

Data, Ontologies, Rules, and the Return of the Blank Node

Markus Krötzsch

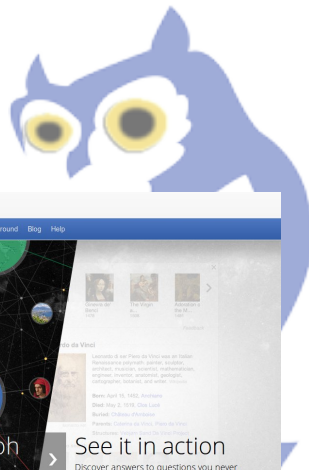
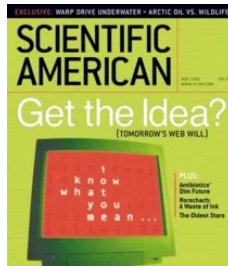
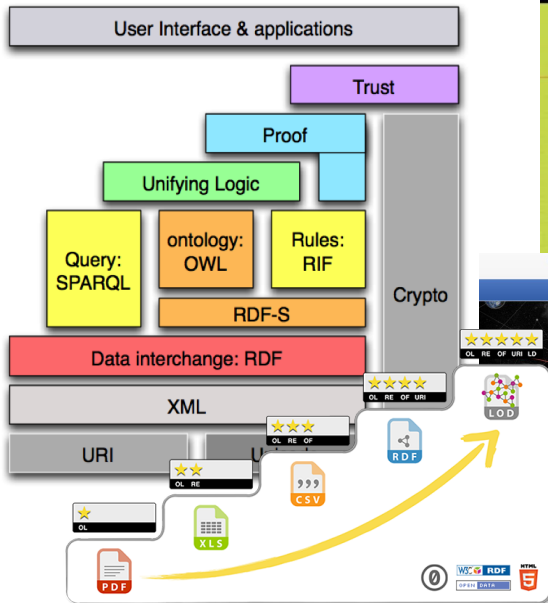
Knowledge-Based Systems, TU Dresden

Virtual

23-27 October 2022, Hangzhou, China



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Insights that Unite Us

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Vocabulary has Meaning

- Identity of “resources”
- Important online (HTTP semantics)
- Important in ontologies (vocabulary)

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- Shared conceptualisation
- Declarativity
- Openness & standards

Insights that Unite Us

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Knowledge is for Sharing

- Shared conceptualisation
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- Openness & standards

Being Pedantic is OK

- Specifications are valued
- Formal semantics matters
- Caring about details

The Triple



The Triple



Great Advantages

- uniformity & simplicity
- scalability
- structural compatibility
- and the powerful “graph” metaphor

The Triple



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- scalability
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- and the powerful “graph” metaphor

But ... the world is complex

- Other communities prefer less normalisation (RDBs, JSON, ...)
- OWL axioms and ShaCL shapes do not fit into single triples
- Modern Knowledge Graphs are not so simple ...

The Knowledge Graph of Wikipedia

- Free, community-built knowledge base
- Large and dynamic:
 - >100,000,000 items
(since 19 Oct 2022)
 - >10,000 properties
 - >14.2B Triples in RDF
 - >20,000,000 edits/month
- International, active community
 - >20,000 active users
(contributing during a month)
- Many uses



Fig.: Wikidata is celebrating its 10th Birthday on 29th Oct 2022



Tim Berners-Lee (Q80)

British computer scientist

[edit](#)

TimBL | Sir Tim Berners-Lee | Timothy John Berners-Lee | TBL | Tim Berners Lee | T. Berners-Lee | T Berners-Lee | Tim Berners-Lee | T.J. Berners-Lee



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instance of



human

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employer



CERN

 [edit](#)

start time	1984
end time	1994
position held	Fellow

▼ 0 references

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award received



Queen Elizabeth Prize for Engineering

 [edit](#)

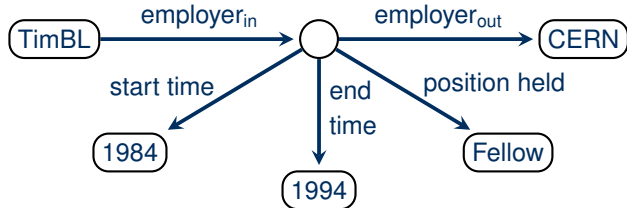
point in time 2013
together with Robert Kahn
Vint Cerf
Louis Pouzin
Marc Andreessen

► 1 reference

Wikidata and the Semantic Web

Each Wikidata statement turns into several triples

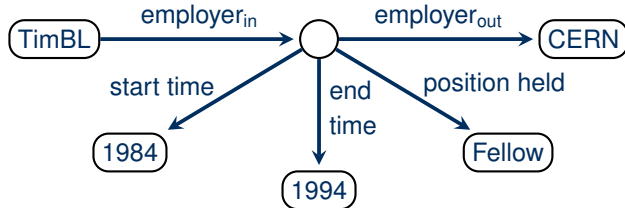
Fig. Sketch of reified statement ►



Wikidata and the Semantic Web

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Wikidata SPARQL & RDF usage

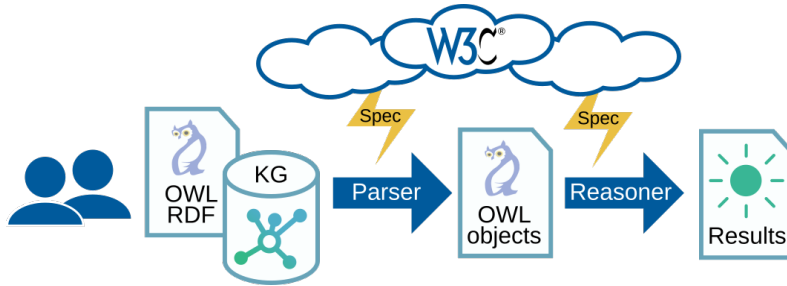
- Official IRI mapping and vocabulary
- Free RDF dumps + LOD exports
- Public live SPARQL endpoint at <https://query.wikidata.org/> (BlazeGraph)

Key technologies for community and 3rd party users!

From objects to triples ... and back?

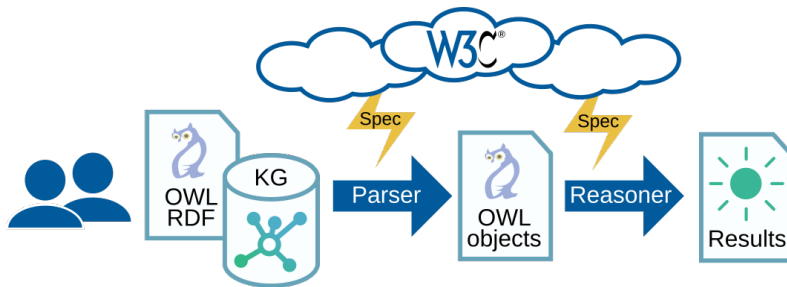
From objects to triples ... and back?

The OWL approach:



From objects to triples ... and back?

The OWL approach:



Great for what it does ... but not always what we need

- Ontological information may be intertwined with KG
- What reasoning we want may depend on context
- We may need new semantic interpretations for our data

New semantic interpretations for data

Wikidata says: “universe — has part(s) of the class — astronomical object”

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Discussion

Read

View source

View history

Search Wikidata



Help:Basic membership properties



Translate this page

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This page in a nutshell:



- Instances are individuals or single things
- Classes are abstractions (that might or might not have instances at Wikidata)
- Wikidata items are instances and/or classes

Contents [hide]

- 1 Introduction
 - 1.1 Definitions
 - 1.2 Examples
 - 1.3 Practical aspects
- 2 instance of (P31)
- 3 subclass of (P279)
- 4 part of (P361)
 - 4.1 Inverse relations of part of (P361)
- 5 Examples
 - 5.1 instance of (P31) vs. subclass of (P279) vs. part of (P361)
 - 5.2 has part(s) (P527) vs. has part(s) of the class (P2670)

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

Lexicographical data
Create a new Lexeme
Recent changes
Random Lexeme

Tools

What links here
Related changes
Special pages
Permanent link
Page information
Wikidata item

In Wikipedia

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Lexicographical data

Tools

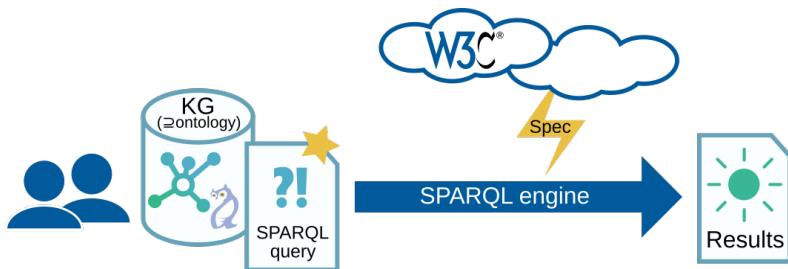
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In Wikipedia

SPARQL to the Rescue



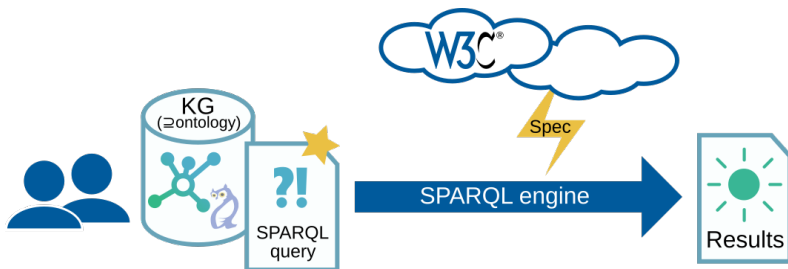
SPARQL to the Rescue



Example: Find all cities

```
SELECT ?city WHERE {  
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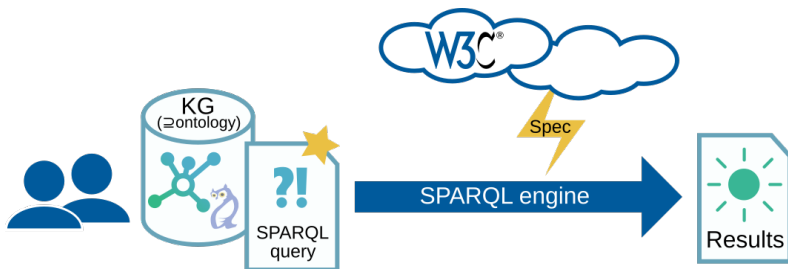


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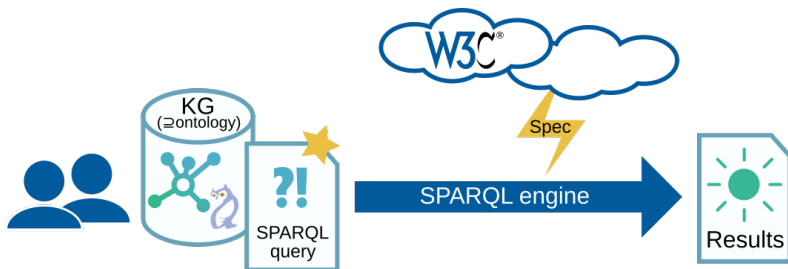


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SPARQL to the Rescue?

**What kind of semantics can
we implement in SPARQL?**

- RDFS
- OWL QL
- OWL RL
- OWL EL
- OWL 2 DL

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  {?C SUBCLASSOF owl:Nothing} UNION  
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    {?D1 DISJOINTCLASSES ?D2} UNION  
    {?V rdf:type owl:AllDisjointClasses . TWO MEMBERS[?V, ?D1, ?D2]}  
  }} UNION  
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Fig. SPARQL pattern for finding empty OWL QL classes
from [Bischof et al. ISWC 2014]

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Theorem:

SPARQL cannot express reasoning tasks that are harder than NLogSpace.

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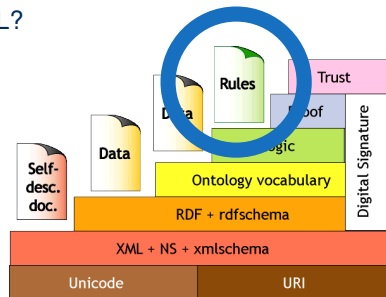
The Rules Layer on the Cake

Where do we get something more powerful than SPARQL?

The Rules Layer on the Cake

Where do we get something more powerful than SPARQL?

Well, it has always been there ...



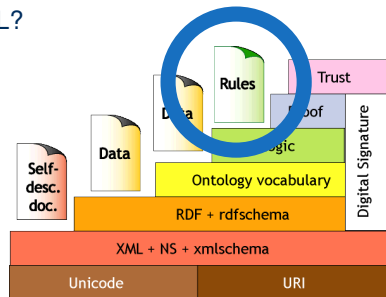
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A Complicated Relationship

- since 2000: **Notation 3 Logic** developed (incl. RDF rules)
- 2004: **SWRL** W3C member submission
- 2005: W3C charts WG for **Rule Interchange Format (RIF)**
- 2009: **OWL RL** becomes W3C Rec
- 2010: RIF enters recommendation
- 2010: 1st **Datalog 2.0 Workshop**
- all this time: SemWeb practitioners use various forms of rules (except RIF)



The Simplest Rule Language

Datalog: a very simple rule language

- Simple predicate-logic rules:
 $\text{rdf:type}(X, Y) \wedge \text{rdfs:subClassOf}(Y, Z) \rightarrow \text{rdf:type}(X, Z)$
- Conjunctive query patterns + recursion
- Polynomial time data complexity
- Fast reasoners with RDF support:
RDFox [Nenov et al. ISWC 2015],
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The Simplest Rule Language

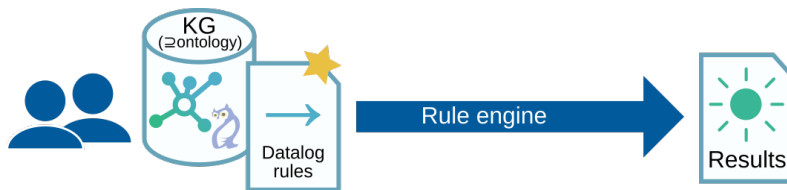
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Nothing complicated

- No negation
- No disjunction
- No built-ins or filters

OWL with Datalog



	SPARQL	Datalog	
RDFS	✓	✓	
OWL QL	✓	✓	[Bischof et al., ISWC 2014] + SPARQL as Datalog
OWL RL	✗	✓	[Krötzsch, ISWC 2012]
OWL EL	✗	✓	[Krötzsch, IJCAI 2011]
OWL DL	✗	✗	Too complex: $N2ExpTime > P$

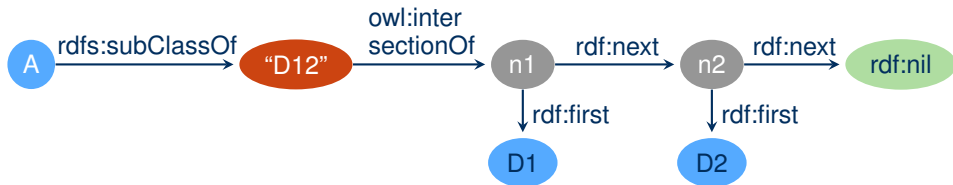
How complicated are these rules?

$\text{subClassOf}(\text{?C}, \text{?D1}) \wedge \text{subClassOf}(\text{?C}, \text{?D2}) \wedge$
 $\text{isInter}(\text{?D12}, \text{?D1}, \text{?D2}) \rightarrow \text{subClassOf}(\text{?C}, \text{?D12})$

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RDF encoding of `SubClassOf(A ObjectIntersectionOf( D1 D2 ) )`:

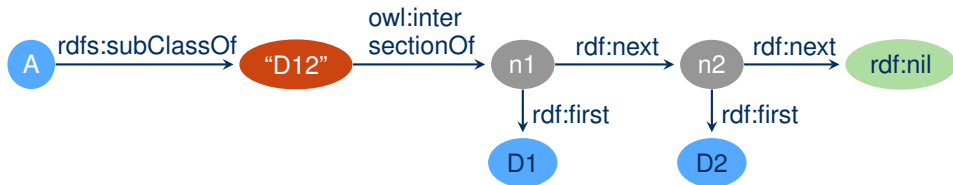


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RDF encoding of $\text{SubClassOf}(\text{A } \text{ObjectIntersectionOf}(\text{D1 } \text{D2}))$:



$\text{TRIPLE}(\text{?D12}, \text{owl:intersectionOf}, \text{?L1}) \wedge$

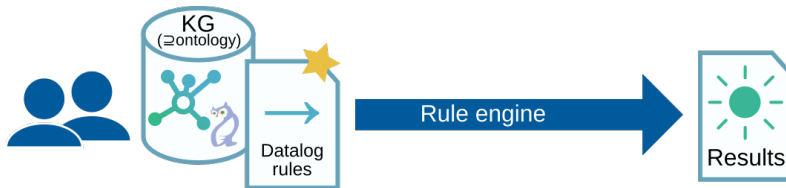
$\text{TRIPLE}(\text{?N1}, \text{rdf:next}, \text{?N2}) \wedge \text{TRIPLE}(\text{?N2}, \text{rdf:next}, \text{rdf:nil}) \wedge$

$\text{TRIPLE}(\text{?N1}, \text{rdf:first}, \text{?D1}) \wedge \text{TRIPLE}(\text{?N2}, \text{rdf:first}, \text{?D2}) \rightarrow \text{isInter}(\text{?D12}, \text{?D1}, \text{?D2})$

→ **10 reasoning rules and 36 parsing rules for much of OWL EL** [ECAI Tutorial 2020]

So ... what have we accomplished?

- From ontologies to data
- From W3C semantics to user-space semantics
- From dedicated reasoners to <50 lines of code



So ... what have we accomplished?

- From ontologies to data
- From W3C semantics to user-space semantics
- From dedicated reasoners to <50 lines of code



However ...

- Triples are not enough! [Krötzsch, IJCAI 2011 & ISWC 2012]
- Flexibility has a performance cost (VLog on Snomed: 2min)
- Getting rules right is not easy

Why Datalog is not enough

Observation 1: Encoding complex objects in RDF requires auxiliary nodes

Observation 2: Datalog can only produce new relationships among existing nodes

Why Datalog is not enough

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~> **Major Weakness:** We can parse complex RDF structures but not create them!

Solution: Enable value invention in rules

```
isInter(?D12, ?D1, ?D2) → TRIPLE(?D12, owl:intersectionOf, _:n1) ∧  
                           TRIPLE(_:n1, rdf:next, _:n2) ∧ TRIPLE(_:n2, rdf:next, rdf:nil) ∧  
                           TRIPLE(_:n1, rdf:first, ?D1) ∧ TRIPLE(_:n2, rdf:first, ?D2)
```

~> “Existential Rules”

From Datalog to Existential Rules

Existential Rules: a simple rule language

- Simple predicate-logic rule, like Datalog
- Conjunctive query patterns + recursion + value invention
- Query answering **undecidable**
- Fast reasoners with RDF support:
RDFox [Nenov et al. ISWC 2015],
VLog [Carral et al. ISWC 2019]

Still nothing complicated

- No negation
- No disjunction
- No built-ins or filters

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Reasoners recursively apply rules
and add new values, hoping for termination

~> Most tool support is for rule sets that “terminate”

The Power of Terminating Existential Rules

Recall:

- Datalog cannot see negative information (no negation)
- Datalog cannot solve non-polynomial tasks

Clear:

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Theorem* [Bourgaux et al., KR 2021]

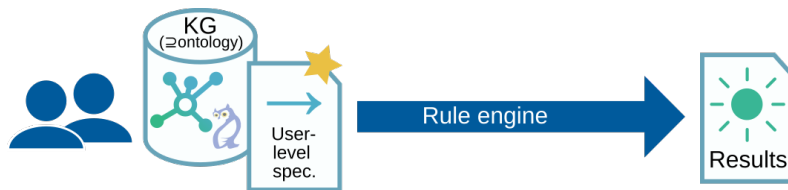
Terminating existential rules can solve **every** computable task that does not depend on negative information.

* Terms and conditions apply; see paper

The Return of the Blank Node?



Summary: User-level specifications for interpreting triples



	SPARQL	Triples-only Datalog	Datalog	Existential Rules
RDFS	✓	✓	✓	✓
OWL QL	✓	✓	✓	✓
OWL RL	✗	✗	✓	✓
OWL EL	✗	✗	✓	✓
OWL DL	✗	✗	✗	✓

Summary: What really matters

We have split the world into triples, but still struggle to put it back together

- SPARQL is a start, but limited
- Rules are powerful, but subtle

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... but declarative, shareable meaning is more relevant than ever.

- Explanation and accountability requires shared concepts
- Declarativity is key to interoperability and scalability
- Knowledge is human, it will not go away

What's next for the “Semantic Web”?

We have **split the world into triples**, but still struggle to put it back together.

The era of **standard semantics has ended** ...

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What shall we do about it?

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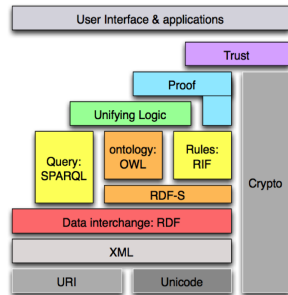
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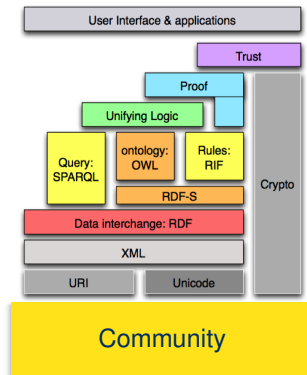
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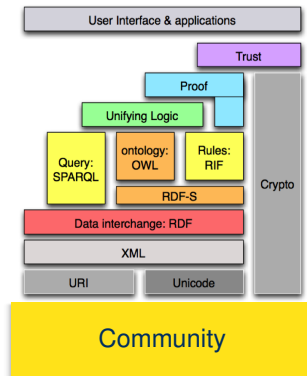
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What shall we do about it?

1. **Appreciate what we stand for**
2. **Spread our values:**
meaning, sharing, precision
3. **Focus on big challenges:**
flexibility, scalability, human collaboration, ...
4. **Find new ways to agree:**
on “standards”, on concepts, on models
5. **Engage with communities**
who care and can help

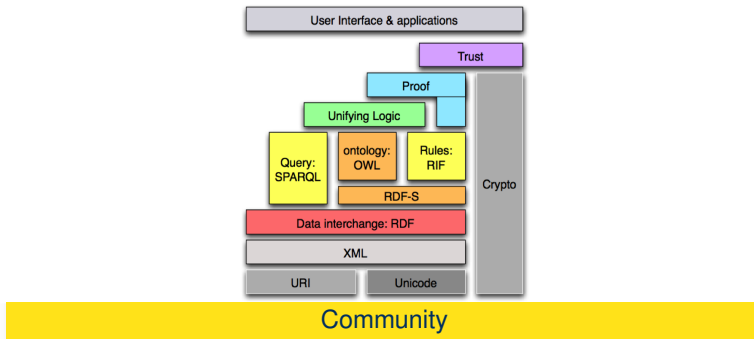


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“Knowledge is human, it will not go away”

References

All titles are links that lead to a download page

[Krötzsch, IJCAI 2011] Markus Krötzsch: [Efficient Rule-Based Inferencing for OWL EL](#). Proc. 22nd International Joint Conference on Artificial Intelligence (IJCAI'11), 2668–2673, 2011.

[Krötzsch, ISWC 2012] Markus Krötzsch: [The Not-So-Easy Task of Computing Class Subsumptions in OWL RL](#). Proc. 11th International Semantic Web Conference (ISWC'11), 279–294, 2012.

[Bischof et al. ISWC 2014] Stefan Bischof, Markus Krötzsch, Axel Polleres, Sebastian Rudolph: [Schema-Agnostic Query Rewriting in SPARQL 1.1](#). Proc. 13th International Semantic Web Conference (ISWC'14), volume 8796 of LNCS, 584–600, 2014.

[Nenov et al. ISWC 2015] Yavor Nenov, Robert Piro, Boris Motik, Ian Horrocks, Zhe Wu, Jay Banerjee: [RDFox: A Highly-Scalable RDF Store](#). Proc. 14th International Semantic Web Conference (ISWC'15) Part II: 3–20, 2015.

[Carral et al. ISWC 2019] David Carral, Irina Dragoste, Larry González, Cerial Jacobs, Markus Krötzsch, Jacopo Urbani: [VLog: A Rule Engine for Knowledge Graphs](#). Proc. 18th International Semantic Web Conference (ISWC'19) Part II, volume 11779 of LNCS, 2019.

[ECAI Tutorial 2020] David Carral, Markus Krötzsch, Jacopo Urbani: [Practical Uses of Existential Rules in Knowledge Representation](#), tutorial at ECAI 2020.

[Bourgaux et al., KR 2021] Camille Bourgaux, David Carral, Markus Krötzsch, Sebastian Rudolph, Michaël Thomazo: [Capturing Homomorphism-Closed Decidable Queries with Existential Rules](#), Proc. 18th International Conference on Principles of Knowledge Representation and Reasoning (KR'21), 141–150, 2021.

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We are always looking for new ideas. How about joining us?

(Just get in touch, and we will see what can be done :-)