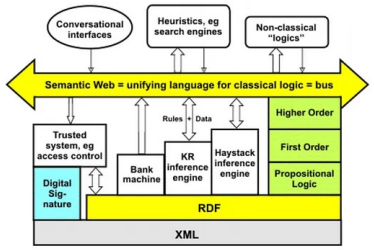
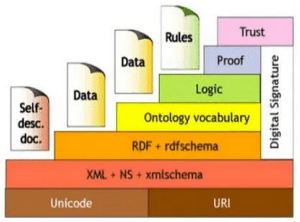
# The different “Shapes” of RDF(S) and OWL: a fragmented history

Or: are Semantic Web standards (still) a good basis for  Knowledge Graphs?

# Great to be back ☺



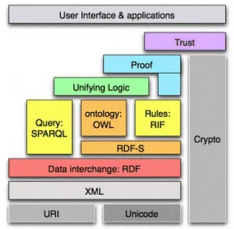
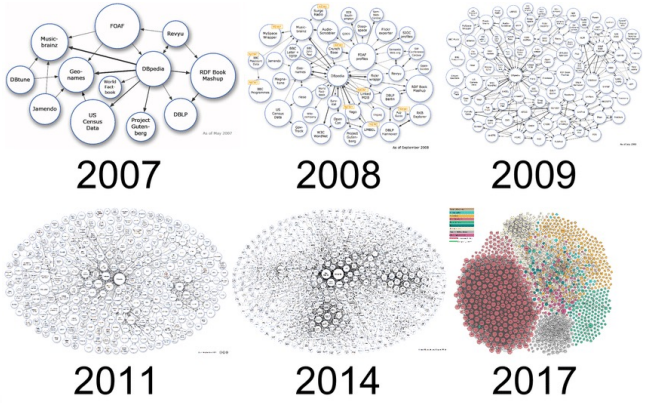
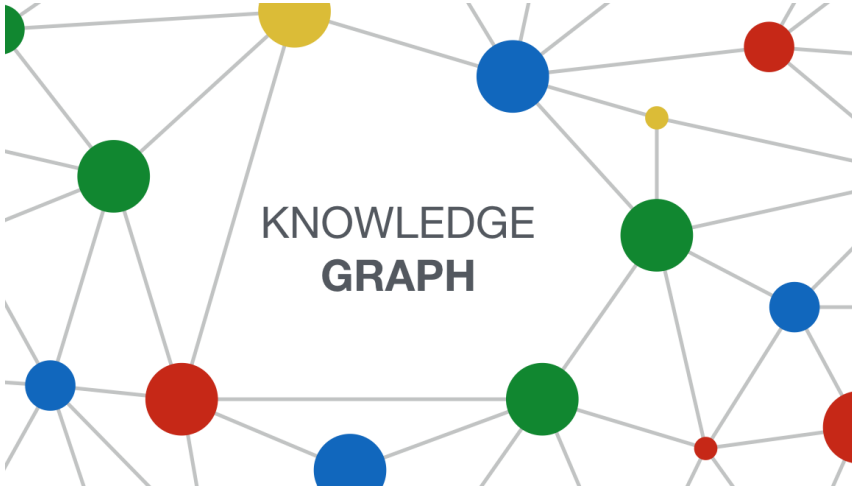




Figure 4. Evolution of the Semantic Web from 2000 to 2005




| | 1999-2002 | | | 2001-2004 | | | 2012-2014 | | 2022-2024 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Recommendations | | | RDF 1.0 | | | RDF 1.1 | | OWL2 | RDF1.2 | | |
| RDF 1999 | RDFS 2000 | OWL 2002 | RDF 2004 | RDFS 2004 | OWL 2004 | RDF 2014 | RDFS 2014 | OWL 2012 | RDF 2024 | RDFS 2024 | OWL 2024 |

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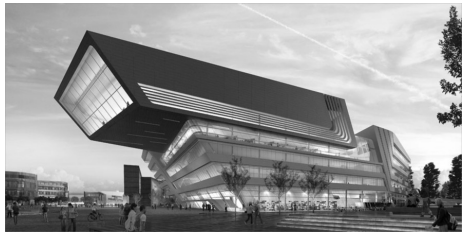
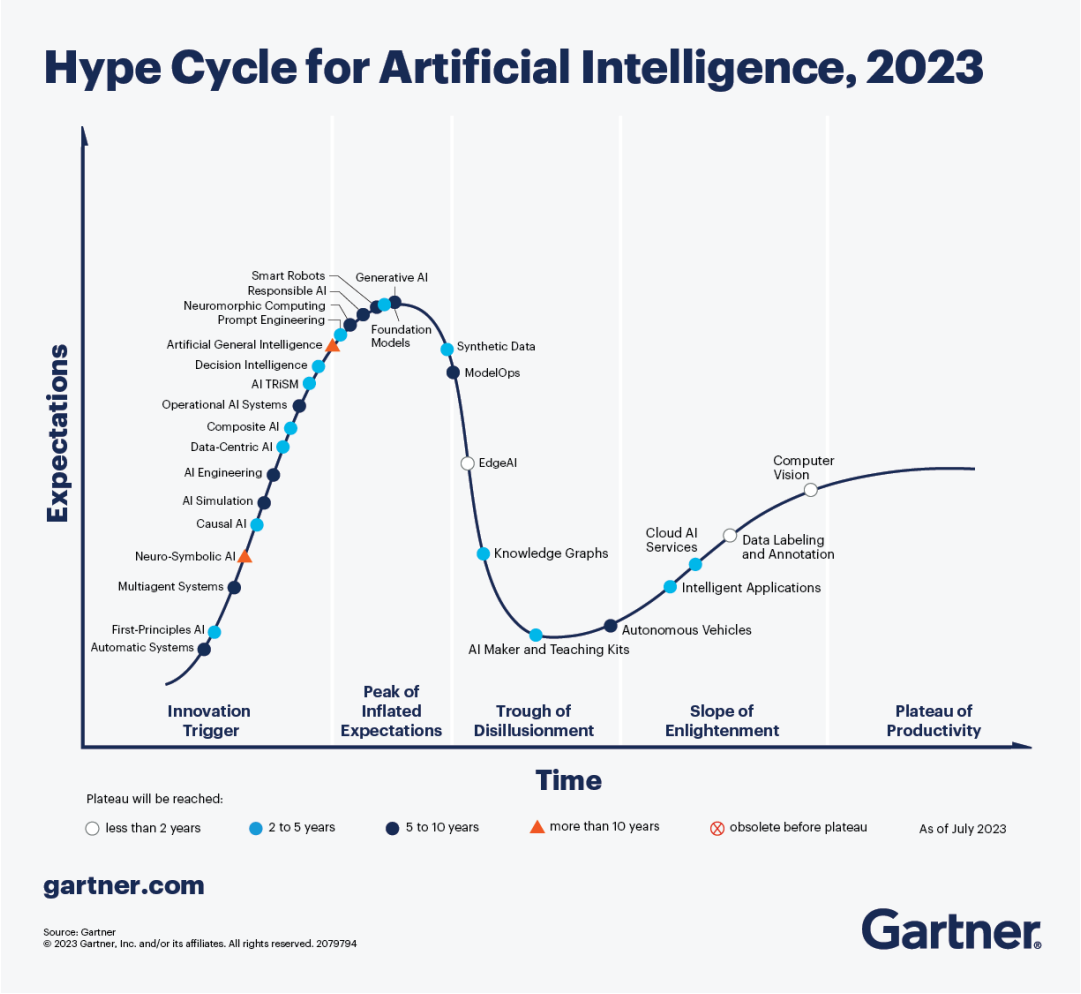


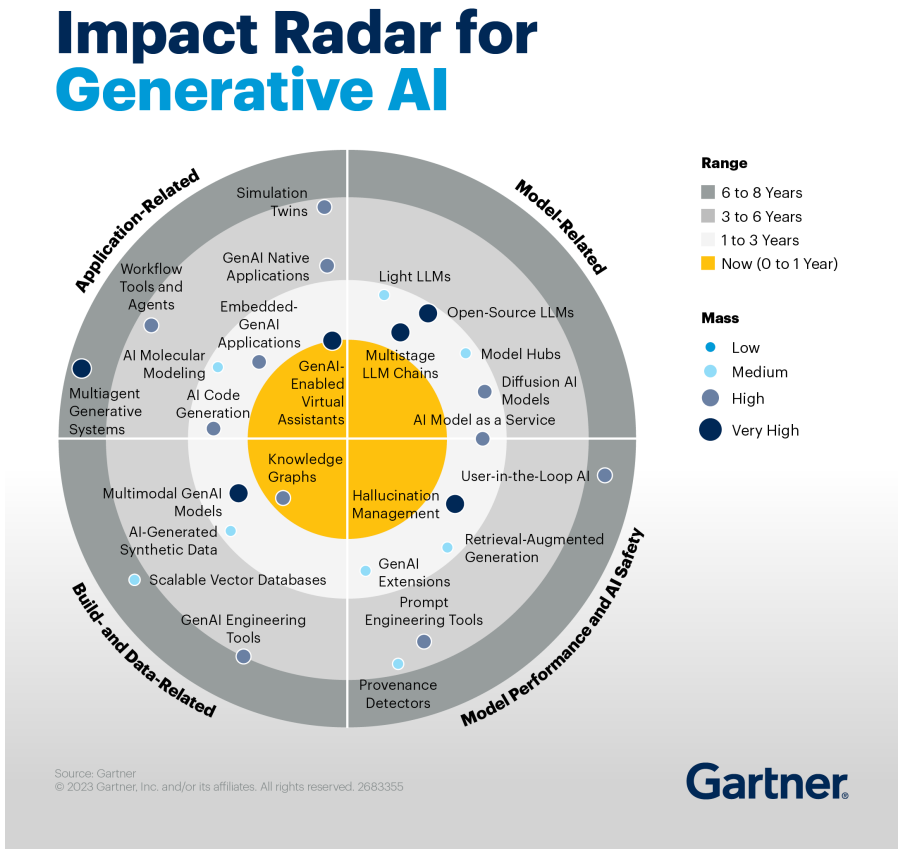
Wirtschaftsuniversität Wien (WU)

# How are Knowledge Graphs actually doing in 2024?

On the one hand…




On the other hand…



# What has changed?

- Adoption of the concept by major commercial players
- Fueled by “AI success stories”
- Standards (RDF, SPARQL) adopted by major vendors
- The focus has shifted
  - from (deductive) reasoning towards data quality (constraints)
  - towards“context”

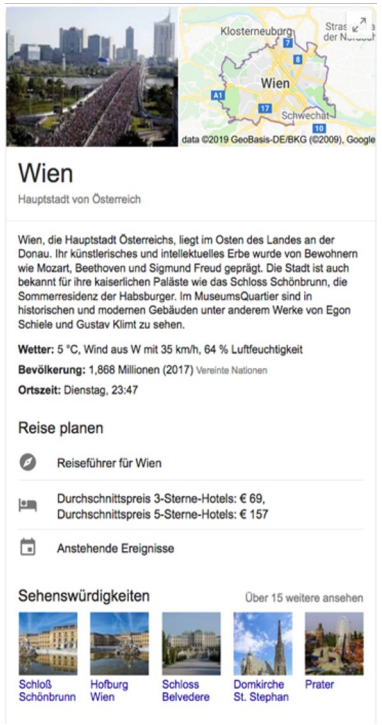
- Are Semantic Web languages (in particulat **RDFS and OWL** …) still fit for this purpose?

# Fueled by “AI success stories” 1/3

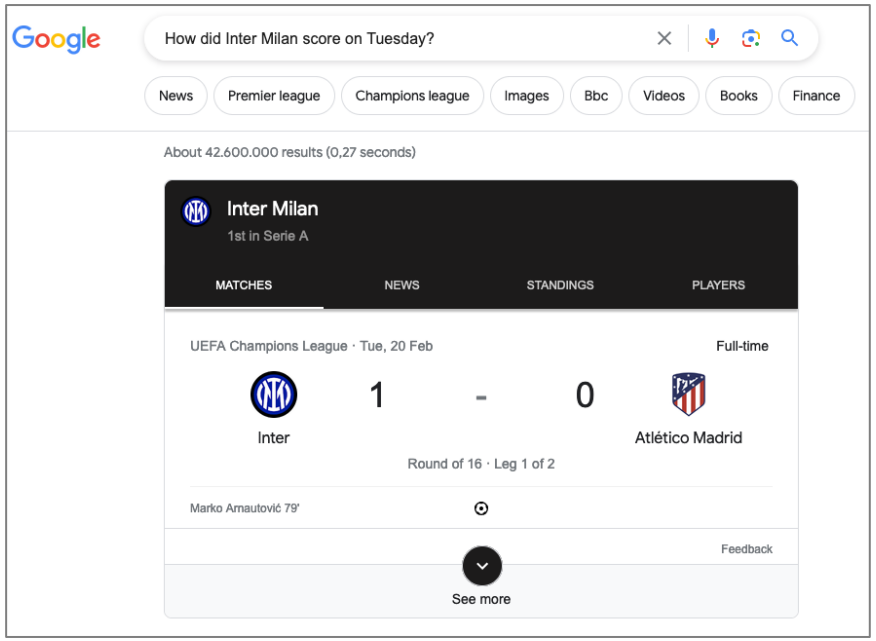
**Google – User Experience:**

- Rich Snippets

- Personalised recommendations across services:



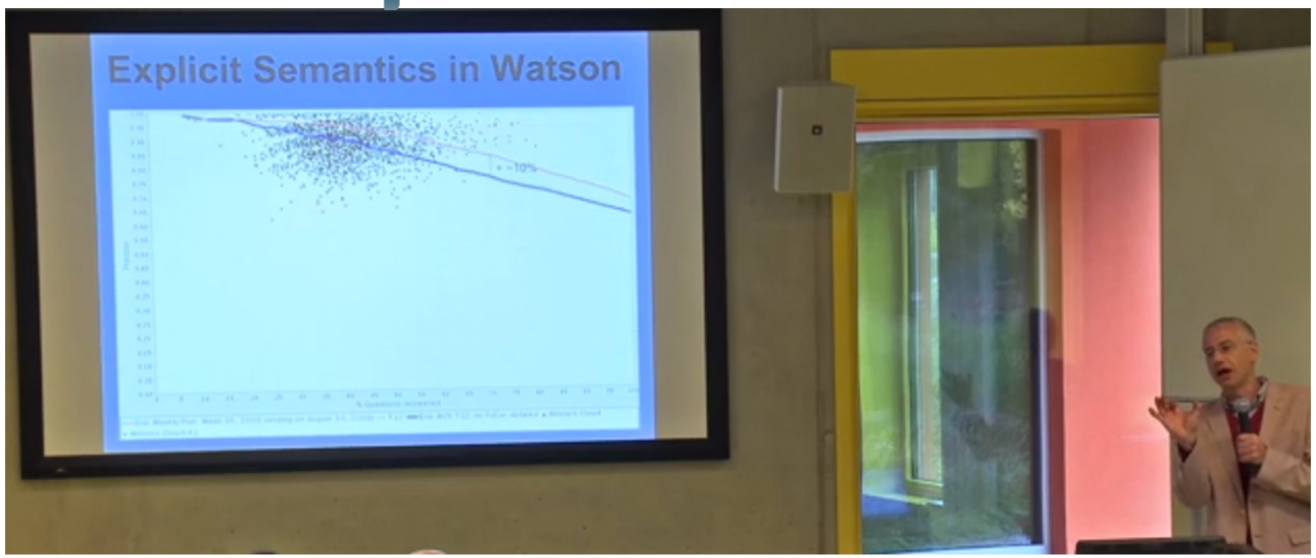


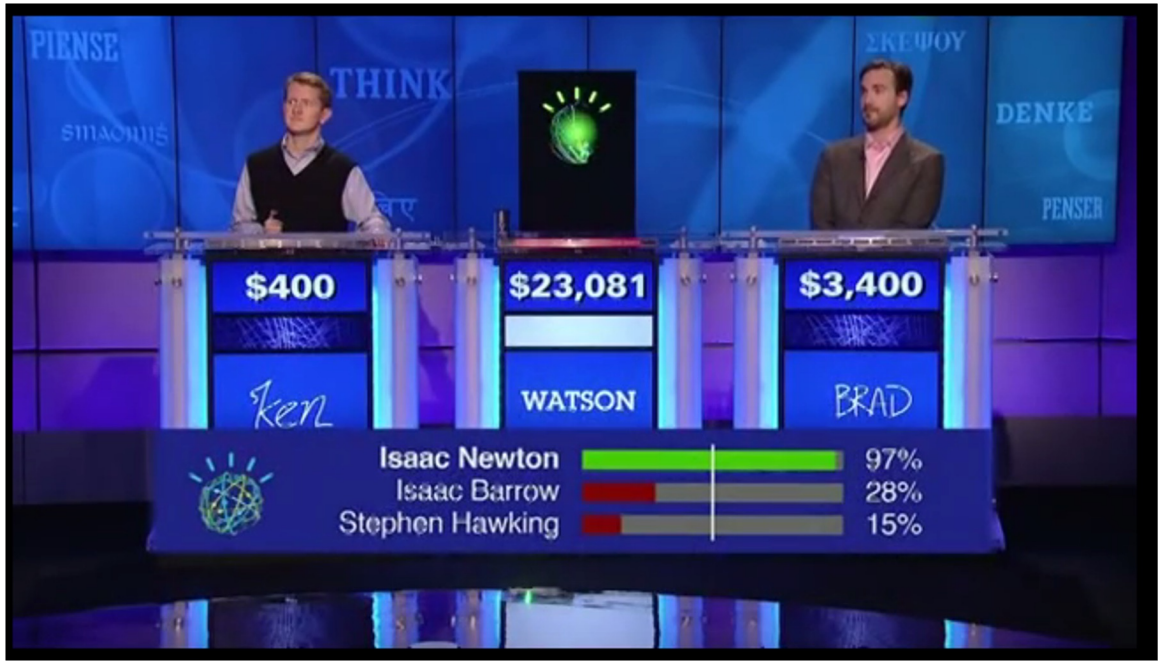


# Fueled by “AI success stories” 2/3

**IBM Watson :**

- Pre-LLM !!!
- Used DBpedia as one of its underlying knowledge bases! Essentially: formulating SPARQL queries underneath and using confidence scores.




https://youtu.be/P0Obm0DBvwI?t=951

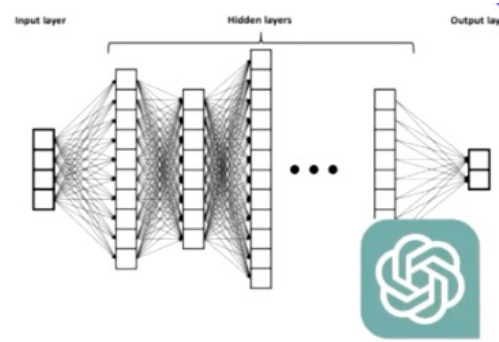
# Fueled by “AI success stories” 3/3
# “The Future of Knowledge Graphs in a World of LLMs”

Denny Vrandečić, WikimediaFoundation, Keynote **KGC23**

~5 seconds

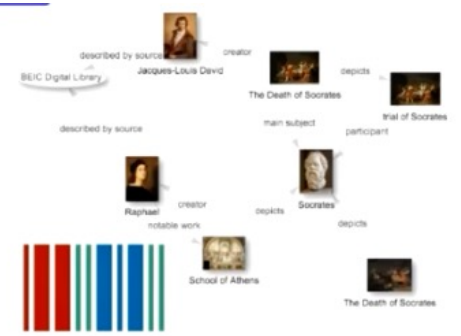
0.56 seconds

0.26 seconds




**Large generative model**

- 6 tokens input
- 60 tokens output (2 tokens)
- 96 layers
- 175 billion parameters




**Knowledge graph lookup**

- Find item out of 100m
- Find key out of 10k
- Logarithmic operations

Who created The School of Athens?

Trend: RAG – Search+KG+LLMs!
ISWC2024 workshop: ***Retrieval-Augmented Generation Enabled by Knowledge Graphs (RAGE-KG)***

# Standards (RDF, SPARQL) adopted by major vendors

"ORACLE supports RDF and SPARQL"

| Rank Mar 2024 | Rank Feb 2024 | Rank Mar 2023 | DBMS | Database Model | Score Mar 2024 | Score Feb 2024 | Score Mar 2023 |
|---|---|---|---|---|---|---|---|
| 1. | 1. | 1. | Oracle | Relational, Multi-model | 1221.06 | -20.39 | -40.23 |
| 2. | 2. | 2. | MySQL | Relational, Multi-model | 1101.50 | -5.17 | -81.29 |
| 3. | 3. | 3. | Microsoft SQL Server | Relational, Multi-model | 845.81 | -7.76 | -76.20 |
| 4. | 4. | 4. | PostgreSQL | Relational, Multi-model | 634.91 | +5.50 | +21.08 |
| 5. | 5. | 5. | MongoDB | Document, Multi-model | 424.53 | +4.18 | -34.25 |
| 6. | 6. | 6. | Redis | Key-value, Multi-model | 157.00 | -3.71 | -15.45 |
| 7. | 7. | ↑ 8. | Elasticsearch | Search engine, Multi-model | 134.79 | -0.95 | -4.28 |
| 8. | 8. | ↓ 7. | IBM Db2 | Relational, Multi-model | 127.75 | -4.47 | -15.17 |
| 9. | 9. | ↑ 11. | Snowflake | Relational | 125.38 | -2.07 | +10.98 |
| 10. | 10. | ↓ 9. | SQLite | Relational | 118.16 | +0.88 | -15.66 |

(Quoting Souripriya Das from Dagstuhl Seminar 24061 a month ago ;-) )

# The focus has shifted

- towards “context”
- from (deductive) reasoning towards data quality (constraints)

## Wikidata

Extremely rich, collaborative Knowledge Graph, directly integrated in Wikipedia

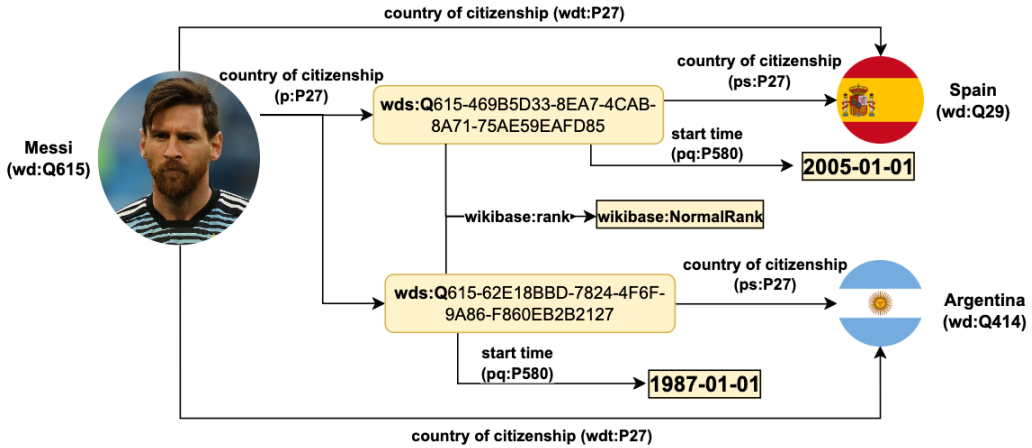
https://www.wikidata.org/wiki/Q615


Available as RDF and can be queried in SPARQL

Rich contextual knowledge

Fine grained data available about context on a statement level:

- time
- provenance
- Information source
- edit information
- **constraints**




# So, what happened to RDFS and OWL?

- Wikidata does not even use OWL and RDFS

- Are Semantic Web languages (in particular **RDFS and OWL** …) still fit for this purpose?

# Starting point/disclaimer:

In this talk, I mainly consider RDFS and OWL as

## RDF graphs

When I talk about OWL fragments, I mean which of the OWL(+RDFS+RDFS) **Vocabulary** can be used ***how (syntactically)*** *in an RDF graph*

- RDF (A-Box) Graph:

  `:s :p :o .`
- RDFS "T-Box Graph":

  `:p rdfs:subClassOf :q.`
- OWL "T-Box Graph":

  `:p rdfs:subClassOf :q.`

  `:p rdf:type owl:inverseFunctionalProperty.`

- RDFS "Vocabulary Graph" :

  `rdfs:Property rdf:type rdfs:Class`

# Recovering history:
# 1999-2000 First versions of RDF + RDFS:

**1999**

- The first recommendation version of the RDF syntax and model (all XML):
  - Ora Lassila, Ralph Swick 22 February 1999
- https://www.w3.org/TR/1999/REC-rdf-syntax-19990222/
  - or: http://web.archive.org/web/20000815062516id_/http://www.w3.org/TR/REC-rdf-syntax/
- The actually first version of the **RDF namespace document** was published a bit before:
- http://web.archive.org/web/19990508090931id_/http://www.w3.org/1999/02/22-rdf-syntax-ns

"RDF is a foundation for processing metadata"

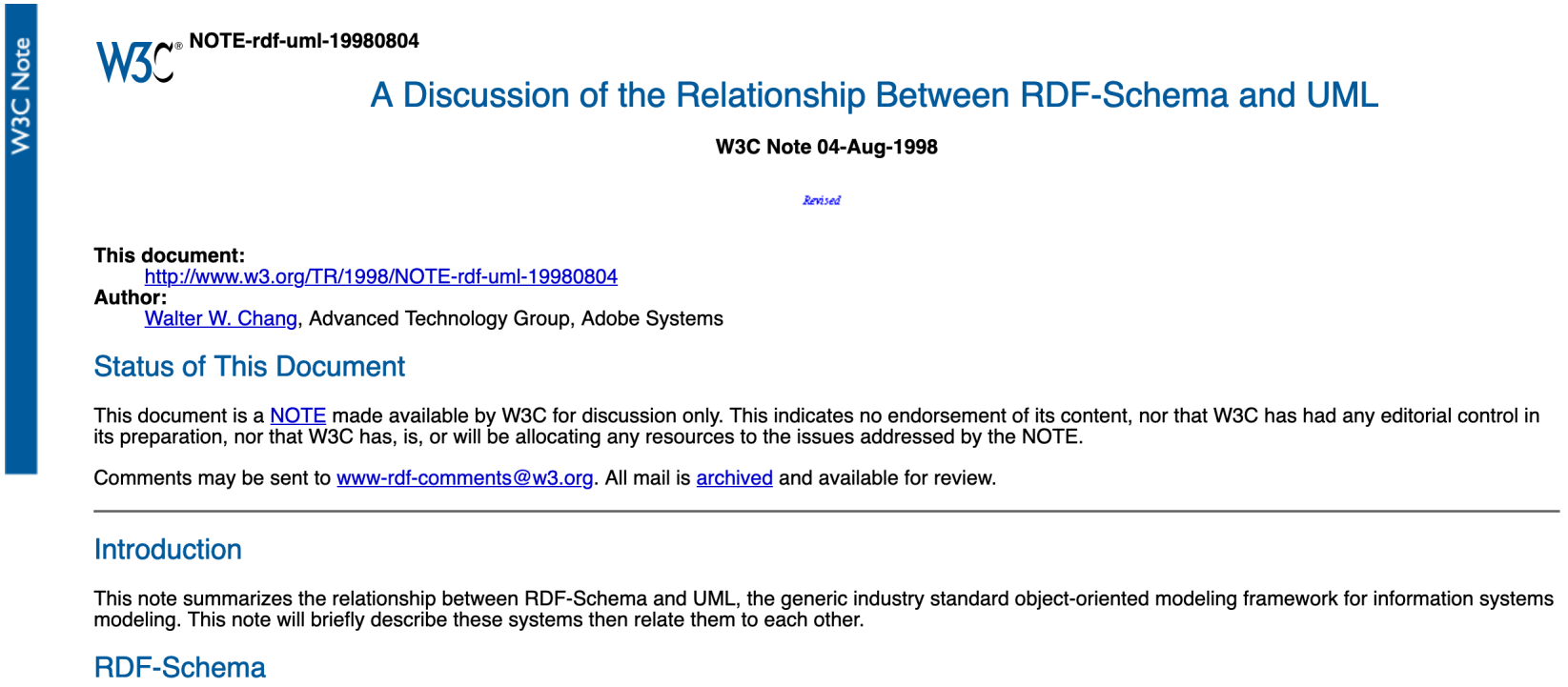
Origins rather
"Web metadata exchange format"
than a"(Graph) data format"

**1999**

- The first recommendation of RDF-Schema:
  - 1999 **Proposed Recommendation** version
  - http://web.archive.org/web/20000815092251/http://www.w3.org/TR/1999/PR-rdf-schema-19990303/
  - never became a Standard, but advanced to Rec only with the RDF 2004 version!
- The first version of the **RDF-Schema namespace document**:
  - https://web.archive.org/web/20000816181854id_/www.w3.org/2000/01/rdf-schema

# First mention of RDF Schema in a W3C published document actually already 1998:

- W3C Note 1998 (https://www.w3.org/TR/?filter-tr-name=RDF)



W3C Note

W3C® NOTE-rdf-uml-19980804

## A Discussion of the Relationship Between RDF-Schema and UML

**W3C Note 04-Aug-1998**

*Revised*

**This document:**
http://www.w3.org/TR/1998/NOTE-rdf-uml-19980804
**Author:**
Walter W. Chang, Advanced Technology Group, Adobe Systems

### Status of This Document

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Comments may be sent to www-rdf-comments@w3.org. All mail is archived and available for review.

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### Introduction

This note summarizes the relationship between RDF-Schema and UML, the generic industry standard object-oriented modeling framework for information systems modeling. This note will briefly describe these systems then relate them to each other.

### RDF-Schema

# **2002**: first (draft) version of OWL

- Namespace document first version online: www.w3.org/2002/07/owl

- http://web.archive.org/web/20020815073440id_/www.w3.org/2002/07/owl

# **2004:** RDF and RDFS 1.0

- **10 February 2004**: Rehaul of the RDF and RDFS vocabulary

- http://web.archive.org/web/20040213221349id_/http://www.w3.org/1999/02/22-rdf-syntax-ns
- https://web.archive.org/web/20040204230820id_/http://www.w3.org/2000/01/rdf-schema

# **2004**: OWL1

- **10 February 2004:** First official Recommendation of OWL

- http://web.archive.org/web/20040405111643id_/http://www.w3.org/2002/07/owl

# **2012**: OWL2

- **11 December 2012:** Quite substantial extension of OWL1
  - various new language features
  - 3 sub”dialects”:
    - OWL RL
    - OWL EL
    - OWL QL

    - Whar changed? Let’s check!
      - http://web.archive.org/web/20121221014933id_/http://www.w3.org/2002/07/owl

# **2014**: RDF1.1 +RDF Schema 1.1

- 25 February 2014
- https://www.w3.org/TR/rdf11-concepts/
- https://www.w3.org/TR/rdf11-schema/

- What's new?
  - https://www.w3.org/TR/rdf11-new/
  - IRIs instead of URIs and special characters allowed in IRIs.
  - New datatypes:
    - **rdf:langString**
    - **rdf:HTML** and **rdf:XMLLiteral** are non-normative in RDF 1.1
  - A table of RDF-compatible XSD datatypes has been added to RDF 1.1 Concepts and Abstract Syntax. Any XSD datatypes not represented in this table are incompatible with RDF

# **2024**: RDF1.2 !

- https://www.w3.org/TR/rdf12-schema/

- What's new?
  - Quoted triples
  - rdf:dirLangString
  - rdf:JSON
  - rdf:HTML and rdf:XMLLiteral now normative

**RDF 1.2 Concepts and Abstract Syntax**

W3C Working Draft 21 January 2024

▾ **More details about this document**

**This version:**
https://www.w3.org/TR/2024/WD-rdf12-concepts-20240121/

**Latest published version:**
https://www.w3.org/TR/rdf12-concepts/

**Latest editor's draft:**
https://w3c.github.io/rdf-concepts/spec/

**History:**
https://www.w3.org/standards/history/rdf12-concepts/
Commit history

**Latest Recommendation:**
https://www.w3.org/TR/rdf11-concepts

**Editors:**
Olaf Hartig
Pierre-Antoine Champin
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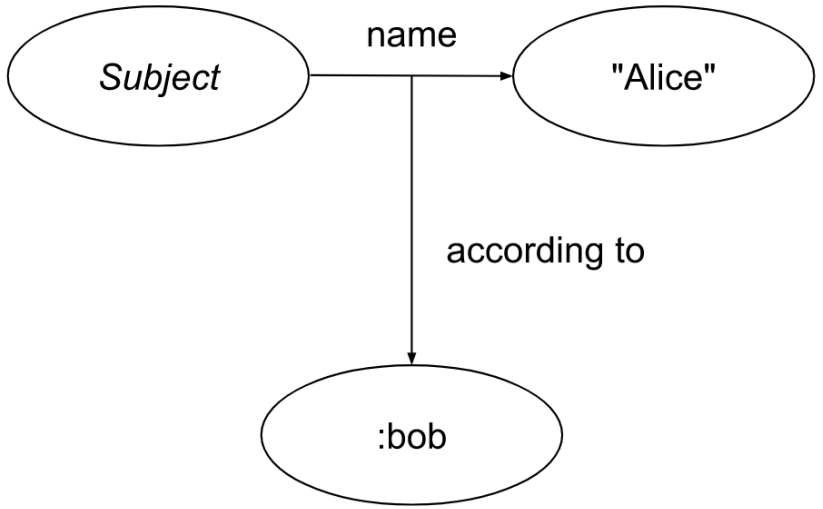
Andy Seaborne



# Let’s put these back on our timeline…

| 1999-2002 | | | 2001-2004 | | | 2012-2014 | | | 2022-2024 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Recommendations | | | RDF 1.0 | | | RDF 1.1 | | OWL2 | RDF1.2 | | |
| RDF 1999 | RDFS 2000 | OWL 2002 | RDF 2004 | RDFS 2004 | OWL 2004 | RDF 2014 | RDFS 2014 | OWL 2012 | RDF 2024 | RDFS 2024 | OWL 2024 |

… and have a closer look:

- Interesting asynchonicity of the standard’s evolution…
- What was there from the beginning?
- Some things came and went…

- Are all of these constructs needed/used? in practice?

~2000

| | | 1999-2002 | | |
|---|---|---|---|---|
| | | First Recommendations | | |
| | Term | RDF 19 | RDFS 20 | OWL 20 |
| Properties | rdf:object | TRUE | TRUE | |
| | rdf:predicate | TRUE | TRUE | |
| | rdf:subject | TRUE | TRUE | FALSE |
| | rdf:type | TRUE | TRUE | TRUE |
| | rdf:value | TRUE | TRUE | TRUE |
| | rdfs:comment | | TRUE | TRUE |
| | rdfs:domain | | TRUE | TRUE |
| | rdfs:label | | TRUE | TRUE |
| | rdfs:range | | TRUE | TRUE |
| | rdfs:seeAlso | | TRUE | TRUE |
| | rdfs:subClassOf | | TRUE | TRUE |
| | rdfs:subPropertyOf | | TRUE | TRUE |
| Classes | rdf:Alt | TRUE | TRUE | FALSE |
| | rdf:Bag | TRUE | TRUE | FALSE |
| | rdf:Property | TRUE | TRUE | TRUE |
| | rdf:Seq | TRUE | TRUE | FALSE |
| | rdf:Statement | TRUE | TRUE | FALSE |
| | rdfs:Class | | TRUE | TRUE |

# Let’s put these on a Tim

| 1999-2002 | | | 2001-2004 | | | 2012- | |
|---|---|---|---|---|---|---|---|
| First Recommendations | | | RDF 1.0 | | | RDF 1.1 | |
| RDF 1999 | RDFS 2000 | OWL 2002 | RDF 2004 | RDFS 2004 | OWL 2004 | RDF 2014 | RDFS |

… and have a closer look:

- Interesting asynchonicity of the standard’s evolution…
- What was there from the beginning?
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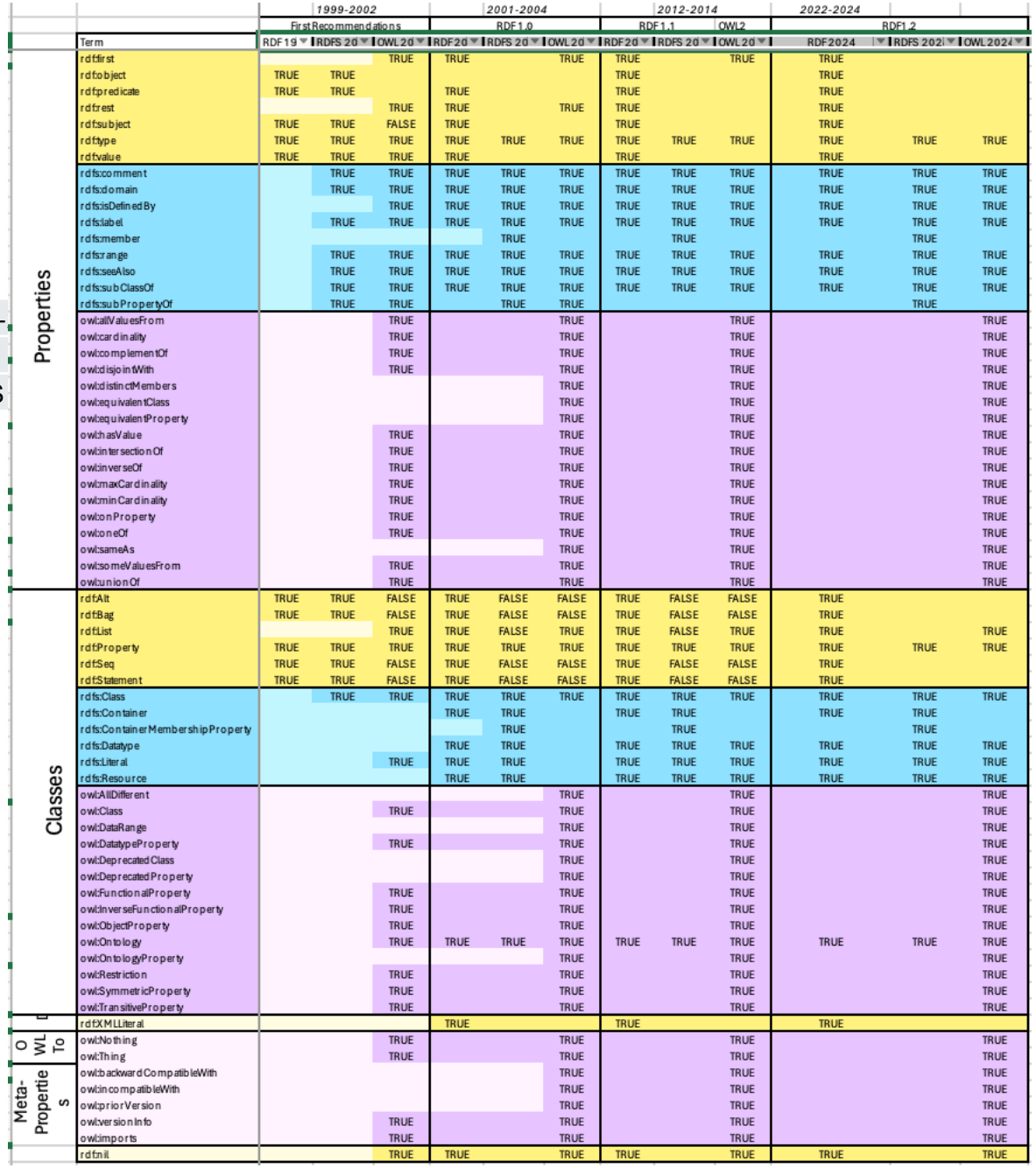
- Are all of these constructs needed/used? in practice?

~2004



| | | 1999-2002 | | | 2001-2004 | | | 2012-2014 | | | 2022-2024 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | First Recommendations | | | RDF 1.0 | | | RDF 1.1 | | OWL2 | RDF 1.2 | | |
| | Term | RDF 19 | RDFS 20 | OWL 20 | RDF 20 | RDFS 20 | OWL 20 | RDF 20 | RDFS 20 | OWL 20 | RDF 2024 | RDFS 202 | OWL 2024 |
| Properties | rdf:first | | | TRUE | TRUE | | TRUE | TRUE | | TRUE | TRUE | | |
| | rdf:object | TRUE | TRUE | | | | | TRUE | | | TRUE | | |
| | rdf:predicate | TRUE | TRUE | | TRUE | | | TRUE | | | TRUE | | |
| | rdf:rest | | | TRUE | TRUE | | TRUE | TRUE | | | TRUE | | |
| | rdf:subject | TRUE | TRUE | FALSE | TRUE | | | TRUE | | | TRUE | | |
| | rdf:type | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdf:value | TRUE | TRUE | TRUE | TRUE | | | TRUE | | | TRUE | | |
| | rdfs:comment | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:domain | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:isDefinedBy | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:label | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:member | | | | | TRUE | | | TRUE | | | TRUE | |
| | rdfs:range | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:seeAlso | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:subClassOf | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:subPropertyOf | | TRUE | TRUE | | TRUE | TRUE | | | | | TRUE | |
| | owl:allValuesFrom | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:cardinality | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:complementOf | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:disjointWith | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:distinctMembers | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:equivalentClass | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:equivalentProperty | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:hasValue | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:intersectionOf | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:inverseOf | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:maxCardinality | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:minCardinality | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:onProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:oneOf | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:sameAs | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:someValuesFrom | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:unionOf | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| Classes | rdf:Alt | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE | TRUE | | |
| | rdf:Bag | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE | TRUE | | |
| | rdf:List | | | TRUE | TRUE | FALSE | TRUE | TRUE | FALSE | TRUE | TRUE | | TRUE |
| | rdf:Property | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdf:Seq | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE | TRUE | | |
| | rdf:Statement | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE | TRUE | | |
| | rdfs:Class | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:Container | | | | TRUE | TRUE | | TRUE | TRUE | | TRUE | TRUE | |
| | rdfs:ContainerMembershipProperty | | | | | TRUE | | | TRUE | | | TRUE | |
| | rdfs:Datatype | | | | TRUE | TRUE | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:Literal | | | TRUE | TRUE | TRUE | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:Resource | | | | TRUE | TRUE | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | owl:AllDifferent | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:Class | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:DataRange | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:DatatypeProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:DeprecatedClass | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:DeprecatedProperty | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:FunctionalProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:InverseFunctionalProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:ObjectProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:Ontology | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | owl:OntologyProperty | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:Restriction | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:SymmetricProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:TransitiveProperty | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| L | rdf:XMLLiteral | | | | TRUE | | | TRUE | | | TRUE | | |
| OWL To | owl:Nothing | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:Thing | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| Meta-Properties | owl:backwardCompatibleWith | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:incompatibleWith | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:priorVersion | | | | | | TRUE | | | TRUE | | | TRUE |
| | owl:versionInfo | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | owl:imports | | | TRUE | | | TRUE | | | TRUE | | | TRUE |
| | rdf:nil | | | TRUE | TRUE | | TRUE | TRUE | | TRUE | TRUE | | TRUE |

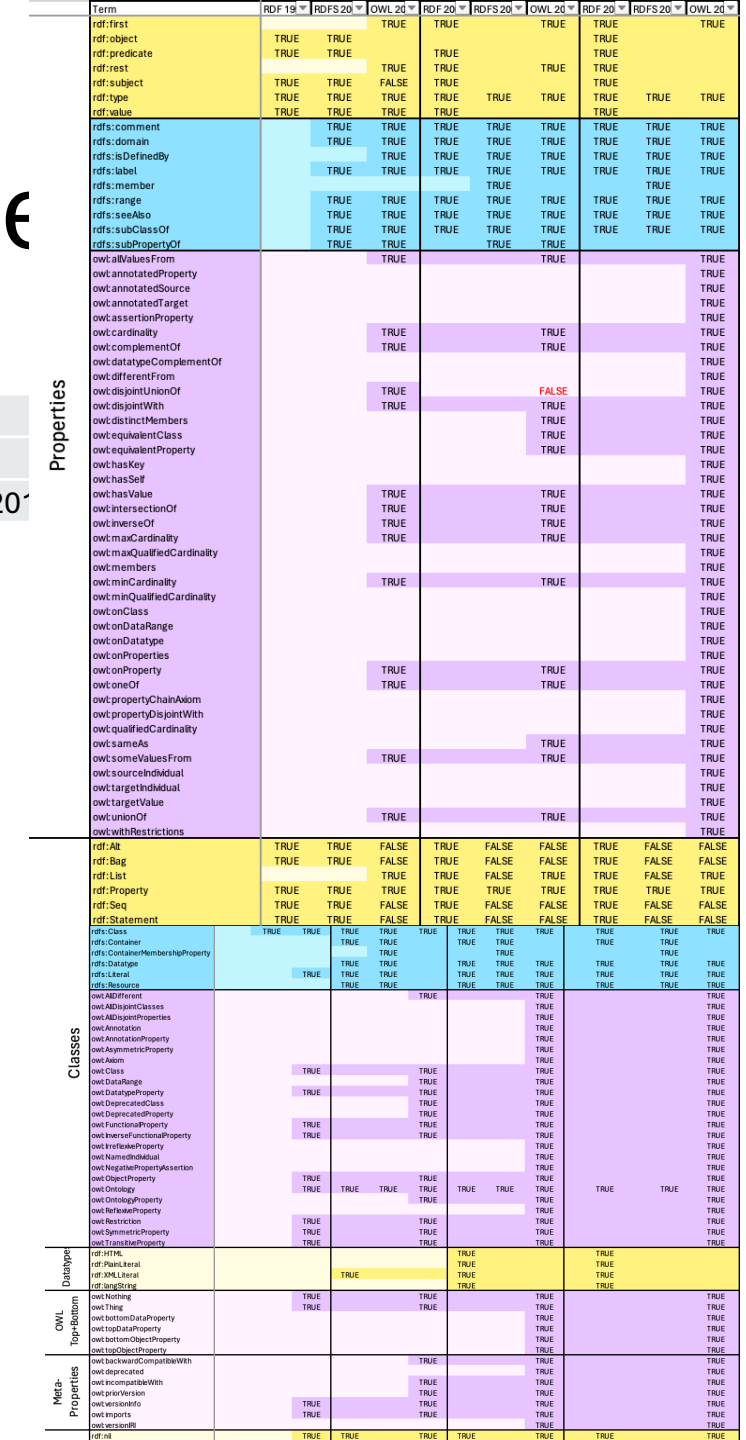
# Let’s put these on a Timeline

| 1999-2002 | | | 2001-2004 | | | 2012-2014 | | |
|---|---|---|---|---|---|---|---|---|
| First Recommendations | | | RDF 1.0 | | | RDF 1.1 | | OWL2 |
| RDF 1999 | RDFS 2000 | OWL 2002 | RDF 2004 | RDFS 2004 | OWL 2004 | RDF 2014 | RDFS 2014 | OWL 20 |

… and have a closer look:

- Interesting asynchonicity of the standard’s evolution…
- What was there from the beginning?
- Some things came and went…

- Are all of these constructs needed/used? in practice?



| | Term | RDF 19 | RDFS 20 | OWL 20 | RDF 20 | RDFS 20 | OWL 20 | RDF 20 | RDFS 20 | OWL 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Properties | rdf:first | | | TRUE | TRUE | | TRUE | TRUE | | TRUE |
| | rdf:object | TRUE | TRUE | | | | | TRUE | | |
| | rdf:predicate | TRUE | TRUE | | TRUE | | | TRUE | | |
| | rdf:rest | | | TRUE | TRUE | | TRUE | TRUE | | |
| | rdf:subject | TRUE | TRUE | FALSE | TRUE | | | TRUE | | |
| | rdf:type | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdf:value | TRUE | TRUE | TRUE | TRUE | | | TRUE | | |
| | rdfs:comment | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:domain | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:isDefinedBy | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:label | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:member | | | | | TRUE | | | TRUE | |
| | rdfs:range | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:seeAlso | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:subClassOf | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:subPropertyOf | | TRUE | TRUE | | TRUE | TRUE | | | |
| | owl:allValuesFrom | | | TRUE | | | TRUE | | | TRUE |
| | owl:annotatedProperty | | | | | | | | | TRUE |
| | owl:annotatedSource | | | | | | | | | TRUE |
| | owl:annotatedTarget | | | | | | | | | TRUE |
| | owl:assertionProperty | | | | | | | | | TRUE |
| | owl:cardinality | | | TRUE | | | TRUE | | | TRUE |
| | owl:complementOf | | | TRUE | | | TRUE | | | TRUE |
| | owl:datatypeComplementOf | | | | | | | | | TRUE |
| | owl:differentFrom | | | | | | | | | TRUE |
| | owl:disjointUnionOf | | | TRUE | | | FALSE | | | TRUE |
| | owl:disjointWith | | | TRUE | | | TRUE | | | TRUE |
| | owl:distinctMembers | | | | | | TRUE | | | TRUE |
| | owl:equivalentClass | | | | | | TRUE | | | TRUE |
| | owl:equivalentProperty | | | | | | TRUE | | | TRUE |
| | owl:hasKey | | | | | | | | | TRUE |
| | owl:hasSelf | | | | | | | | | TRUE |
| | owl:hasValue | | | TRUE | | | TRUE | | | TRUE |
| | owl:intersectionOf | | | TRUE | | | TRUE | | | TRUE |
| | owl:inverseOf | | | TRUE | | | TRUE | | | TRUE |
| | owl:maxCardinality | | | TRUE | | | TRUE | | | TRUE |
| | owl:maxQualifiedCardinality | | | | | | | | | TRUE |
| | owl:members | | | | | | | | | TRUE |
| | owl:minCardinality | | | TRUE | | | TRUE | | | TRUE |
| | owl:minQualifiedCardinality | | | | | | | | | TRUE |
| | owl:onClass | | | | | | | | | TRUE |
| | owl:onDataRange | | | | | | | | | TRUE |
| | owl:onDatatype | | | | | | | | | TRUE |
| | owl:onProperties | | | | | | | | | TRUE |
| | owl:onProperty | | | TRUE | | | TRUE | | | TRUE |
| | owl:oneOf | | | TRUE | | | TRUE | | | TRUE |
| | owl:propertyChainAxiom | | | | | | | | | TRUE |
| | owl:propertyDisjointWith | | | | | | | | | TRUE |
| | owl:qualifiedCardinality | | | | | | | | | TRUE |
| | owl:sameAs | | | | | | TRUE | | | TRUE |
| | owl:someValuesFrom | | | TRUE | | | TRUE | | | TRUE |
| | owl:sourceIndividual | | | | | | | | | TRUE |
| | owl:targetIndividual | | | | | | | | | TRUE |
| | owl:targetValue | | | | | | | | | TRUE |
| | owl:unionOf | | | TRUE | | | TRUE | | | TRUE |
| | owl:withRestrictions | | | | | | | | | TRUE |
| Classes | rdf:Alt | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE |
| | rdf:Bag | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE |
| | rdf:List | | | TRUE | TRUE | FALSE | TRUE | TRUE | FALSE | TRUE |
| | rdf:Property | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdf:Seq | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE |
| | rdf:Statement | TRUE | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE | FALSE | FALSE |
| | rdfs:Class | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:Container | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | |
| | rdfs:ContainerMembershipProperty | | | TRUE | TRUE | | TRUE | | TRUE | |
| | rdfs:Datatype | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:Literal | TRUE | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | rdfs:Resource | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | owl:AllDifferent | | | | TRUE | | TRUE | | | TRUE |
| | owl:AllDisjointClasses | | | | | | TRUE | | | TRUE |
| | owl:AllDisjointProperties | | | | | | TRUE | | | TRUE |
| | owl:Annotation | | | | | | TRUE | | | TRUE |
| | owl:AnnotationProperty | | | | | | TRUE | | | TRUE |
| | owl:AsymmetricProperty | | | | | | TRUE | | | TRUE |
| | owl:Axiom | | | | | | TRUE | | | TRUE |
| | owl:Class | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:DataRange | | | | TRUE | | TRUE | | | TRUE |
| | owl:DatatypeProperty | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:DeprecatedClass | | | | TRUE | | TRUE | | | TRUE |
| | owl:DeprecatedProperty | | | | TRUE | | TRUE | | | TRUE |
| | owl:FunctionalProperty | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:InverseFunctionalProperty | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:IrreflexiveProperty | | | | | | TRUE | | | TRUE |
| | owl:NamedIndividual | | | | | | TRUE | | | TRUE |
| | owl:NegativePropertyAssertion | | | | | | TRUE | | | TRUE |
| | owl:ObjectProperty | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:Ontology | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | owl:OntologyProperty | | | | TRUE | | TRUE | | | TRUE |
| | owl:ReflexiveProperty | | | | | | TRUE | | | TRUE |
| | owl:Restriction | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:SymmetricProperty | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:TransitiveProperty | TRUE | | | TRUE | | TRUE | | | TRUE |
| Datatypes | rdf:HTML | | | | | TRUE | | | TRUE | |
| | rdf:PlainLiteral | | | | | TRUE | | | TRUE | |
| | rdf:XMLLiteral | | TRUE | | | TRUE | | | TRUE | |
| | rdf:langString | | | | | TRUE | | | TRUE | |
| OWL Top+Bottom | owl:Nothing | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:Thing | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:bottomDataProperty | | | | | | TRUE | | | TRUE |
| | owl:topDataProperty | | | | | | TRUE | | | TRUE |
| | owl:bottomObjectProperty | | | | | | TRUE | | | TRUE |
| | owl:topObjectProperty | | | | | | TRUE | | | TRUE |
| Meta-Properties | owl:backwardCompatibleWith | | | | TRUE | | TRUE | | | TRUE |
| | owl:deprecated | | | | | | TRUE | | | TRUE |
| | owl:incompatibleWith | | | | TRUE | | TRUE | | | TRUE |
| | owl:priorVersion | | | | TRUE | | TRUE | | | TRUE |
| | owl:versionInfo | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:imports | TRUE | | | TRUE | | TRUE | | | TRUE |
| | owl:versionIRI | | | | | | TRUE | | | TRUE |
| | rdf:nil | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |

# ~2014

… and RDF1.2 adding a couple more as we speak ;-)

# Even the smallest fragment…

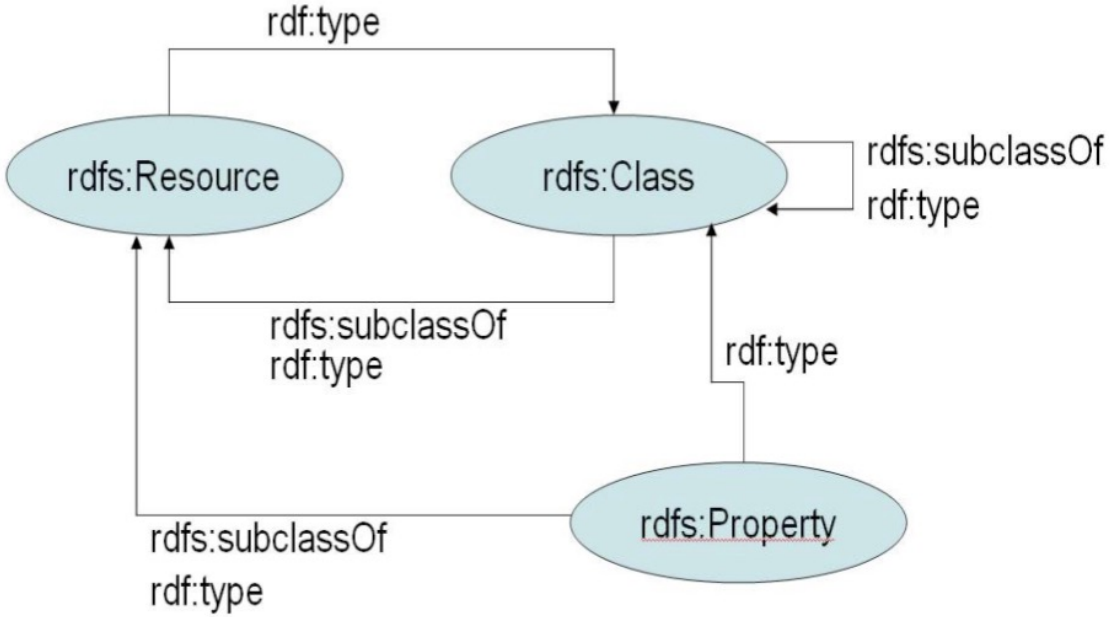
- … allows things (syntactically) that don't make  intuitive sense, or at least seem to be "distracting"… to most people who do NOT come from an RDF world.

Note: I'd argue that this is possibly one of the reasons for "slow" adpotion.

| | | 1999-2002 | | |
|---|---|---|---|---|
| | | First Recommendations | | |
| | Term | RDF 19 | RDFS 20 | OWL 20 |
| Properties | rdf:object | TRUE | TRUE | |
| | rdf:predicate | TRUE | TRUE | |
| | rdf:subject | TRUE | TRUE | FALSE |
| | rdf:type | TRUE | TRUE | TRUE |
| | rdf:value | TRUE | TRUE | TRUE |
| | rdfs:comment | | TRUE | TRUE |
| | rdfs:domain | | TRUE | TRUE |
| | rdfs:label | | TRUE | TRUE |
| | rdfs:range | | TRUE | TRUE |
| | rdfs:seeAlso | | TRUE | TRUE |
| | rdfs:subClassOf | | TRUE | TRUE |
| | rdfs:subPropertyOf | | TRUE | TRUE |
| Classes | rdf:Alt | TRUE | TRUE | FALSE |
| | rdf:Bag | TRUE | TRUE | FALSE |
| | rdf:Property | TRUE | TRUE | TRUE |
| | rdf:Seq | TRUE | TRUE | FALSE |
| | rdf:Statement | TRUE | TRUE | FALSE |
| | rdfs:Class | | TRUE | TRUE |

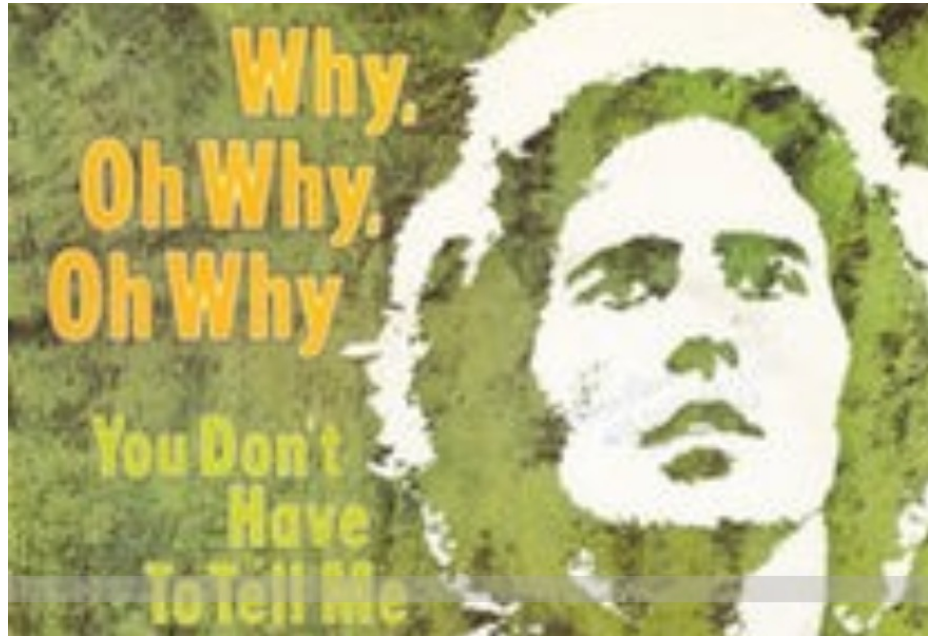
# “axiomatic” triples

- The vast majority of axiomatic triples seem to be an unnecessary burden, e.g.:




Only there to make the integration of axioms into the graph work, in a way to “justify” the ”mix” of syntax and semantics.

# This IS possible…




```
rdf:subClassOf
    a owl:SymmetricProperty .

rdf:type
    rdfs:subPropertyOf rdfs:subClassOf, owl:imports.

rdfs:subClassOf
    rdfs:subPropertyOf rdfs:Resource,
    rdfs:subPropertyOf .
```

BTW, you here can sure think of similar issues in “SHACL graphs”… Botomline requirement:

You want to have the axioms and constraints represented in/with the graph, but you want to *syntactically* ensure, it keeps *separable*

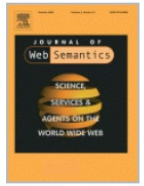
# Apart from the official W3C standards

- There's a long list of OWL "fragments"
  - partially syntactically
  - partially semantically

  motivated:
  - **OWL "ter Horst"** (2005) syntactic/semantic (Horn Logic)
  - **OWL Flight** (2005) semantic (CWA/Constraint reading)
  - **RDFS-** … Minimal RDFS (2007) syntactic/semantic
  - **OWL LD** (2012) syntactic/usage-motivated
  - Other fragments under discusion in the course of **OWL2, such as "RDFS3.0"**:
    - https://www.w3.org/2007/OWL/wiki/Fragments

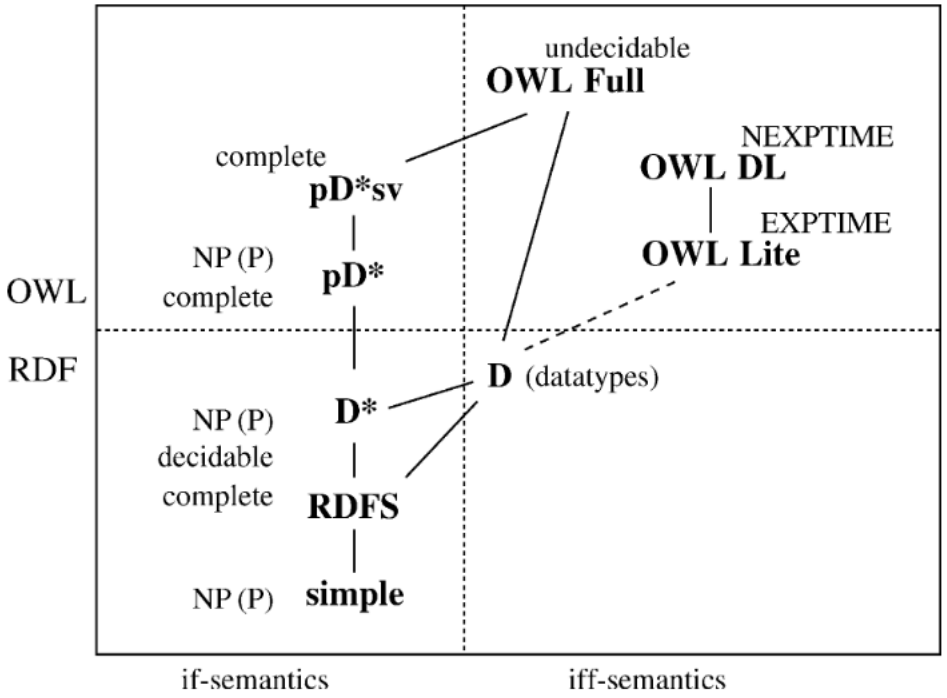
# OWL “ter Horst” (2005)

Journal of Web Semantics
Volume 3, Issues 2–3, October 2005, Pages 79-115



## Completeness, decidability and complexity of entailment for RDF Schema and a semantic extension involving the OWL vocabulary ☆

Herman J. ter Horst



# **OWL Flight** (2005)

**OWL DL vs. OWL Flight: Conceptual Modeling and Reasoning for the Semantic Web**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Dieter Fensel
Digital Enterprise Research Institute (DERI)
University of Innsbruck, Austria
National University of Ireland, Galway, Ireland


"Semantic" fragment:

- Datalog-Based semantics
- Unique Names Assumption
- Important thing: proposing alternative **constraint reading** of property restrictions!

# OWL IC (2010)

- Similar idea!
- Read (some) OWL axioms as constraints


Proceedings of the Twenty-Fourth AAAI Conference on Artificial Intelligence (AAAI-10)

**Integrity Constraints in OWL**

**Jiao Tao[1], Evren Sirin[2], Jie Bao[1], Deborah L. McGuinness[1]**
[1] Department of Computer Science, Rensselaer Polytechnic Institute, Troy, NY 12180, USA
[2] Clark & Parsia, LLC, Washington, DC 20001, USA

- E.g.:

```
CatOwner rdfs:subClassOf[ a owl:Restriction;
                          owl:onProperty owns;
                          owl:somevaluesFrom Cat ]
```

  - "deductive" reading: there is a (possibly unknown) cat
  - vs.
  - "constraining" reading: there has to be a (known) owned cat

- Problem: what about UNA? What about CWA?

… and it's pretty ugly to write this as RDF triples

# OWL LD (2012)

**OWL: Yet to arrive on the Web of Data?**


Birte Glimm
Ulm University, Institute of Artificial Intelligence, 89069 Ulm, Germany

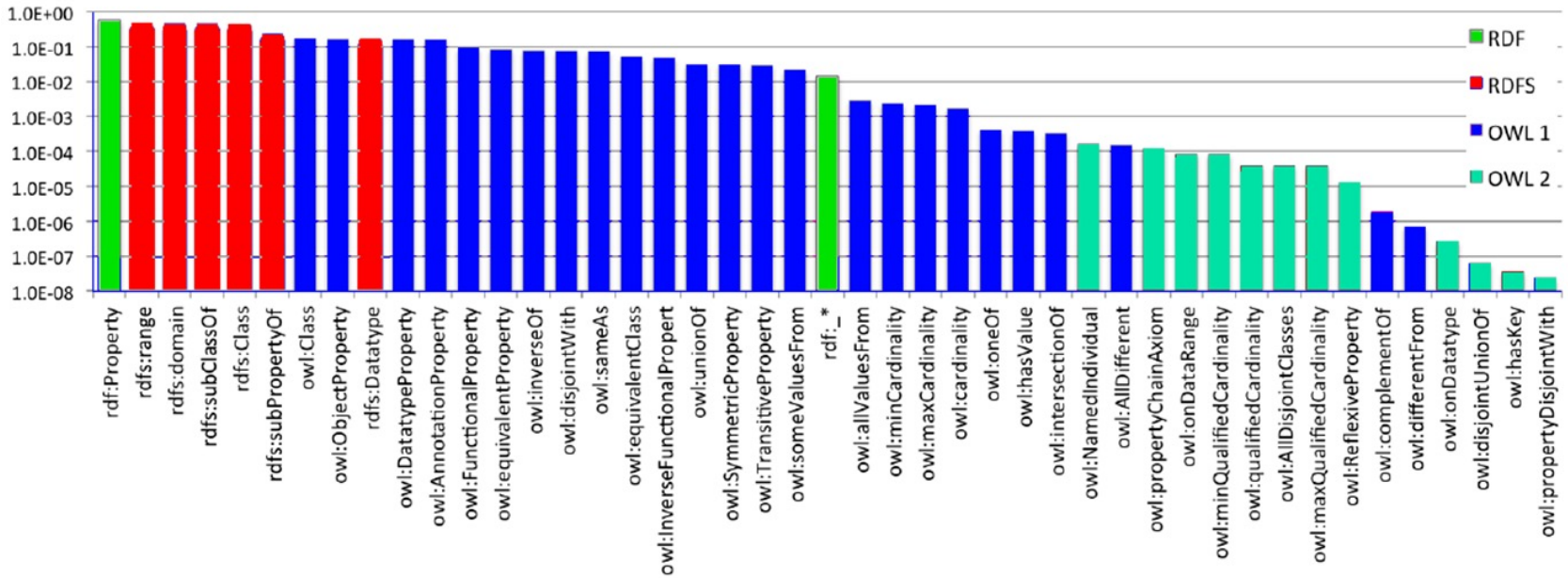
Aidan Hogan
Digital Enterprise Research Institute, National University of Ireland Galway, Ireland

Markus Krötzsch
University of Oxford, Department of Computer Science, OX1 3QD Oxford, United Kingdom

Axel Polleres
Siemens AG Österreich, Siemensstrasse 90, 1210 Vienna, Austria


- Goal: Define a fragement of “really used” OWL based on vocabulary usage
  - RDF Schema features amongst the most prominently used
  - OWL 2 features not used a lot prominently

RDF | RDFS | OWL | OWL 2



# OWL LD (2012)

**OWL: Yet to arrive on the Web of Data?**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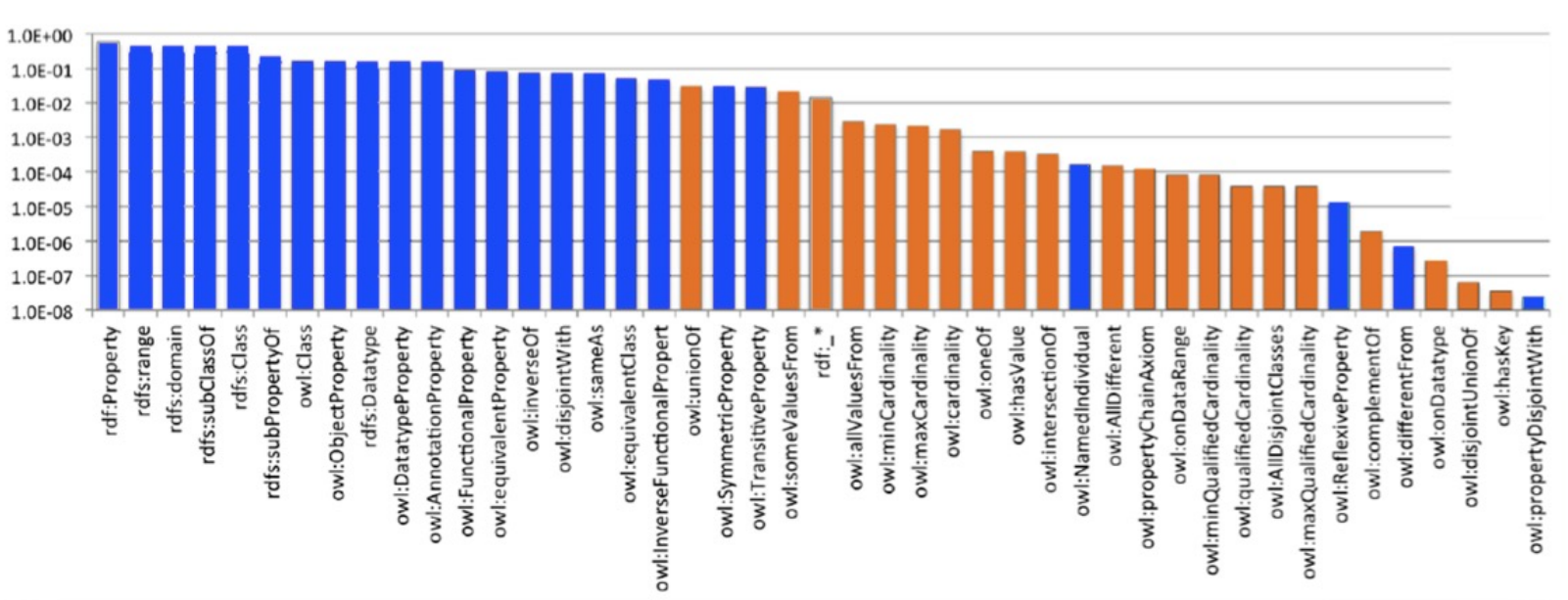
Markus Krötzsch
University of Oxford, Department of Computer Science, OX1 3QD Oxford, United Kingdom

Axel Polleres
Siemens AG Österreich, Siemensstrasse 90, 1210 Vienna, Austria


- Goal: Define a fragement of "really used" OWL based on vocabulary usage
  - RDF Schema features amongst the most prominently used
  - OWL 2 features not used a lot prominently
  - **Mostly single-triple expressible axioms**

**→Essential idea:**
**"Single-triple axiom OWL RL "**



# **RDFS-** (2007)

## Minimal Deductive Systems for RDF

Sergio Muñoz[1], Jorge Pérez[2,3], and Claudio Gutierrez[4]

[1] Universidad Católica de la Santísima Concepción, Chile
[2] Pontificia Universidad Católica de Chile
[3] Universidad de Talca, Chile
[4] Universidad de Chile

- Arguing (well!) that only a minimal subset of the RDFS vocabulary is semantically relevant, obviously, this is a subset of OWL LD

# So, let’s maybe dare a “fresh start” on Ontologies & Shapes?

## Idea:

- Let’s dare to keep it simple and constrain ourselves! ☺

- Start minimal.

# Incremental Proposal, how could it look?

- Start from
  - ***standard-use*** of the
  - ***minimal RDFS*** vocabulary
- And extend this fragments by *features* (from **OWL LD)**:
  - both syntactically and semantically
  - start with UNA, CWA, add (limited) equality reasoning later)

- Goal: build up – gradually –
  - **Useful** and "**Safe**" OWL fragment(s)
  - Canonical means to fall back/repair non-compliant OWL ontologies to meet the required restrictions.

- Hope (hidden goal): these safe fragments are also "compatible" with
  - New standards for constraints and SHAPES (SHACL, ShEx, etc.)
  - Modeling **context**!

# Reasonable starting points 1/3:

## Standard use of the RDF, RDFS, and OWL vocabulary

*Definition 2.3 (Non-Standard-use, extending Definition 5.5 of Hogan [22]).* Let RDF, RDFS, OWL, and XSD, denoted by the prefix URIs http://www.w3.org/1999/02/22-rdf-syntax-ns#, http://www.w3.org/2000/01/rdf-schema#, and http://www.w3.org/2002/07/owl#, respectively, denote the *reserved* namespaces. Let $G_{RDF}$, $G_{RDFS}$, and $G_{OWL}$, respectively, denote the RDF graphs accessible at these URIs, where we write $G_{res} = G_{RDF} \cup G_{RDFS} \cup G_{OWL}$. A *non-standard triple* in any RDF graph other than $G_{res}$ is a triple where:

- a class in $G_{res}$ appears in a position other than as the value of `rdf:type`, or
- a property in $G_{res}$ appears outside of the predicate position.

Further restrictions well conceivable, and expressible in SHAPEs:
e.g.

- Use annotation properties only on URIs that denote an ontology.
- Don't explicitly use classes in G_res

**What Are Links in Linked Open Data? A Characterization and Evaluation of Links between Knowledge Graphs on the Web**

ARMIN HALLER, Australian National University, Australia
JAVIER D. FERNÁNDEZ, Complexity Science Hub Vienna, Austria
MAULIK R. KAMDAR, Stanford University, USA
AXEL POLLERES, Vienna University of Economics and Business, Austria

# Reasonable starting points 1/3:
## Going beyond “Standard use”

- More “tool-supportable” OWL fragments, e.g. enforce (or repair) what makes sense for ontology editors:
  - Keep DatatypeProperties and ObjectProperties separate, i.e. ensure all properties are either DatatypeProperties **xor** ObjectProperties
  - Disallow meta-modelling (or enable canonical ways to disambiguate user-defined URIs used as classes and instances).
  - Disallow “cycles” in taxonomies
  - Disable “URI hijacking”

  …

  ***Open question:***
  ***(How) can we also enforce this by syntactic restrictions on vocabulary usage?***

# Reasonable starting points 2/3:

- Minimal RDFS:
  - Argue – essentially that for RDFS, only the properties
    - `rdfs:subPropertyOf` *[sp]*,
    - `rdfs:subClassOf [sc]`,
    - `rdfs:domain [dom]`,
    - `rdfs:range [range]`
    - `rdf:type [type]`

    are relevant.

**Minimal Deductive Systems for RDF**

Sergio Muñoz[1], Jorge Pérez[2,3], and Claudio Gutierrez[4]

[1] Universidad Católica de la Santísima Concepción, Chile
[2] Pontificia Universidad Católica de Chile
[3] Universidad de Talca, Chile
[4] Universidad de Chile

1. *Simple:*
   (a) $\frac{G}{G'}$ *for a map* $\mu : G' \to G$ (b) $\frac{G}{G'}$ *for* $G' \subseteq G$

---

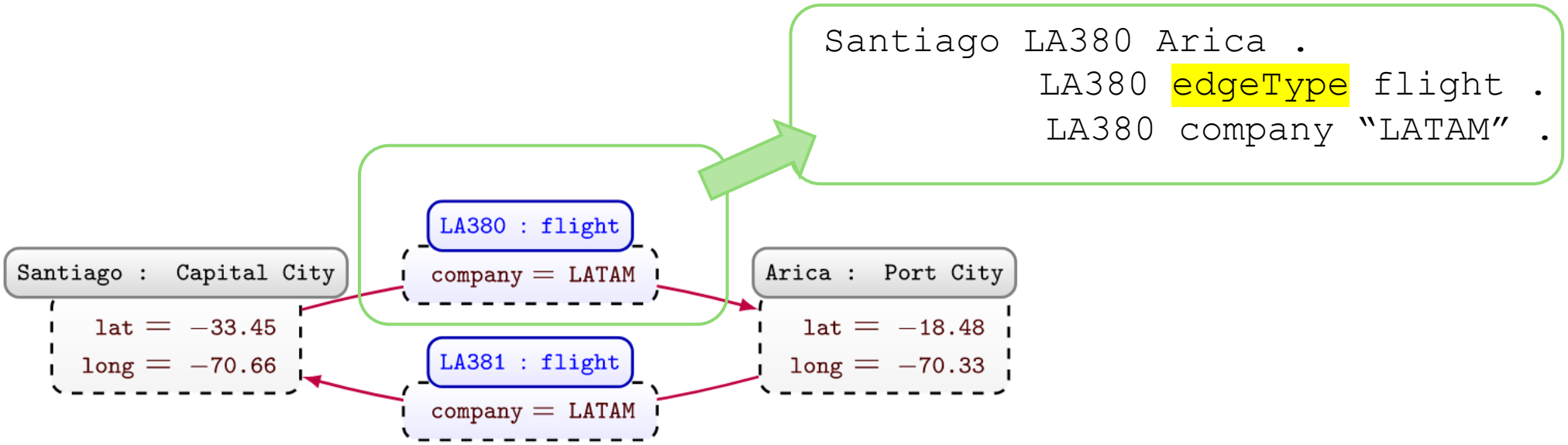
2. *Subproperty:*
   (a) $\frac{(\mathcal{A},\mathtt{sp},\mathcal{B})\ (\mathcal{B},\mathtt{sp},\mathcal{C})}{(\mathcal{A},\mathtt{sp},\mathcal{C})}$ (b) $\frac{(\mathcal{A},\mathtt{sp},\mathcal{B})\ (\mathcal{X},\mathcal{A},\mathcal{Y})}{(\mathcal{X},\mathcal{B},\mathcal{Y})}$
3. *Subclass:*
   (a) $\frac{(\mathcal{A},\mathtt{sc},\mathcal{B})\ (\mathcal{B},\mathtt{sc},\mathcal{C})}{(\mathcal{A},\mathtt{sc},\mathcal{C})}$ (b) $\frac{(\mathcal{A},\mathtt{sc},\mathcal{B})\ (\mathcal{X},\mathtt{type},\mathcal{A})}{(\mathcal{X},\mathtt{type},\mathcal{B})}$
4. *Typing:*
   (a) $\frac{(\mathcal{A},\mathtt{dom},\mathcal{B})\ (\mathcal{X},\mathcal{A},\mathcal{Y})}{(\mathcal{X},\mathtt{type},\mathcal{B})}$ (b) $\frac{(\mathcal{A},\mathtt{range},\mathcal{B})\ (\mathcal{X},\mathcal{A},\mathcal{Y})}{(\mathcal{Y},\mathtt{type},\mathcal{B})}$
5. *Implicit Typing:*
   (a) $\frac{(\mathcal{A},\mathtt{dom},\mathcal{B})\ (\mathcal{C},\mathtt{sp},\mathcal{A})\ (\mathcal{X},\mathcal{C},\mathcal{Y})}{(\mathcal{X},\mathtt{type},\mathcal{B})}$ (b) $\frac{(\mathcal{A},\mathtt{range},\mathcal{B})\ (\mathcal{C},\mathtt{sp},\mathcal{A})\ (\mathcal{X},\mathcal{C},\mathcal{Y})}{(\mathcal{Y},\mathtt{type},\mathcal{B})}$

---

6. *Subproperty Reflexivity:*
   (a) $\frac{(\mathcal{X},\mathcal{A},\mathcal{Y})}{(\mathcal{A},\mathtt{sp},\mathcal{A})}$ (c) $\frac{}{(p,\mathtt{sp},p)}$ *for* $p \in \rho\mathrm{df}$
   (b) $\frac{(\mathcal{A},\mathtt{sp},\mathcal{B})}{(\mathcal{A},\mathtt{sp},\mathcal{A})\ (\mathcal{B},\mathtt{sp},\mathcal{B})}$ (d) $\frac{(\mathcal{A},p,\mathcal{X})}{(\mathcal{A},\mathtt{sp},\mathcal{A})}$ *for* $p \in \{\mathtt{dom},\mathtt{range}\}$
7. *Subclass Reflexivity:*
   (a) $\frac{(\mathcal{A},\mathtt{sc},\mathcal{B})}{(\mathcal{A},\mathtt{sc},\mathcal{A})\ (\mathcal{B},\mathtt{sc},\mathcal{B})}$ (b) $\frac{(\mathcal{X},p,\mathcal{A})}{(\mathcal{A},\mathtt{sc},\mathcal{A})}$ *for* $p \in \{\mathtt{dom},\mathtt{range},\mathtt{type}\}$

# Reasonable Starting points 3/3: Connecting RDF to Property Graphs (PGs)…

- … needs ***Reification***, but reification does not necessarily complicate things!



# Reasonable Starting points 3/3: Connecting RDF to Property Graphs (PGs)…

**Don't Like RDF Reification?**
**Making Statements about Statements Using Singleton Property**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- … needs ***Reification***, but reification does not necessarily complicate things!

e.g. Singleton reification (with reasonable syntactic constraints) can cover PGs…

- i.e., something like:

1. **Drop namespaces (or restrict to 1 namespace)**
2. **edgeType a owl:inverseFunctionalProperty.**
3. **edgeType rdfs:subPropertyOf rdfs:subPropertyOf.**
4. Shape constraint:
   each other property used on a property in the domain of **edgeType**
   is constrained to be **a owl:DatatypeProperty**

# Take-home messages:

| | 1999-2002 | | | 2001-2004 | | | 2012-2014 | | 2022-2024 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Recommendations | | | RDF 1.0 | | | RDF 1.1 | | OWL2 | RDF1.2 | | |
| RDF 1999 | RDFS 2000 | OWL 2002 | RDF 2004 | RDFS 2004 | OWL 2004 | RDF 2014 | RDFS 2014 | OWL 2012 | RDF 2024 | RDFS 2024 | OWL 2024 |

- RDF remains  a great “graph exchange” format…
  - … although it was not created for that!
  - A lot of work and thought have been put into it, over 20+ years, which we should probably not re-invent.
  - some things are more complicated than needed/actually useful.

- The RDF, RDFS and OWL vocabulary allow us to store axioms within the data
  - feature or bug? … **probably** it’s a feature
  - BUT: the reserved vocabulary should (IMHO) not be tempered with → needs syntactic consgtraints (“shapes”)

- Unifying RDF, PGs (and even RDB) under one roof should be nicely possible under an RDF “roof”
  - if we enforce syntactic restrictions to **constrain (reserved) vocabulary usage** by shape constraints.

- Which language for “shape constraints”?
  - Partially, the OWL and RDFS vocabulary can be “read as constraints” itself (OWL IC, OWL Flight approaches)
  - SHACL? SheX?
  - Probably more features needed for things (e.g. acyclicity checks) covered by neither

Let’s dare to take step(s) back and (re-)start simple(r)!