Semantic Web – State of the Art

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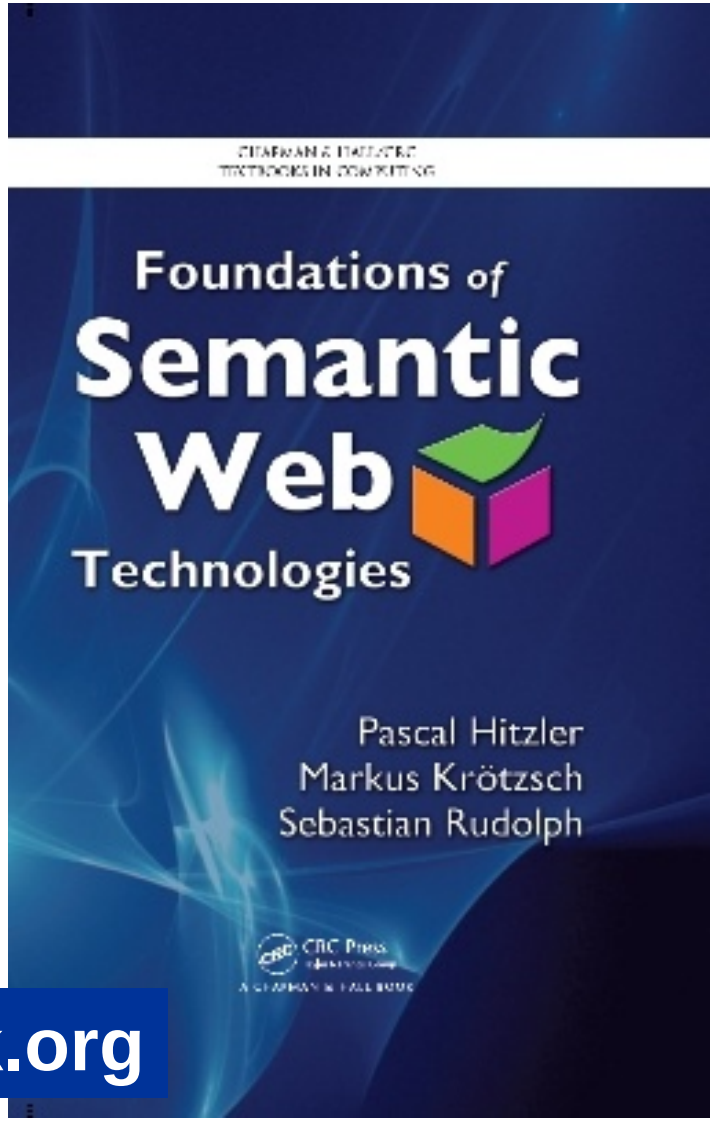
Introduction to key foundations

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

Textbook (Chinese translation)

Pascal Hitzler, Markus Krötzsch, Sebastian Rudolph

语义Web技术基础

Tsinghua University Press (清华大学出版社），2012, to appear

Translators:

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

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

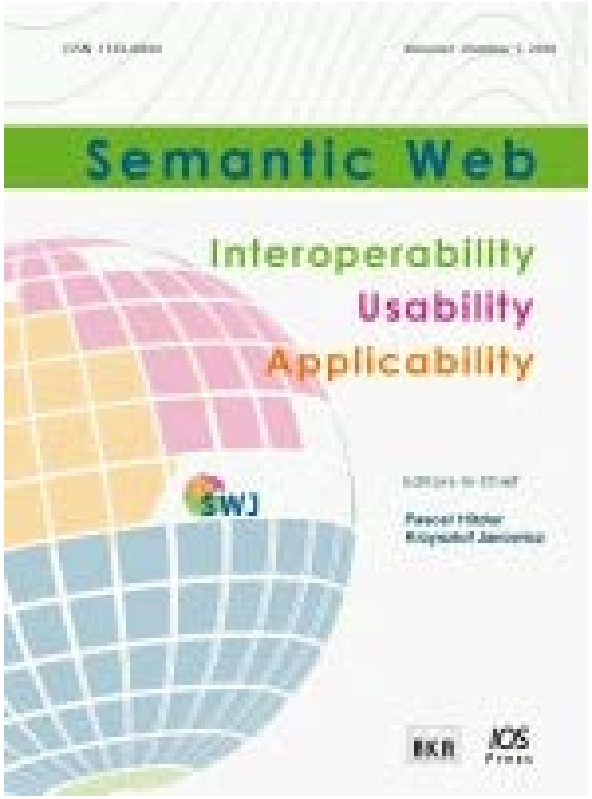
Semantic Web journal

- **EiCs: Pascal Hitzler**
  Krzysztof Janowicz

- **New journal with significant 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/**

Contents

- What is Semantic Web?
  - Limitations of the current World Wide Web
  - The basic Semantic Web idea
  - Semantic Web Semantics
- Semantic Data Web (state of the art)
  - its limitations
  - and how to overcome them
- Some current work

The current (World Wide) Web

- Immensely successful.
- Huge amounts of data.
- Syntax standards for transfer of structured data.
- Machine-processable, human-readable documents.

BUT:

- Content/knowledge cannot be accessed by machines.
  Meaning (semantics) of transferred data is not accessible.

Examples

- **Find that landmark article on data integration written by an Indian researcher in the 1990s.**
  [If you manage this without knowing the answer, let me know how you did it.]

- **Which car is called a “duck” in German?**
  [This needs some intelligent integration of content from different websites plus background knowledge.]

Another example

"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 required knowledge is on the Web – most of it even in machine-readable form.

However, without automated processing and reasoning we cannot obtain a useful answer.

Very brief history of the Semantic Web

- invented ca. 1989.
- 1990s: W3C metadata activity (lead 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
- Major IT companies and
  venture capital now investing.

Semantic Technologies in the US

- **Funding available e.g. via**
  - **NIH**
  - **NSF**
  - **DoD, DoE, AFRL**
  - **IARPA, DARPA**
  - **...**

- **Considerable industrial take-up**
  - **Annual Semantic Technology Conference in CA Taylored towards industry**
  - **Major IT players (Oracle, IBM, HP, ...) invest**
  - **Major government contractors (BBN, Lockheed, ...)**
  - **Venture capital (e.g. Vulcan, Inc.).**

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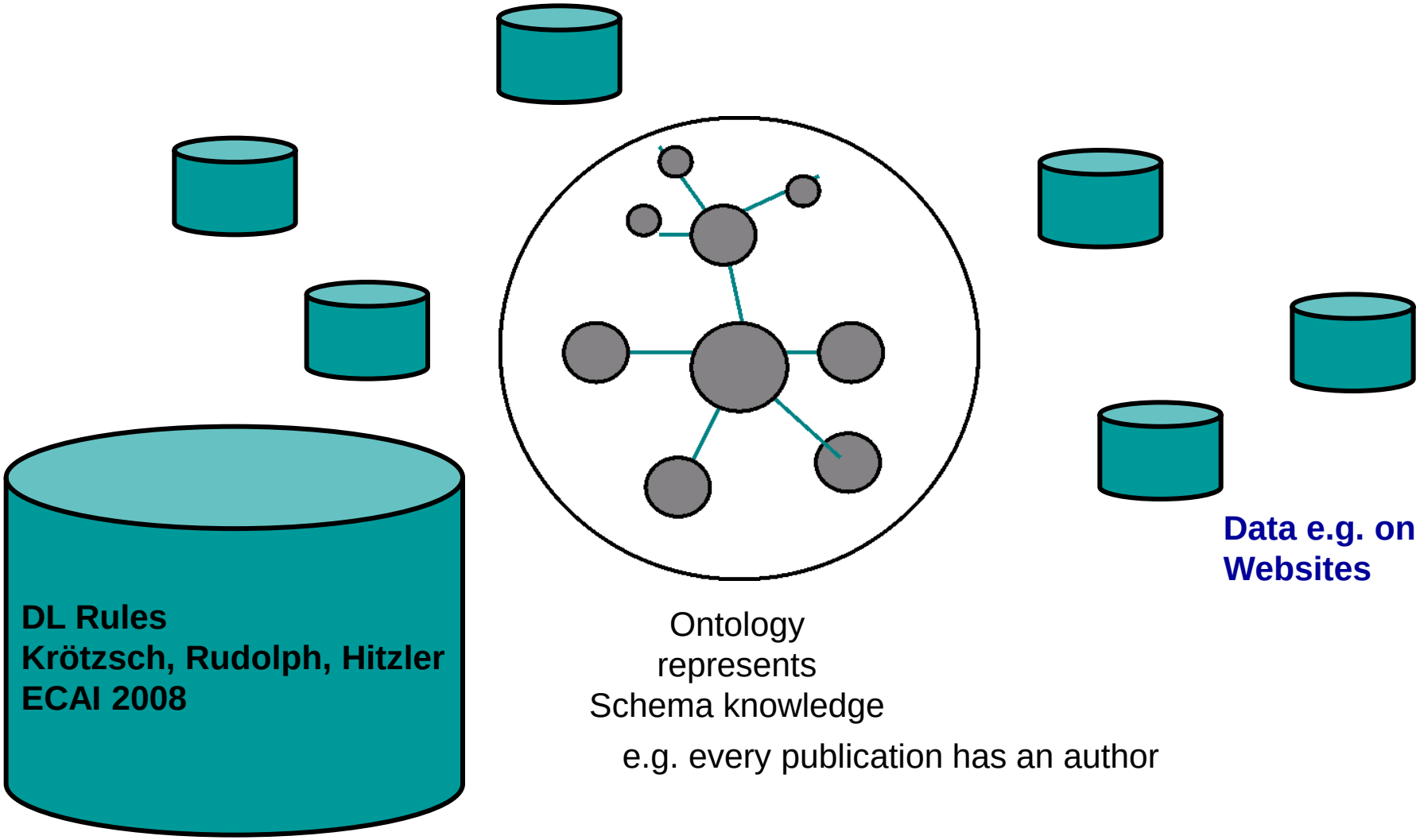
Basic Idea of the Semantic Web



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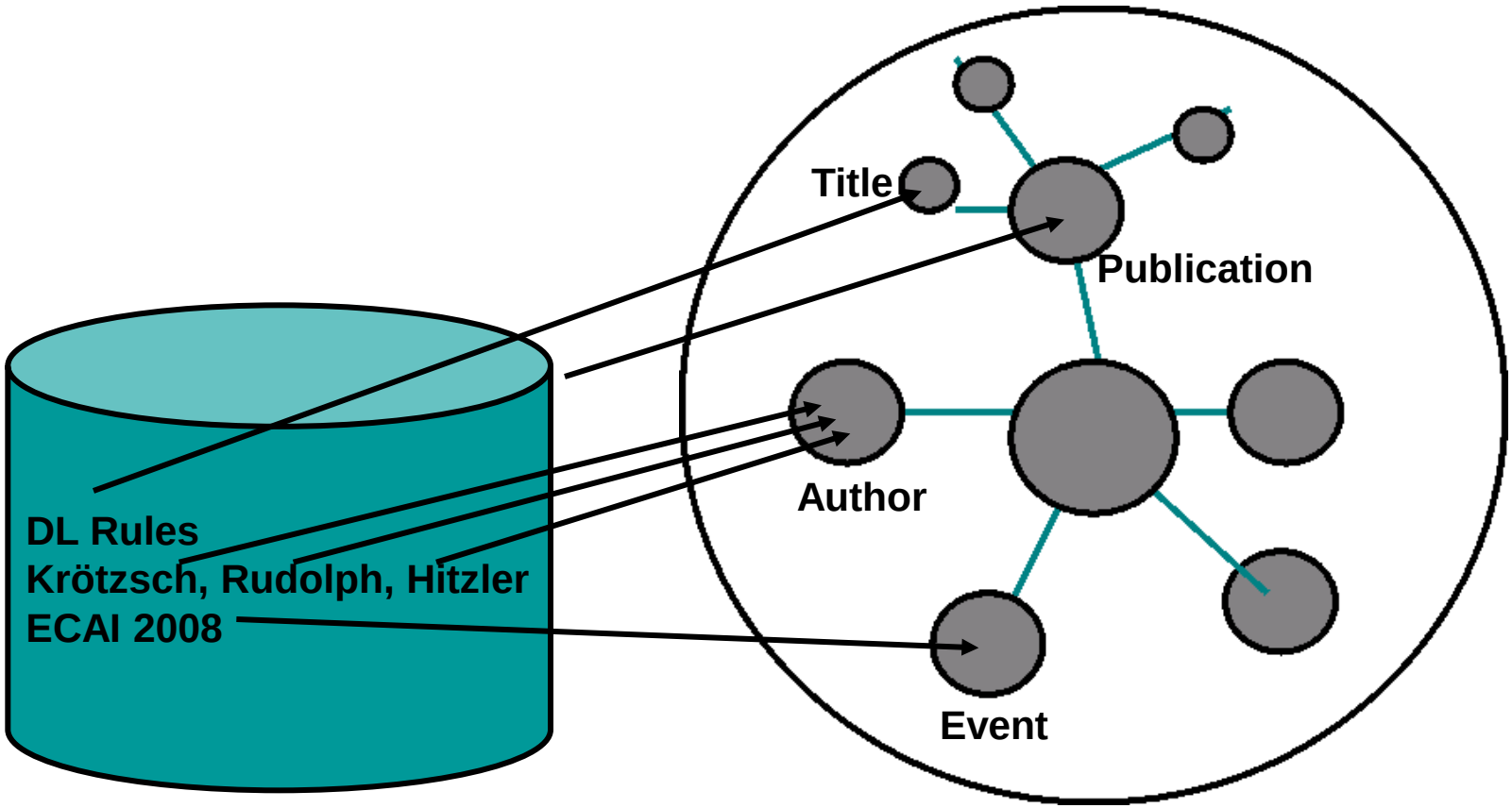
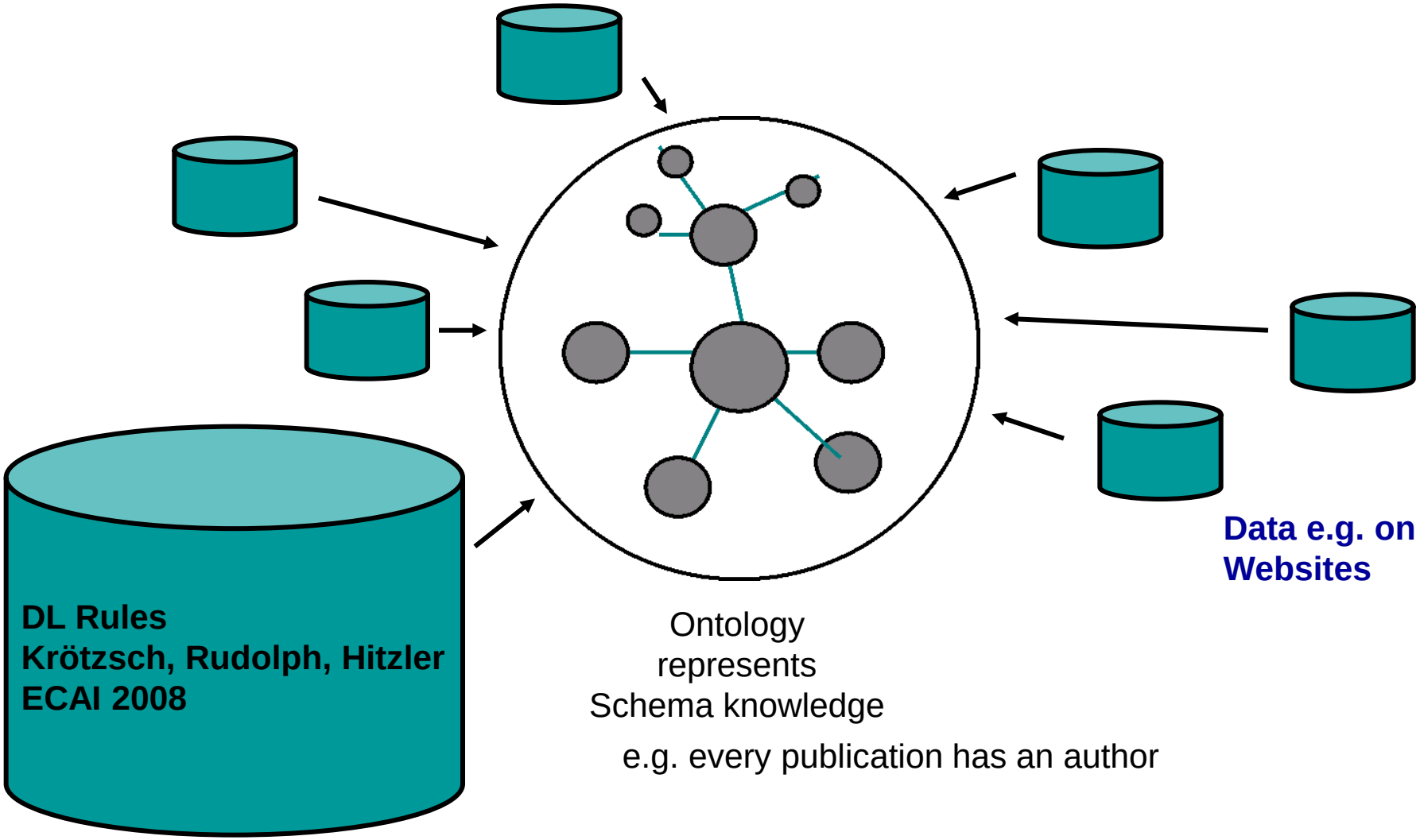


e.g. every publication has an author

Basic Idea of the Semantic Web



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What Is Semantic Web Semantics?

- **Opinions Differ. Here's my take.**

- **Semantic Web requires a shareable, declarative and *computable* semantics.**
- **I.e., the semantics must be a formal entity which is clearly defined and automatically computable.**

- **Ontology languages provide this by means of their formal semantics.**
- **Semantic Web Semantics is given by a relation – the *logical consequence* relation.**

- **Note: This is considerably more than saying that the semantics of an ontology is the set of its logical consequences!**

In other words

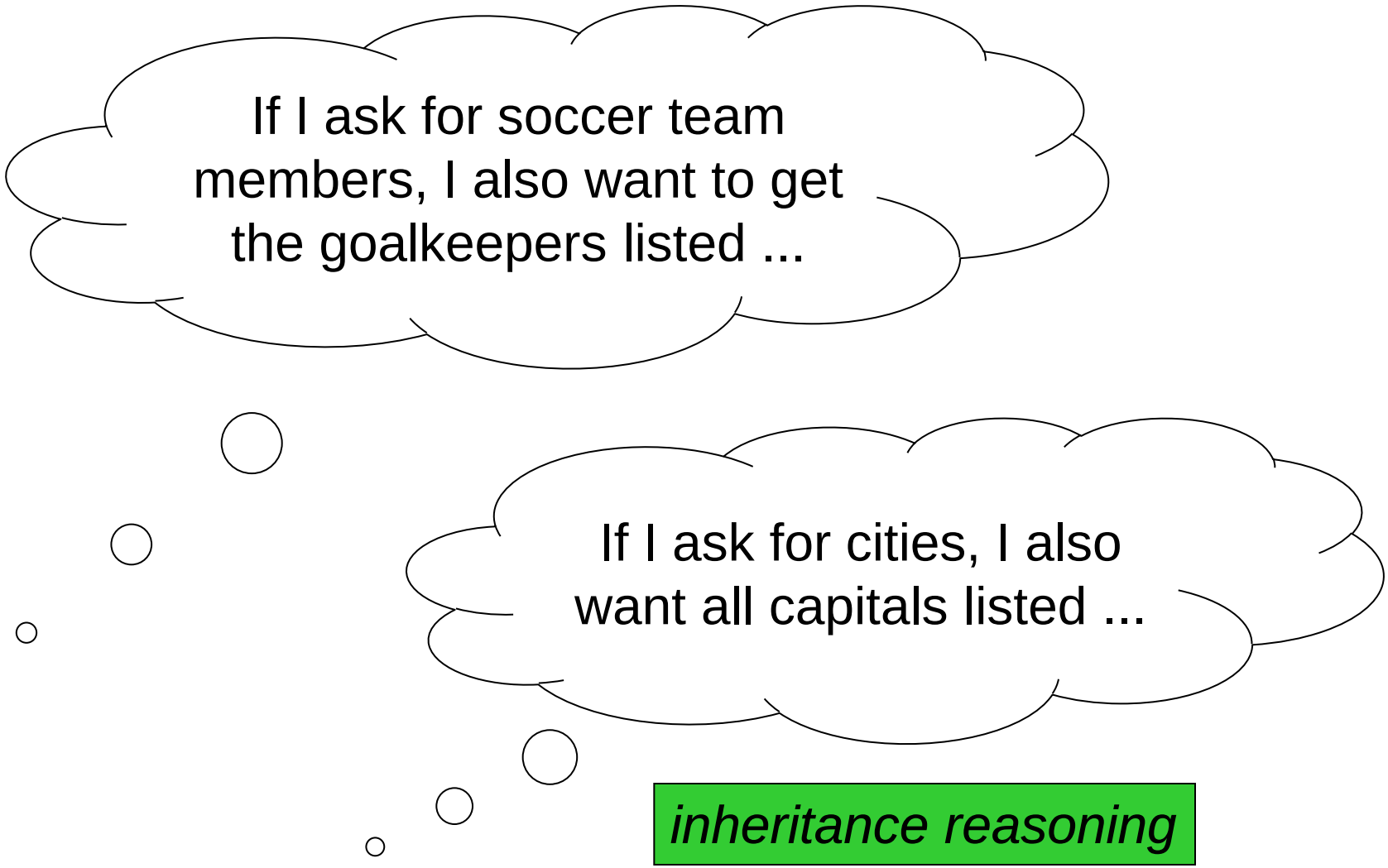
We capture the meaning of information

not by specifying its meaning (which is impossible)
but by specifying

how information interacts with other information.

We describe the meaning indirectly through its effects.

Simple Logical Reasoning



Less Simple Reasoning

answering requires merging of knowledge from many websites and using background knowledge.

What was again the name of that russian researcher who worked on resolution-based calculi for EL?

Which car is called „duck“ in German?

What is "Käuzchen" in english?

SNOMED CT

- **SNOMED CT: commercial ontology, medical domain ca. 300,000 axioms**

- $\mathbf{InjuryOfFinger} \;\acute{}\; \mathbf{Injury} \sqcap \mathbf{9site.Finger_S}$
  $\mathbf{InjuryOfHand} \;\acute{}\; \mathbf{Injury} \sqcap \mathbf{9site.Hand_S}$
  $\mathbf{Finger_S} \sqsubseteq \mathbf{Hand_P}$
  $\mathbf{Hand_P} \sqsubseteq \mathbf{Hand_S} \sqcap \mathbf{9part.Hand_E}$

- **Reasoning has been used e.g. for**
  - **classification (computing the hidden taxonomy) e.g., InjuryOfFinger ⊑ InjuryOfHand**
  - **bug finding**

Reasoning Needs

Inspired by presentation by Evan Sandhaus, ISWC2010

x newsFrom rome .
rome locatedIn italy .

we want to conclude:
x newsFrom italy .

Take your news database.
Take location info from somewhere on linked data.
Materialize the new newsFrom triples.

Reasoning Needs

x	newsFrom	rome .	newsFrom(x,y)
rome	locatedIn	italy .	locatedIn(y,z)

we want to conclude:

x	newsFrom	italy .	newsFrom(x,z)

newsFrom(x,y) ÆlocatedIn(y,z) ! newsFrom(x,z)

newsFrom o locatedIn v newsFrom

using owl:propertyChainAxiom

Reasoning Needs

e.g. knowledge base of authors and papers

<paper> hasAuthor <author> .

insufficient because author order is missing

use of RDF-lists not satisfactory due to lack of formal semantics.

better:

<paper> hasAuthorNumbered _:x .
_:x authorNumber n^^xsd:positiveInteger ;
authorName <author> .

hasAuthorNumbered(x,y) ÆauthorName(y,z) ! hasAuthor(x,z)

Reasoning Needs

<paper> hasAuthorNumbered _:x .
_:x authorNumber n^^xsd:positiveInteger ;
authorName <author> .

hasAuthorNumbered(x,y) ÆauthorName(y,z) ! hasAuthor(x,z)

in OWL:

Paper v 9hasAuthorNumbered.NumberedAuthor
NumberedAuthor v
9authorNumber.<xsd:positiveInteger> u 9authorName.>

hasAuthorNumbered ± authorName v hasAuthor

these are not rules!

Reasoning Needs

Paper v 9hasAuthorNumbered.NumberedAuthor

NumberedAuthor v
9authorNumber.<xsd:positiveInteger> u 9authorName.>

hasAuthorNumbered ± authorName v hasAuthor

Paper(x) ÆhasAuthorNumbered(x,y) ÆauthorNumber(y,1) Æ
authorName(y,z) ! hasFirstAuthor(x,z)

in OWL:

Paper ´ 9paper.Self

9authorNumber.{1} ´ 9authorNumberOne.Self

paper ± hasAuthorNumbered ± authorNumberOne ± authorName
v hasFirstAuthor

Reasoning as first-class citizen

Why would we want to have knowledge/rules such as

newsFrom(x,y) ÆlocatedIn(y,z) ! newsFrom(x,z)

if we can also just do this with some software code?

- **It declaratively describes what you do.**
- **It separates knowledge (as knowledge base) from programming.**
- **It makes knowledge shareable.**
- **It makes knowledge easier to maintain.**

So what happened?

- In 2004, two W3C Recommendations were completed:
  - RDF + RDF Schema with formal model-theoretic semantics
  - OWL with formal model-theoretic semantics

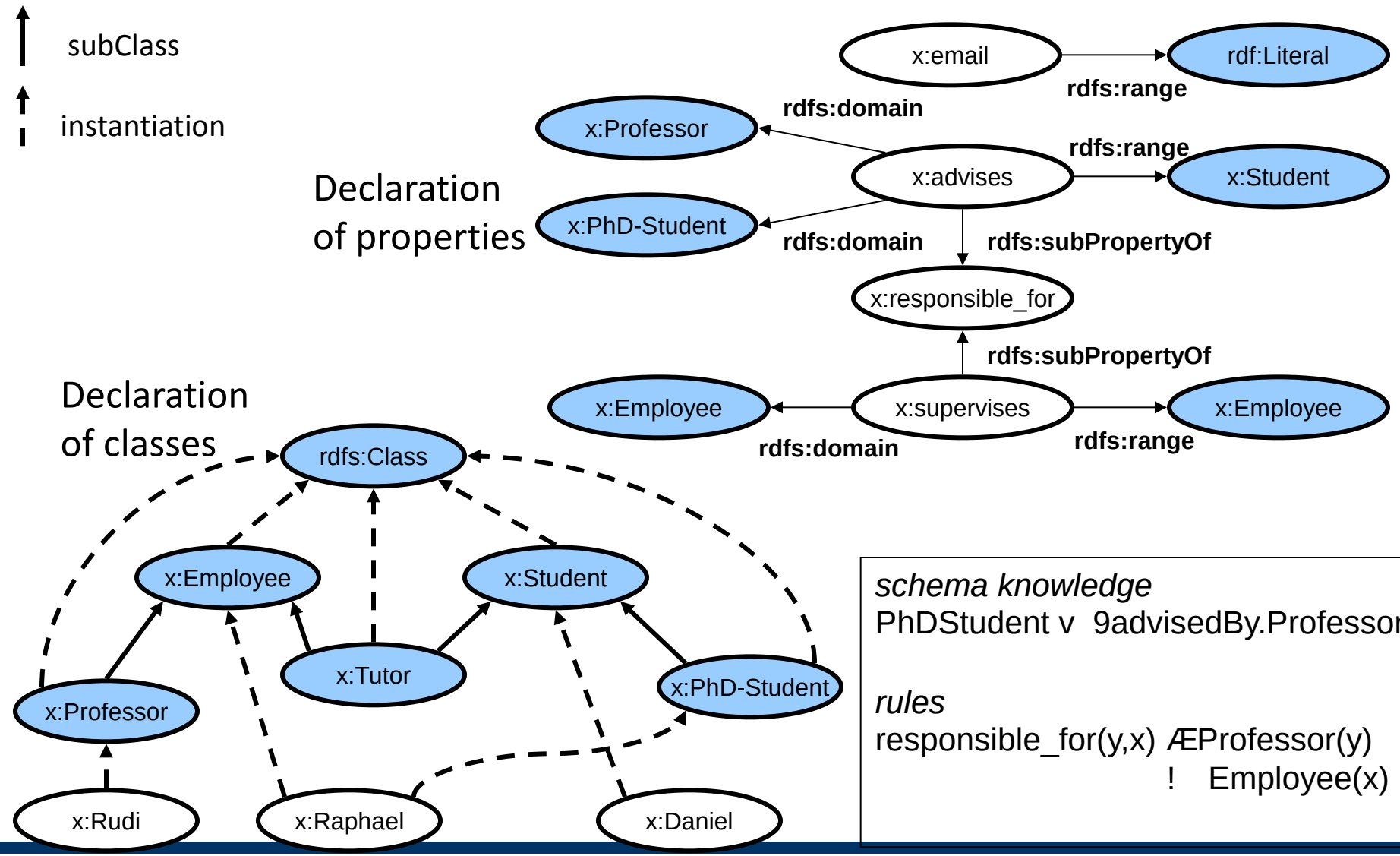
- OWL 2 update emerged 2009.
- RDF update is being discussed right now.

Ontology languages

- **Of central importance for the realisation of Semantic Technologies are suitable representation languages.**
- **Meaning (semantics) provided via logic and deduction algorithms.**
- **Scalability is a challenge.**

Language standards recommended by W3C

Ontology Example



schema knowledge

PhDStudent v 9advisedBy.Professor

rules

responsible_for(y,x) ÆProfessor(y)
! Employee(x)

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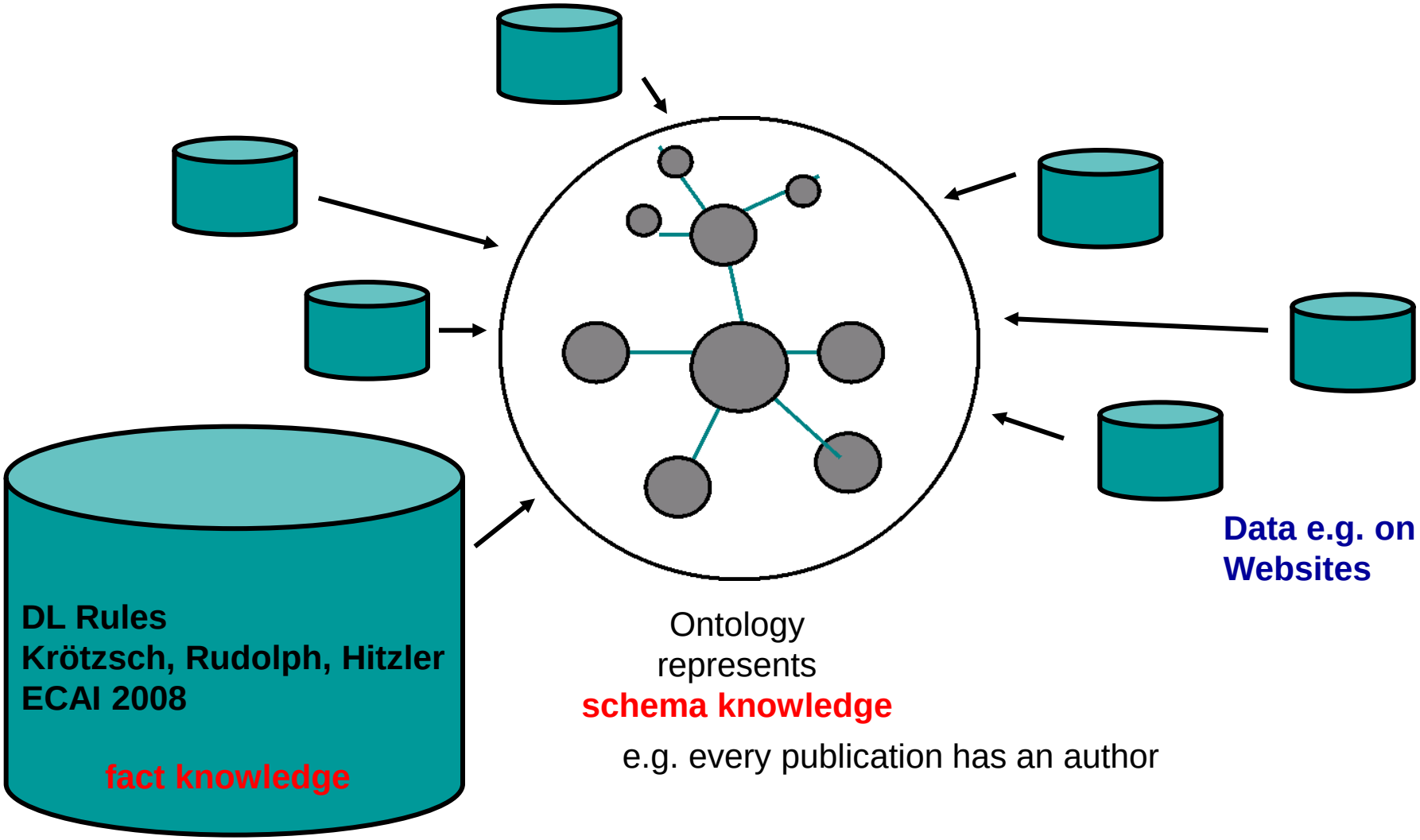
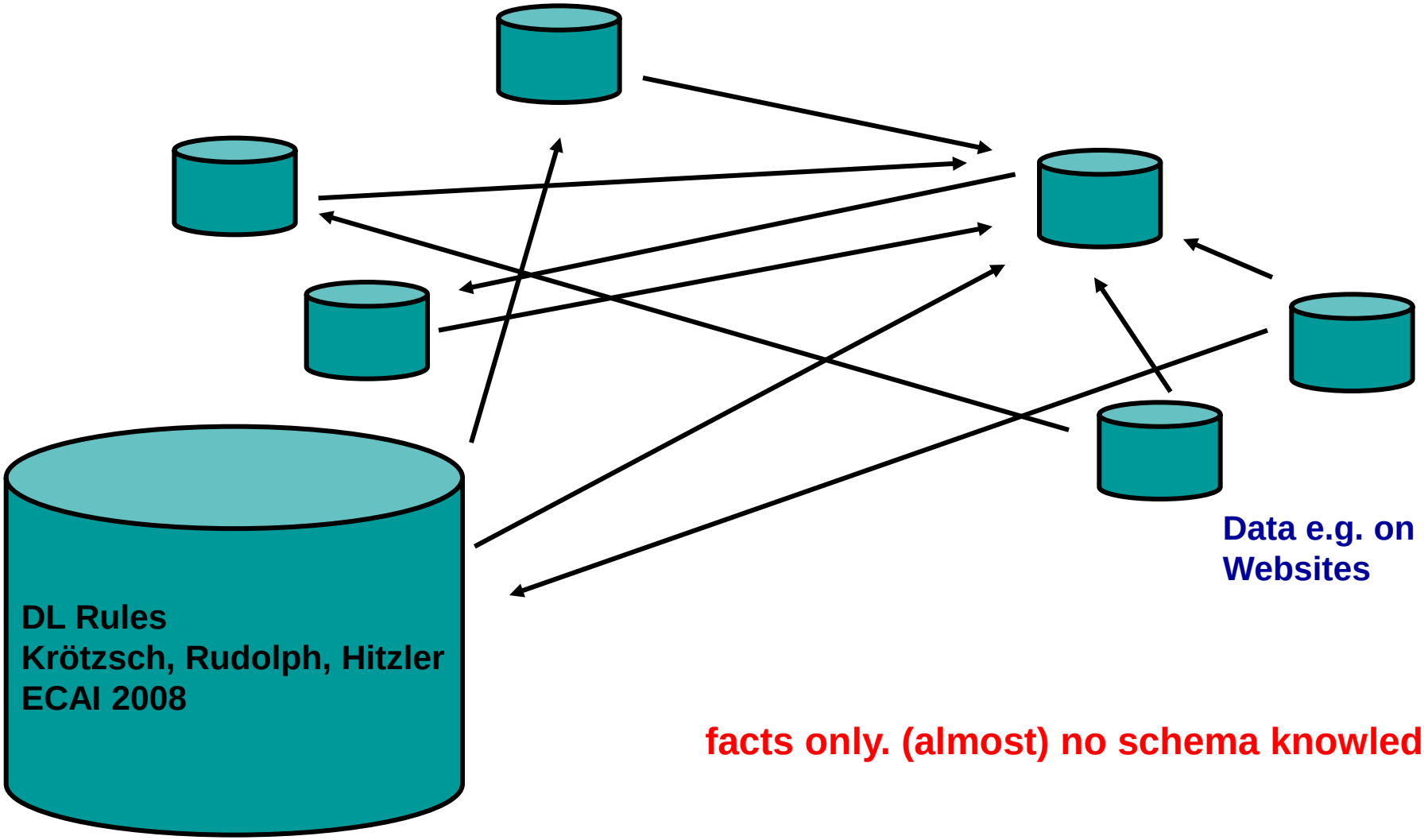
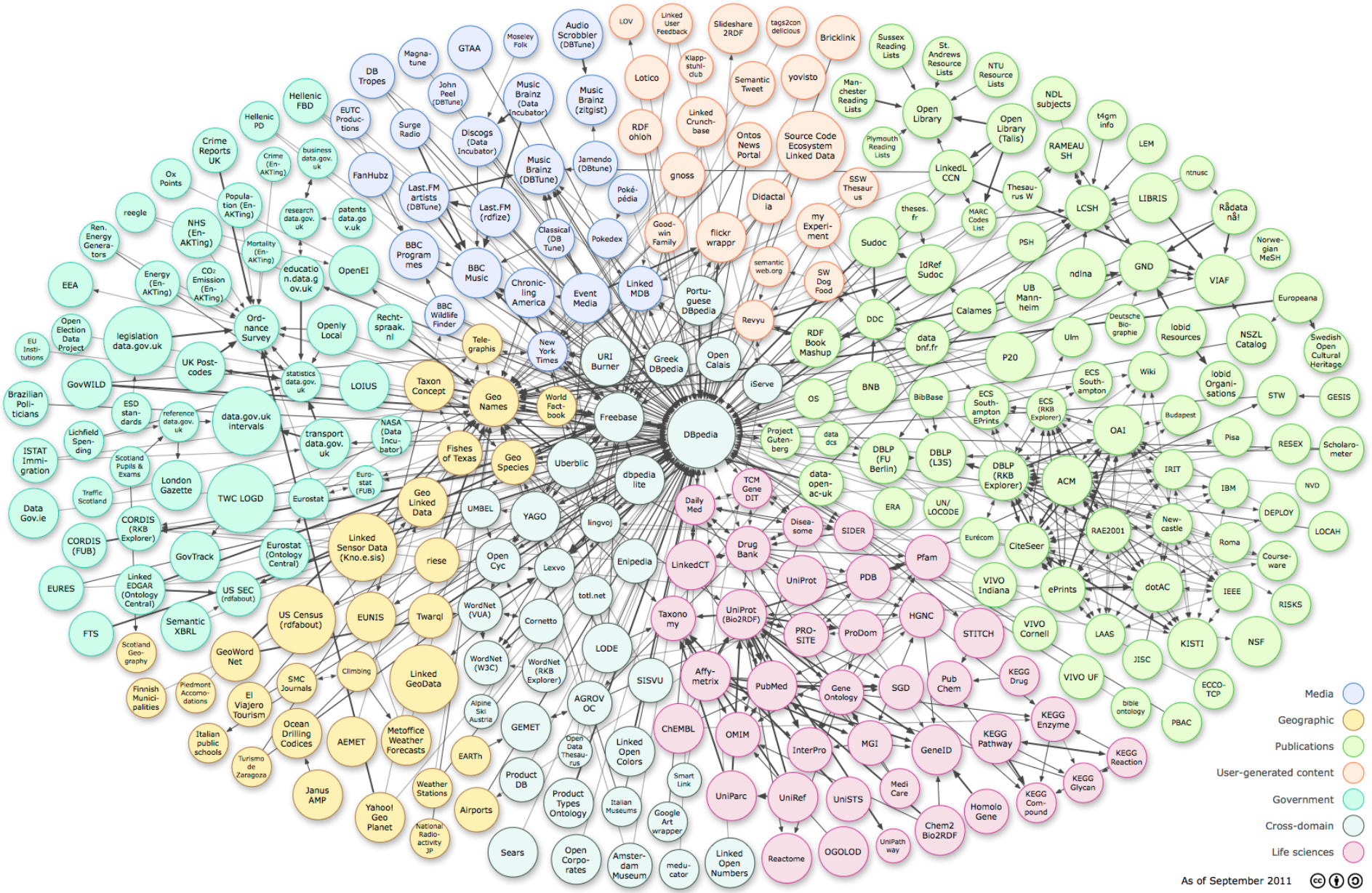


Currently it‘s looking like this



facts only. (almost) no schema knowledge

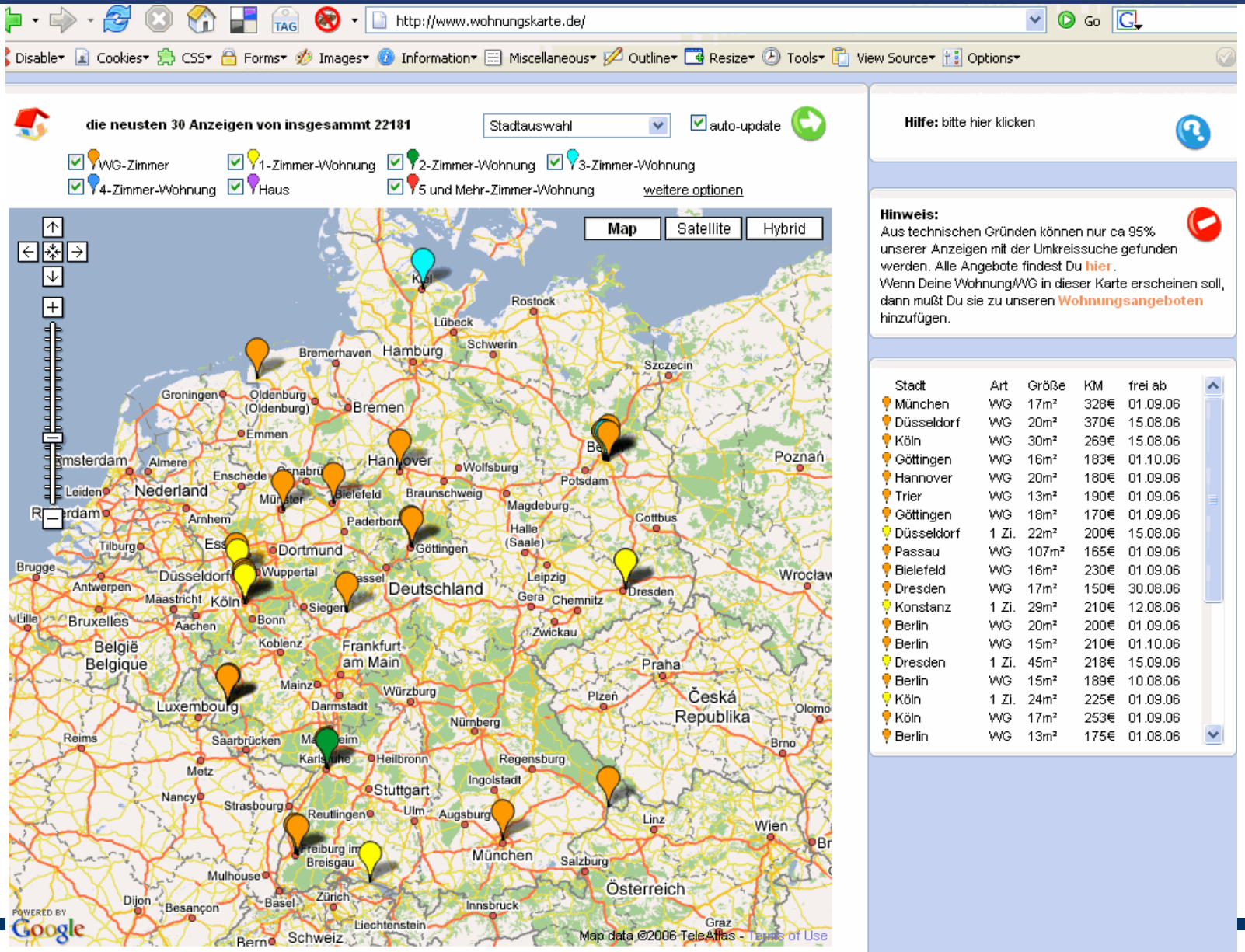
Linked Open Data



Media
Geographic
Publications
User-generated content
Government
Cross-domain
Life sciences

As of September 2011

Mashups


http://www.wohnungskarte.de/
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die neusten 30 Anzeigen von insgesammt 22181
Stadtauswahl
auto-update
WG-Zimmer
1-Zimmer-Wohnung
2-Zimmer-Wohnung
3-Zimmer-Wohnung
4-Zimmer-Wohnung
Haus
5 und Mehr-Zimmer-Wohnung
weitere optionen
Map
Satellite
Hybrid
Hilfe: bitte hier klicken
Hinweis:
Aus technischen Gründen können nur ca 95% unserer Anzeigen mit der Umkreissuche gefunden werden. Alle Angebote findest Du hier.
Wenn Deine Wohnung/WG in dieser Karte erscheinen soll, dann mußt Du sie zu unseren Wohnungsangeboten hinzufügen.
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Leipzig
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Dresden
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Chemnitz
Lille
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Aachen
Bonn
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Zwickau
België
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Koblenz
Frankfurt am Main
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Mainz
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Nürnberg
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Saarbrücken
Heilbronn
Regensburg
Brno
Metz
Ingolstadt
Nancy
Stuttgart
Strasbourg
Reutlingen
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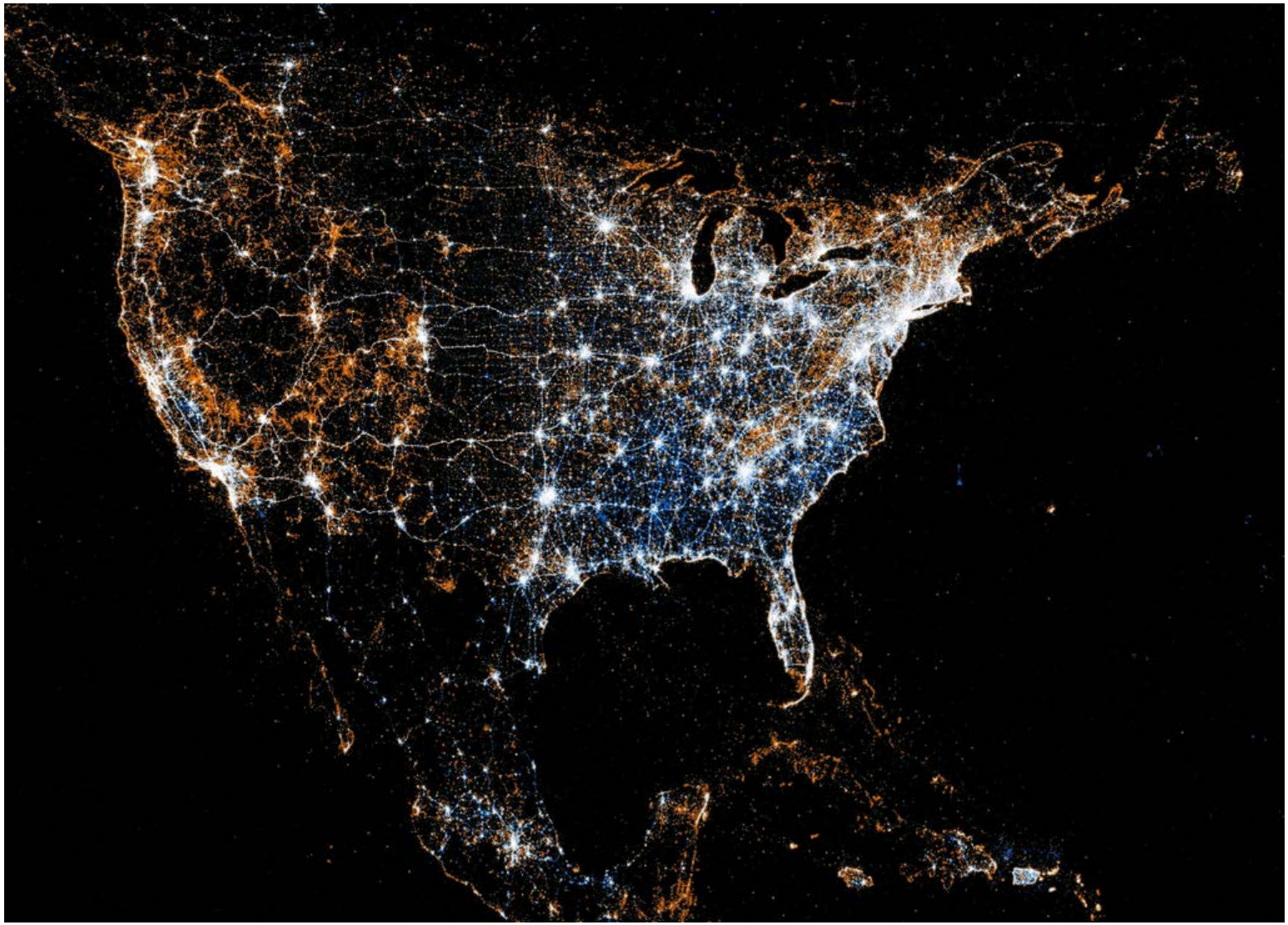
Mashups – GEOtweets



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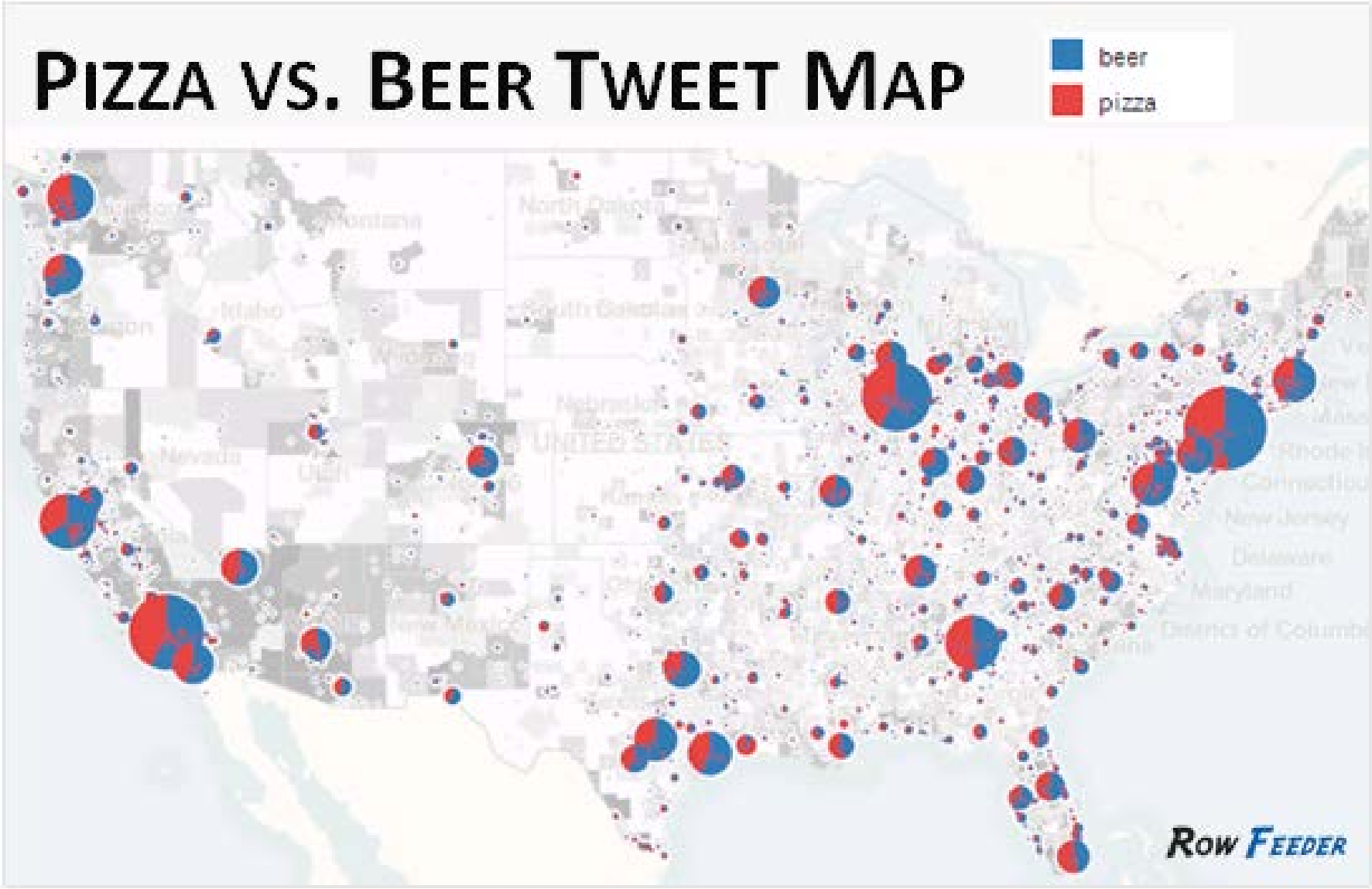

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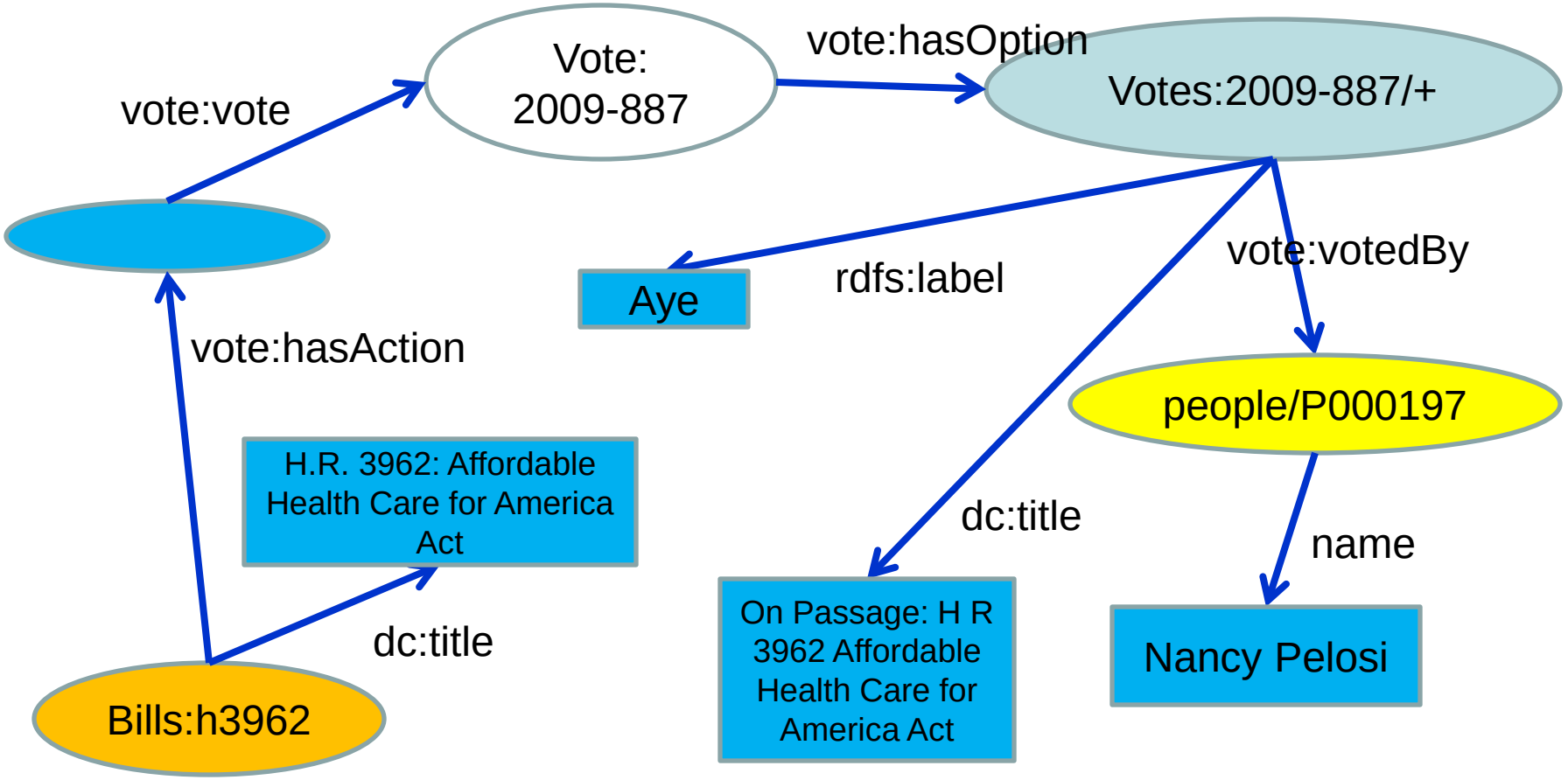
Example: GeoNames

Populated Place Features (city, village,...)			
2,518,403	P.PPL	populated place	a city, town, village, or other agglomeration of buildings where people live and work
48,483	P.PPLX	section of populated place	
39,336	P.PPLL	populated locality	an area similar to a locality but with a small group of dwellings or other buildings
13,306	P.PPLQ	abandoned populated place	
2,684	P.PPLA4	seat of a fourth-order administrative division	
2,028	P.PPLA	seat of a first-order administrative division	seat of a first-order administrative division (PPLC takes precedence over PPLA)
1,847	P.PPLW	destroyed populated place	a village, town or city destroyed by a natural disaster, or by war
1,006	P.PPLF	farm village	a populated place where the population is largely engaged in agricultural activities
930	P.PPLA3	seat of a third-order administrative division	
695	P.PPLA2	seat of a second-order administrative division	
253	P.PPLS	populated places	cities, towns, villages, or other agglomerations of buildings where people live and work
249	P.STLMT	israeli settlement	
235	P.PPLC	capital of a political entity	
57	P.		
29	P.PPLR	religious populated place	a populated place whose population is largely engaged in religious occupations
6	P.PPLG	seat of government of a political entity	
2,629,547	Total for P		

rdfs:subClassOf?

Example: GovTrack

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



Example: GovTrack

```
bills/h3962       dc:title           "H.R. 3962: ..." ;
                  usbill:hasAction   _:bnode0 .
_:bnode0          usbill:vote        votes/2009-887 .
votes/2009-887    vote:hasOption     votes/2009-887/+ .
                  dc:title       "On Passage: H.R. 3962 ..." ;
votes/2009-887/+  rdfs:label         "Aye" ;
                  vote:votedBy       people/P000197 .
people/P000197    usgovt:name        "Nancy Pelosi" .
```

Example querying LoD

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

In principle, all the knowledge is there:

- **GovTrack**
- **GeoNames**
- **DBPedia**
- **US Census**

But even with LoD we cannot answer this query.

Example querying LoD

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

Some missing puzzle pieces:

- Where is the data?
  - GovTrack
    GeoNames
    US Census
    requires intimate knowledge of the LoD data sets

Example querying LoD

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

Some missing puzzle pieces:

- Where is the data?
  (smart federation needed)
- Missing background (schema) knowledge.
  (enhancements of the LoD cloud)
- Crucial info still hidden in texts.
  (ontology learning from texts)
- Added reasoning capabilities (e.g., spatial).
  (new ontology language features)

Don’t get me wrong

Linked Open Data is great, useful, cool, and a very important step.

But we need to make use of the added value of formal semantics in order to advance towards the Semantic Web vision!

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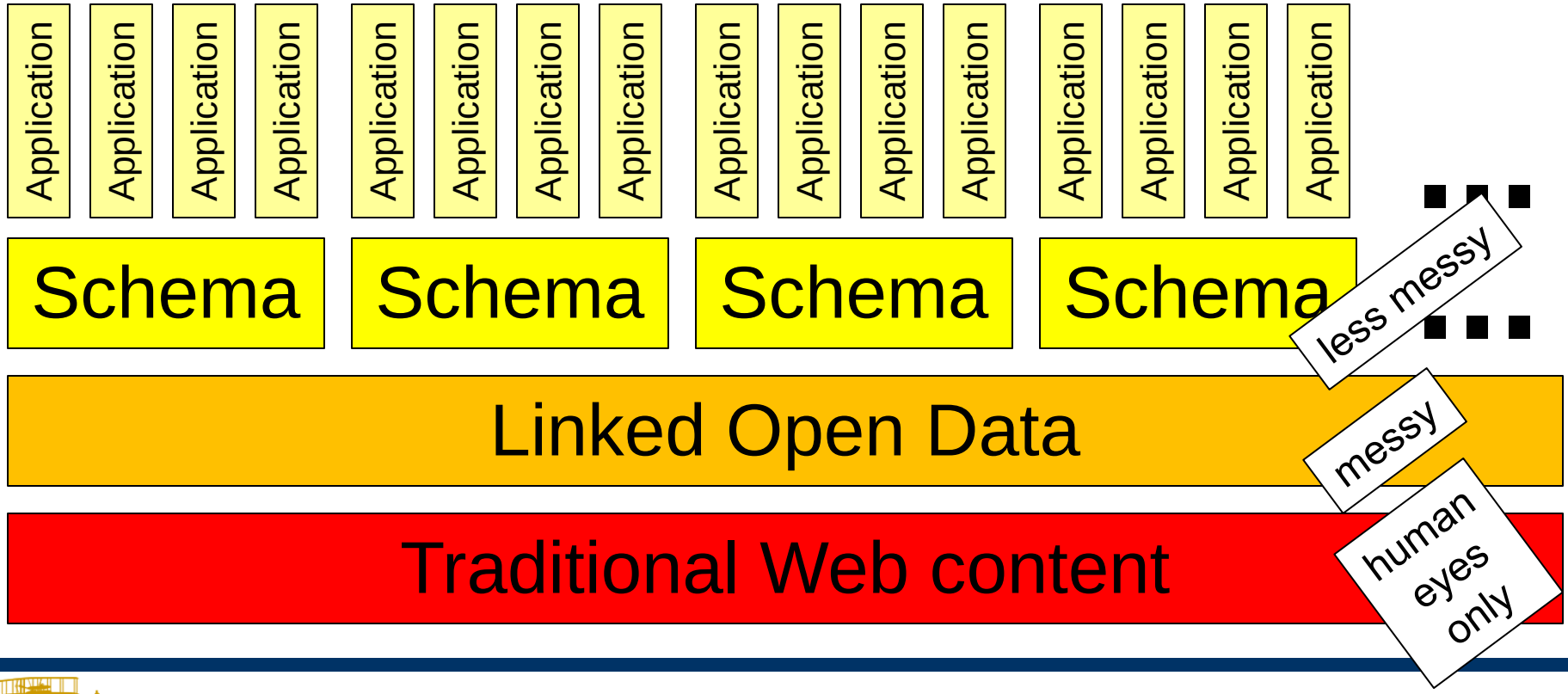
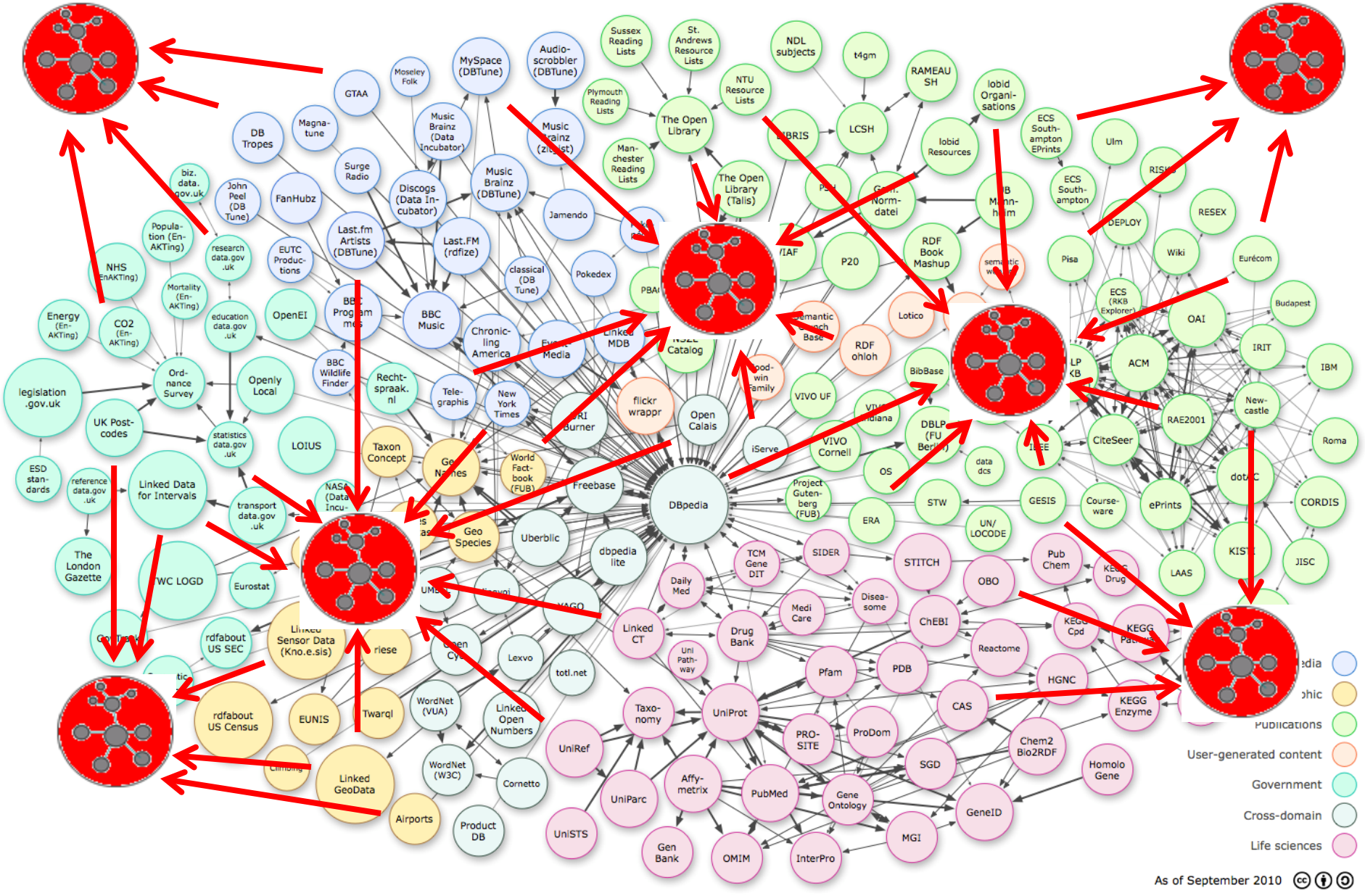
The Semantic Data Web Layer Cake

To leverage LoD, we require schema knowledge

- **application-type driven (reusable for same kind of application)**
- **less messy than LoD (as required by application)**
- **overarching several LoD datasets (as required by application)**



Schema on top of the LoD cloud



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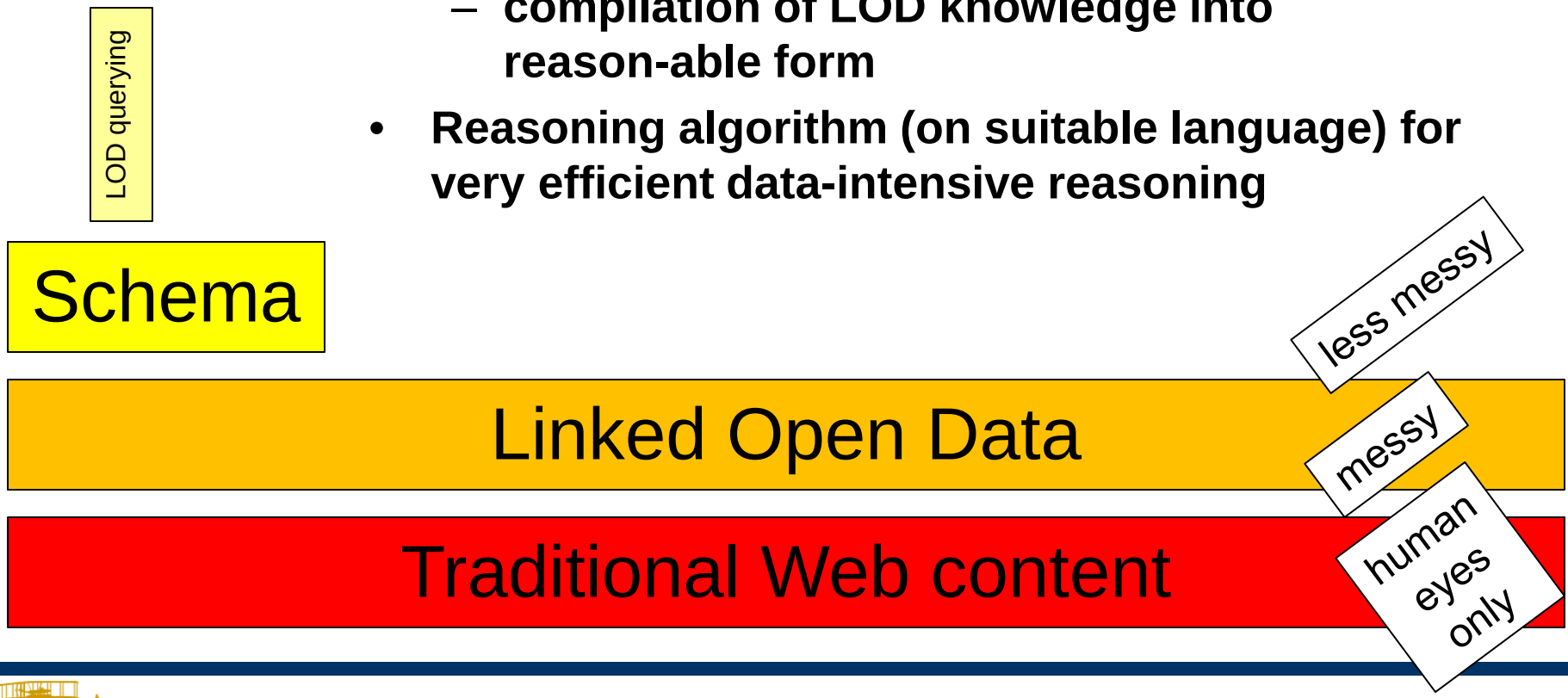
LOQuS – Querying Linked Open Data

Work in progress.

- **Schema creation for**
  - **query federation**
  - **utilizing background knowledge**
  - **compilation of LOD knowledge into reason-able form**
- **Reasoning algorithm (on suitable language) for very efficient data-intensive reasoning**



BLOOMS

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

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

Jain, Hitzler et al, ISWC2010

BLOOMS

Table 1. Results on the oriented matching track. Results for RiMOM and AROMA have been taken from the OAEI 2009 website. Legends: Prec=Precision, A-API=Alignment API, OMV=OMViaUO, NaN=division by zero, likely due to empty alignment.

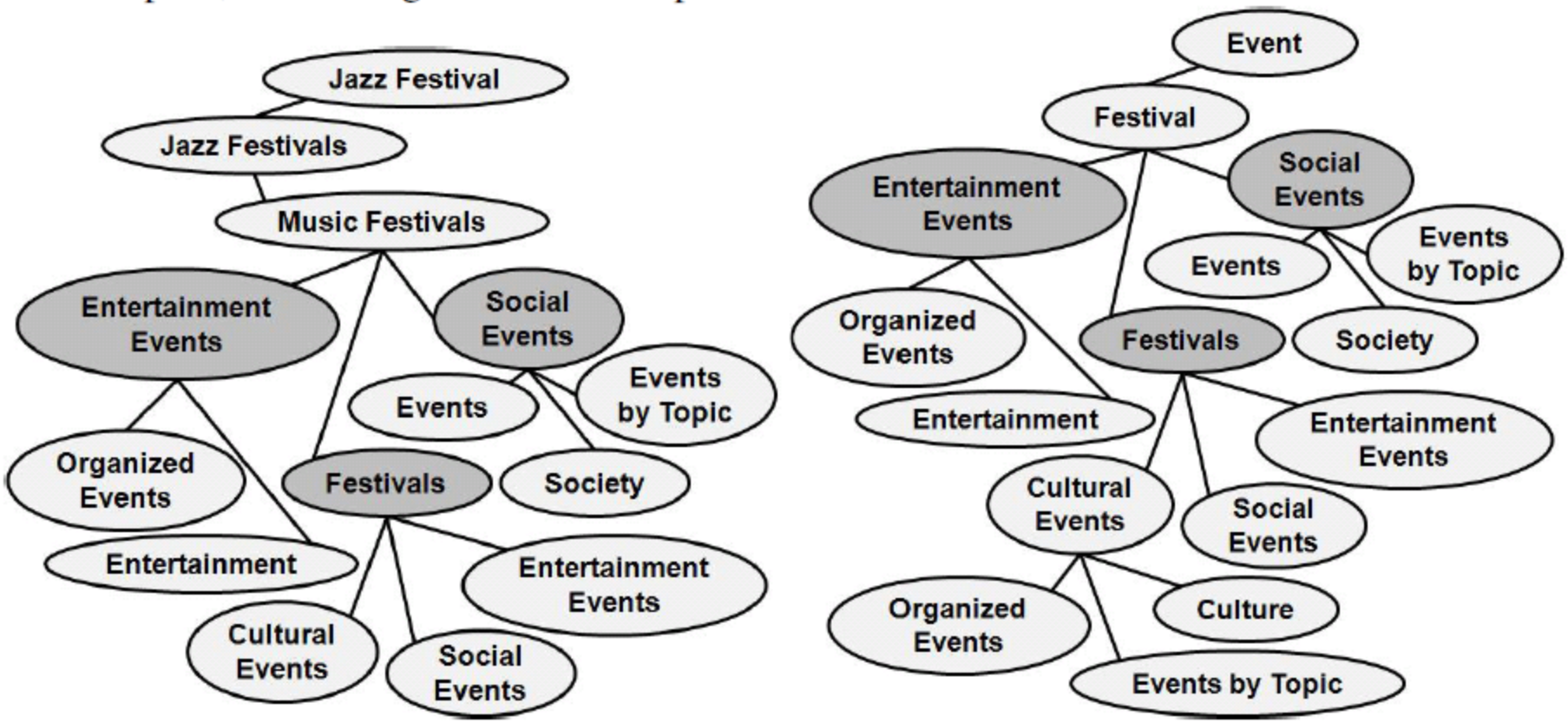
Ontology Alignment Initiative—Oriented Matching Track												
	A-API		OMV		S-Match		AROMA		RiMoM		BLOOMS	
Test	Prec	Rec	Prec	Rec	Prec	Rec	Prec	Rec	Prec	Rec	Prec	Rec
1XX	0	0	0.02	0.06	0.01	0.71	NaN	0	1	1	1	1
2XX	0	0	0.01	0.03	0.05	0.30	0.84	0.08	0.67	0.85	0.52	0.51
3XX	0.01	0.03	0.02	0.047	0.01	0.14	0.72	0.11	0.59	0.81	1	0.84
Avg.	0.00	0.01	0.02	0.04	0.03	0.38	0.63	0.07	0.75	0.88	0.84	0.78

BLOOMS

1. **Pre-processing of the input ontologies** in order to (i) remove property restrictions, individuals, and properties, and to (ii) tokenize composite class names to obtain a list of all simple words contained within them, with stop words removed.
2. **Construction of the BLOOMS forest** T_C for each class name C, using information from Wikipedia.
3. **Comparison of constructed BLOOMS forests**, which yields decisions which class names are to be aligned.
4. **Post-processing** of the results with the help of the Alignment API and a reasoner.

BLOOMS trees

Fig. 1. BLOOMS trees for Jazz Festival with sense Jazz Festival and for Event with sense Event. To save space, some categories are not expanded to level 4.



BLOOMS

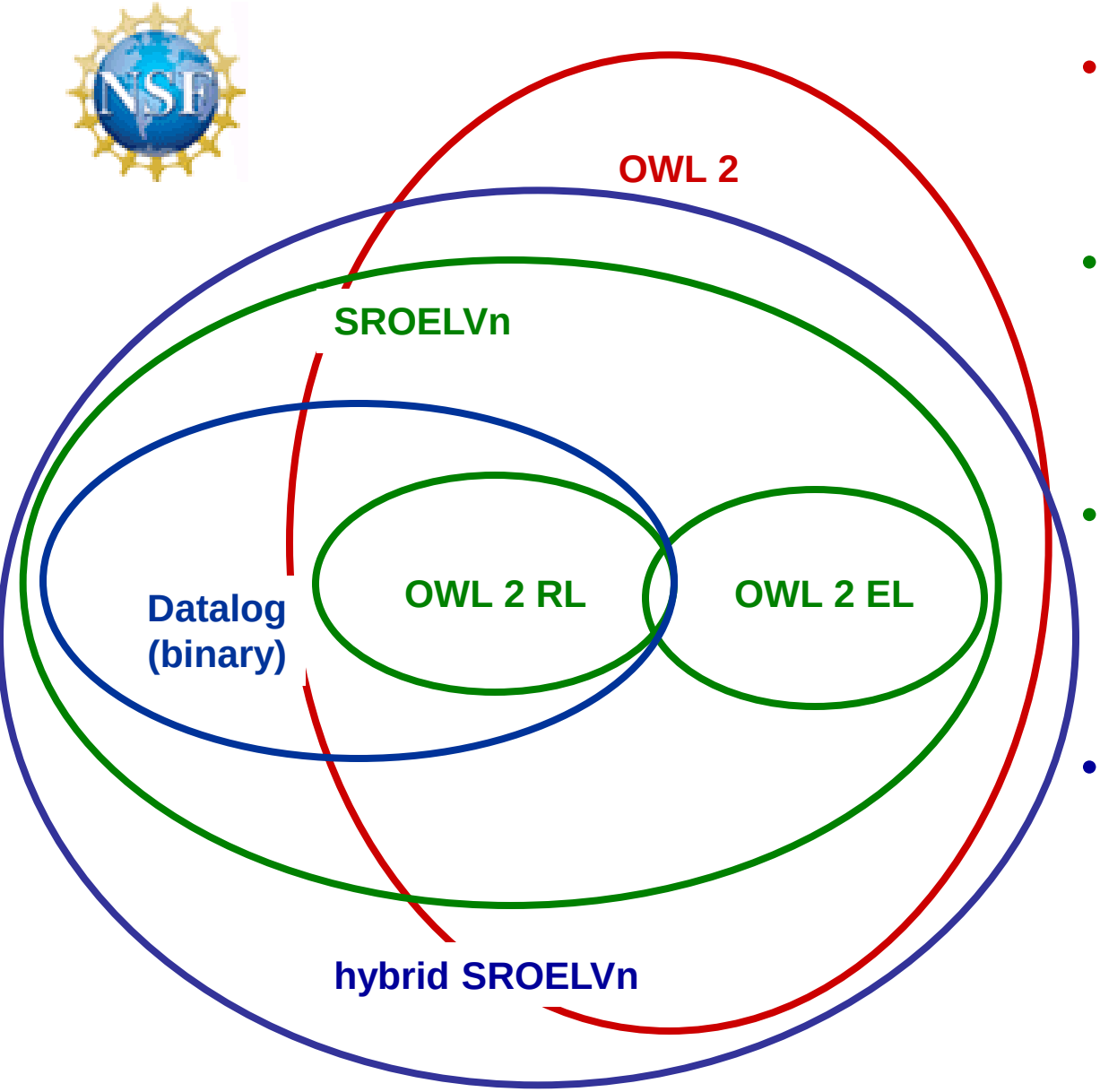
1. **Pre-processing of the input ontologies** in order to (i) remove property restrictions, individuals, and properties, and to (ii) tokenize composite class names to obtain a list of all simple words contained within them, with stop words removed.
2. **Construction of the BLOOMS forest** T_C for each class name C, using information from Wikipedia.
3. **Comparison of constructed BLOOMS forests**, which yields decisions which class names are to be aligned.
4. **Post-processing** of the results with the help of the Alignment API and a reasoner.

BLOOMS and LOQuS

1. **Pre-processing of the input ontologies** in order to (i) remove property restrictions, individuals, and properties, and to (ii) tokenize composite class names to obtain a list of all simple words contained within them, with stop words removed.
2. **Construction of the BLOOMS forest** T_C for each class name C, using information from Wikipedia.
3. **Comparison of constructed BLOOMS forests**, which yields decisions which class names are to be aligned.
4. **Post-processing** of the results with the help of the Alignment API and a reasoner.

- **We're currently evaluating the LOQuS querying approach while utilizing BLOOMS.**

Reasoning: useful scalable languages



- **OWL 2: complexity > exponential**
- **SROELVn: complexity = polynomial [WWW2011]**
- **OWL 2 EL and RL: complexity = polynomial**
- **hybrid SROELVn + Datalog: data complexity = polynomial [follows from AIJ2011]**

Thanks!

Collaborators on the covered topics:

Kno.e.lab:	**David Carral Martinez, Amit Joshi, Adila Krisnadhi, Fred Maier, Kunal Sengupta, Cong Wang**
Kno.e.sis:	**Prateek Jain, Amit Sheth**
Accenture:	**Kunal Verma, Peter Z. Yeh**
Karlsruhe:	**Sebastian Rudolph**
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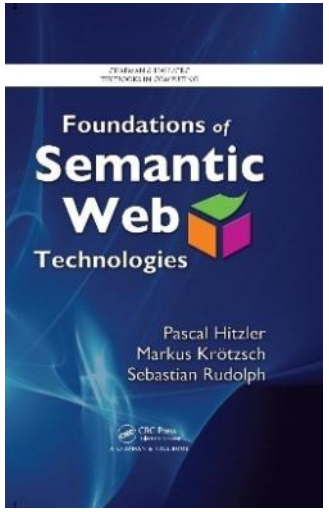
Oxford:	**Markus Krötzsch**
UCSB:	**Krzysztof Janowicz**

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



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