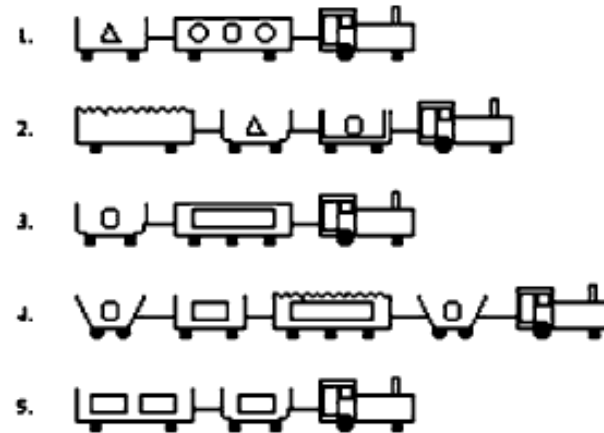


Approach similar to inductive logic programming, but using Description Logics (the logic underlying OWL).

Positive examples:



negative examples:



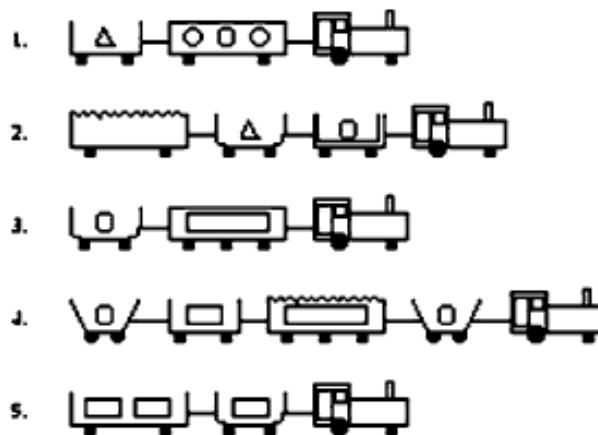
Task: find a class description (logical formula) which separates positive and negative examples.



Positive examples:



negative examples:



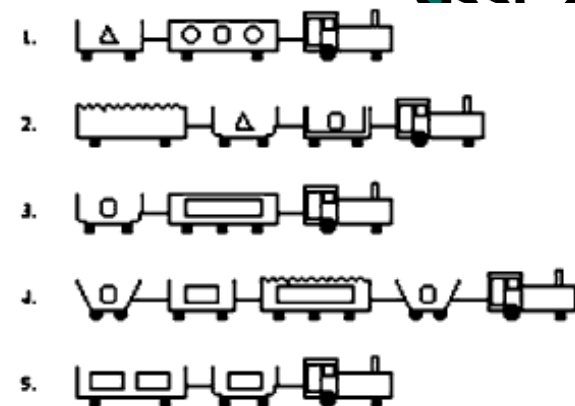
DL-Learner result:

$\exists \text{hasCar} . (\text{Closed} \cap \text{Short})$

In FOL:

$\{x \mid \exists y (\text{hasCar}(x, y) \wedge \text{Closed}(y) \wedge \text{Short}(y))\}$

DL-Learner uses refinement operators to construct ever better approximations of a solution.



$\top$

Train – covers all examples.

$\exists \text{hasCar}.\top$

$\exists \text{hasCar}.\text{Closed}$  – covers all positives, two negatives

$\exists \text{hasCar}(\text{Closed} \sqcap \text{Short})$  – solution

# Proof of Concept Experiment

Positive:



Negative:







Come from the MIT ADE20k dataset

<http://groups.csail.mit.edu/vision/datasets/ADE20K/>

They come with annotations of objects in the picture:

```
001 # 0 # 0 # sky # sky # ""
002 # 0 # 0 # road, route # road # ""
005 # 0 # 0 # sidewalk, pavement # sidewalk # ""
006 # 0 # 0 # building, edifice # building # ""
007 # 0 # 0 # truck, motortruck # truck # ""
008 # 0 # 0 # hovel, hut, hutch, shack, shanty # hut # ""
009 # 0 # 0 # pallet # pallet # ""
011 # 0 # 0 # box # boxes # ""
001 # 1 # 0 # door # door # ""
002 # 1 # 0 # window # window # ""
009 # 1 # 0 # wheel # wheel # ""
```



# Mapping to SUMO

Simple approach: for each known object in image, create an individual for the ontology which is in the appropriate SUMO class:



- contains road1
- contains window1
- contains door1
- contains wheel1
- contains sidewalk1
- contains truck1
- contains box1
- contains building1





- Suggested Merged Upper Ontology  
<http://www.adampease.org/OP/>
- Approx. 25,000 common terms covering a wide range of domains
- Centrally, a relatively naïve class hierarchy.
- Objects in image annotations became individuals (constants), which were then typed using SUMO classes.



## Positive:

img1: road, window, door, wheel, sidewalk, truck, box, building

img2: tree, road, window, timber, building, lumber

img3: hand, sidewalk, clock, steps, door, face, building, window, road

## Negative:

img4: shelf, ceiling, floor

img5: box, floor, wall, ceiling, product

img6: ceiling, wall, shelf, floor, product

## DL-Learner results include:

$\exists$ contains.Transitway

$\exists$ contains.LandArea

# Proof of Concept Experiment

Positive:



Negative:



$\exists$ contains.Transitway

$\exists$ contains.LandArea



- |  |     |                                    |      |
|--|-----|------------------------------------|------|
| $\exists$ contains.Window              | (1) | $\exists$ contains.LandTransitway  | (6)  |
| $\exists$ contains.Transitway          | (2) | $\exists$ contains.LandArea        | (7)  |
| $\exists$ contains.SelfConnectedObject | (3) | $\exists$ contains.Building        | (8)  |
| $\exists$ contains.Roadway             | (4) | $\forall$ contains. $\neg$ Floor   | (9)  |
| $\exists$ contains.Road                | (5) | $\forall$ contains. $\neg$ Ceiling | (10) |

# Experiment 2

Positive (selection):



Negative (selection):



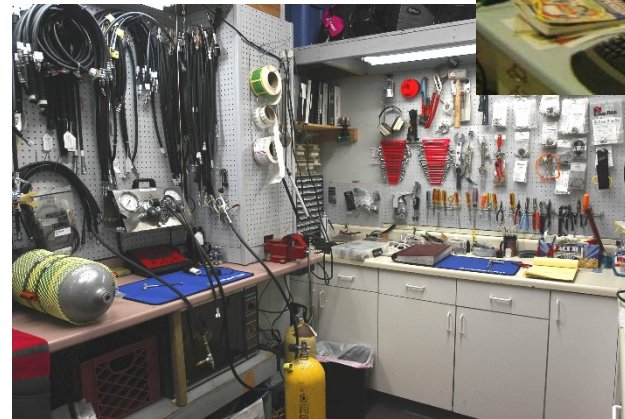
∃contains. (DurableGood  $\sqcap$   $\neg$ ForestProduct)

# Experiment 3

Positive:



Negative:



$\forall \text{contains.} (\neg \text{Furniture} \sqcap \neg \text{IndustrialSupply})$



# Experiment 4

## Positive (selection):



## Negative (selection):



∄contains.SentientAgent

# Experiment 5

Positive:



Negative (selection):



$\exists$ contains.BodyOfWater



- Utilize more sophisticated ontology.
- Utilize more sophisticated mappings.
- Explain hidden neurons.
- Tune DL-Learner better to the specific task.

**Collaborators Derek Doran and Ning Xie (Web and Complex Systems Lab)**



**They explore how to determine groups of hidden neurons which often fire together and thus may indicate the “detection” of certain features.**

**We plan to apply the above mentioned DL-Learner approach also to these groups of hidden neurons, in order to determine which features they detect.**

**Thanks!**

- 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.
- Pascal Hitzler, Markus Krötzsch, Sebastian Rudolph, *Foundations of Semantic Web Technologies*. Chapman and Hall/CRC Press, 2010.



- **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.**
- **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.**
- **Krzysztof Janowicz, Frank van Harmelen, James A. Hendler, Pascal Hitzler, Why the Data Train Needs Semantic Rails. AI Magazine 26 (1), 2015, 5-14.**





- **Michelle Cheatham, Pascal Hitzler, String Similarity Metrics for Ontology Alignment.** In: H. Alani, L. Kagal, A. Fokoue, P. Groth, C. Biemann, J.X. Parreira, L. Aroyo, N. Noy, C. Welty, K. Janowicz (eds.), **The Semantic Web - ISWC 2013.** 12th International Semantic Web Conference, Sydney, NSW, Australia, October 21-25, 2013, Proceedings, Part II. Lecture Notes in Computer Science Vol. 8219, Springer, Heidelberg, 2013, pp. 294-309.
- **Michelle Cheatham, Pascal Hitzler, The Properties of Property Alignment.** In: Proceedings OM-2014, The Ninth International Workshop on Ontology Matching, at the 13th International Semantic Web Conference, ISWC 2014, Riva del Garda, Trentino, Italy, October 2014. To appear.





- **Maryam Labaf, Pascal Hitzler, Anthony B. Evans, Propositional Rule Extraction from Neural Networks under Background Knowledge. In: Proceedings of the Twelfth International Workshop on Neural-Symbolic Learning and Reasoning, NeSy'17, London, UK, July 2017.**
- **Md. Kamruzzaman Sarker, Ning Xie, Derek Doran, Michael Raymer, Pascal Hitzler, Explaining Trained Neural Networks with Semantic Web Technologies: First Steps. In: Proceedings of the Twelfth International Workshop on Neural-Symbolic Learning and Reasoning, NeSy'17, London, UK, July 2017.**

- S. Bader and P. Hitzler, Dimensions of neural-symbolic integration – a structured survey. In: S. Artemov et al. (eds). We Will Show Them: Essays in Honour of Dov Gabbay, Volume 1. College Publications, London, 2005, pp. 167-194.
- B. Hammer, P. Hitzler (eds.). Perspectives of Neural-Symbolic Integration. *Studies in Computational Intelligence*, Vol. 77. Springer, 2007, ISBN 978-3-540-73952-1.
- Cellinese, N., Lapp, H.: An Ontology-Based system for querying life in a Post-Taxonomic age (2015), [https://figshare.com/articles/An Ontology Based System for Quering Life in a Post Taxonomic Age/1401984](https://figshare.com/articles/An_Ontology_Based_System_for_Quering_Life_in_a_Post_Taxonomic_Age/1401984)
- Denny Vrandečić, Markus Krötzsch. Wikidata: A Free Collaborative Knowledgebase. In *Communications of the ACM* 57:10. ACM 2014.

- **Artur d'Avila Garcez, Tarek R. Besold, Luc de Raedt, Peter Földiák, Pascal Hitzler, Thomas Icard, Kai-Uwe Kühnberger, Luis C. Lamb, Risto Miikkulainen, Daniel L. Silver, Neural-Symbolic Learning and Reasoning: Contributions and Challenges. In: Andrew McCallum, Evgeniy Gabrilovich, Ramanathan Guha, Kevin Murphy (eds.), Proceedings of the AAI 2015 Spring Symposium on Knowledge Representation and Reasoning: Integrating Symbolic and Neural Approaches. Technical Report SS-15-03, AAAI Press, Palo Alto, 2015.**
- **Jens Lehmann, Pascal Hitzler, Concept Learning in Description Logics Using Refinement Operators. Machine Learning 78 (1-2), 203-250, 2010.**
- **Ramanathan V. Guha, Dan Brickley, Steve Macbeth: Schema.org: Evolution of Structured Data on the Web. ACM Queue 13(9): 10 (2015)**

- **Wouter Beek, Laurens Rietveld, Stefan Schlobach, Frank van Harmelen, LOD Laundromat: Why the Semantic Web Needs Centralization (Even If We Don't Like It). IEEE Internet Computing 20(2): 78-81 (2016)**
- **Adila Krisnadhi, Nazifa Karima, Pascal Hitzler, Reihaneh Amini, Michelle Cheatham, Víctor Rodríguez-Doncel, Krzysztof Janowicz, Ontology Design Patterns for Linked Data Publishing. In: Pascal Hitzler, Aldo Gangemi, Krzysztof Janowicz, Adila Krisnadhi, Valentina Presutti (eds.), Ontology Engineering with Ontology Design Patterns: Foundations and Applications. Studies on the Semantic Web Vol. 25, IOS Press/AKA Verlag, pp. 201-232.**

