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 😳





TU Wien



Univ. Innsbruck



Univ. Rey Juan Carlos Madrid



NUI Galway Ireland





Siemens AG Wirtschaftsuniversität Wien Österreich (WU)

How are Knowledge Graphs actually doing in 2024?

On the one hand...

Hype Cycle for Artificial Intelligence, 2023



On the other hand...

Impact Radar for Generative AI



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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:



Wetter: 5 °C, Wind aus W mit 35 km/h, 64 % Luftfeuchtigkeit Bevölkerung: 1,868 Millionen (2017) Vereinte Nationen Ortszeit: Dienstag, 23:47

Reise planen

Reiseführer für Wien

Durchschnittspreis 3-Sterne-Hotels: € 69, Durchschnittspreis 5-Sterne-Hotels: € 157

Anstehende Ereignisse



Google	vx 755	>	< Q
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Departs Seatt Tuesday, Jan	le, uary 13		
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Arrives San Fr Tuesday, Jan	rancisco, uary 13		
Scheduled 7:15	PM Ter	minal	Gate
6:49 PM	2		-



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/P0Obm0DBvwl?t=951

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

Denny Vrandečić, WikimediaFoundation, Keynote KGC23



Standards (RDF, SPARQL) adopted by major vendors

"ORACLE supports RDF and SPARQL"

	Rank				S	core	
Mar 2024	Feb 2024	Mar 2023	DBMS	Database Model	Mar 2024	Feb 2024	Mar 2023
1.	1.	1.	Oracle 音	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.	个 8.	Elasticsearch	Search engine, Multi-model 👔	134.79	-0.95	-4.28
8.	8.	4 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.	4 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)



....

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

	Item Discussion
WIKIDATA	Lionel Messi (Q615)
	Argentine association football player (born 1987)
fain page	Lionel Andres Messi I Messi I Lionel Andrés Messi Cuccittini I Lionel Andrés Messi I Leo Messi
Community portal Project chat	✓ In more languages Configure



Extremely rich, collaborative Knowledge Graph, directly integrated in Wikipedia

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

Diff selection:

egend: (cur) (latest | earlies

View logs for this item (view abuse log)

Revision history of "Lionel Messi" (Q615)

✓ Filter rev	visions
iff selection: Ma	rk the radio buttons of the revisions to compare and hit enter or the button at the bottom.
egend: (cur) = c	difference with latest revision, (prev) = difference with preceding revision, m = minor edit.
atest I earliest) V	View (newer 50 older 50) (20 50 100 250 500)
Compare selec	cted revisions
(cur I prev)	08:21, 21 February 2024 Poig97 (talk I contribs) (523,166 bytes) (+111) (Added link to [fawikiquol

(Tag: Wikidata User Interface)
ports team (P54): Inter Miami CF (Q16844931), bot (details))
ports team (P54): Argentina national association football team (Q79800), bot (deta
ports team (P54): Paris Saint-Germain F.C. (Q483020), bot (details))
ports team (P54): FC Barcelona (Q7156), bot (details))

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

- 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.

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

• RDFS "Vocabulary Graph" :

rdfs:Property rdf:type rdfs:Class



<u>http://web.archive.org/web/19990508090931id /http://www.w3.org/1999/02/22-rdf-syntax-ns</u>

1999

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

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)

More NOTE-rdf-umi-19980804 A Discussion of the Relationship Between RDF-Schema and UML W3C Note 04-Aug-1998 Level This document: <u>http://www.w3.org/TR/1998/NOTE-rdf-umi-19980804</u> Author: Walter W. Chang, Advanced Technology Group, Adobe Systems Status of This Document This document is a <u>NOTE</u> made available by W3C for discussion only. This indicates no endorsement of its content, nor that W3C has had any editorial control in its preparation, nor that W3C has, is, or will be allocating any resources to the issues addressed by the NOTE. Comments may be sent to <u>www-rdf-comments@w3.org</u>. All mail is <u>archived</u> and available for review.

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: <u>www.w3.org/2002/07/owl</u>

• <u>http://web.archive.org/web/20020815073440id_/www.w3.org/2002/07/owl</u>

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
- <u>https://web.archive.org/web/20040204230820id_/http://www.w3.org/2000/01/rdf-schema</u>

2004: OWL1

• 10 February 2004: First official Recommendation of OWL

• <u>http://web.archive.org/web/20040405111643id_/http://www.w3.org/2002/07/owl</u>

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!
 - <u>http://web.archive.org/web/20121221014933id /http://www.w3.org/2002/07/owl</u>

2014: RDF1.1 + RDF Schema 1.1

- 25 February 2014
- <u>https://www.w3.org/TR/rdf11-concepts/</u>
- <u>https://www.w3.org/TR/rdf11-schema/</u>
- What's new?
 - <u>https://www.w3.org/TR/rdf11-new/</u>
 - 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 !

- <u>https://www.w3.org/TR/rdf12-schema/</u>
- What's new?
 - Quoted triples
 - rdf:dirLangString
 - rdf:JSON
 - rdf:HTML and rdf:XMLLiteral now normative

Too Working Bran 21 bandary 20



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 Gregg Kellogg 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	RD	F1.2
RDF 1999 RDFS 2000 OWL 2002	RDF 2004 RDFS 2004 OWL 2004	RDF 2014 RDFS 2014 OWL 20	012 RDF 2024 R	DFS 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?

			1999-2002					
		First Recommendations						
	Term	RDF 19	RDFS 20 🔻	OWL 20 -				
	rdf:object	TRUE	TRUE					
	rdf:predicate	TRUE	TRUE					
	rdf:subject	TRUE	TRUE	FALSE				
ŝ	rdf:type	TRUE	TRUE	TRUE				
Ę	rdf:value	TRUE	TRUE	TRUE				
	rdfs:comment		TRUE	TRUE				
ă	rdfs:domain		TRUE	TRUE				
Prol	rdfs:label		TRUE	TRUE				
	rdfs:range		TRUE	TRUE				
	rdfs:seeAlso		TRUE	TRUE				
	rdfs:subClassOf		TRUE	TRUE				
	rdfs:subPropertyOf		TRUE	TRUE				
S	rdf:Alt	TRUE	TRUE	FALSE				
ē	rdf:Bag	TRUE	TRUE	FALSE				
SS	rdf:Property	TRUE	TRUE	TRUE				
9 9	rdf:Seq	TRUE	TRUE	FALSE				
D	rdf:Statement	TRUE	TRUE	FALSE				
U	rdfs:Class		TRUE	TRUE				

Let's put these on a Tim

	1999-2002			2001-2004			2012-	
First F	Recommend	lations		RDF 1.0		RD	F 1.1	Ż
RDF 1999	RDFS 2000	OWL 2002	RDF 2004	RDFS 2004	OWL 2004	RDF 2014	RDFS	

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		1999-2002 2001-2004			2012-2014			2022-2024					
		First	Recommend	ations		RDF 1.0	-	RD	F1.1	OWL2		RDF1.2	
	Term	RDF19 🔻	RDFS 20 🔻	OWL 20	RDF20 🔻	RDFS 20 🔻	OWL 20	RDF20 🔻	RDFS 20	OWL20	RDF2024	* RDFS 202 *	OWL2024
	rdf:first			TRUE	TRUE		TRUE	TRUE		TRUE	TRUE		
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	r d f:su b ject	TRUE	TRUE	FALSE	TRUE			TRUE			TRUE		
	rdf:type	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfxalue	TRUE	TRUE	TRUE	TRUE			TRUE			TRUE		
	r d fs:co mmen t		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	r d fs:d o main		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	r d fs:isDefin ed By			TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
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5	rdts:subPropertyOf		TRUE	TRUE		TRUE	TRUE			20112		TRUE	70115
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	rdfBar	TRUE	TRUE	FAISE	TRUE	FAISE	FAISE	TRUE	FAISE	FAISE	TRUE		
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	rdfProperty	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfSen	TRUE	TRUE	FAISE	TRUE	FAISE	FAISE	TRUE	FAISE	FAISE	TRUE	mor	mor
	rdfStatement	TRUE	TRUE	FAISE	TRUE	FAISE	FAISE	TRUE	FALSE	FAISE	TRUE		
	rdfs:Class	mor	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:Container		mor	mor	TRUE	TRUE		TRUE	TRUE		TRUE	TRUE	
	rd fs:Container Membership Property					TRUE			TRUE			TRUE	
	rd fs:Datatype				TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	rd fs:Literal			TRUE	TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
S	rdfs:Resource				TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
š	owl:AllDifferent						TRUE			TRUE			TRUE
as	o wl:Class			TRUE			TRUE			TRUE			TRUE
Ö	o wl:DataRan ge						TRUE			TRUE			TRUE
-	owl:DatatypeProperty			TRUE			TRUE			TRUE			TRUE
	o wl:Dep r ecated Class						TRUE			TRUE			TRUE
	owl:Deprecated Property						TRUE			TRUE			TRUE
	owl:FunctionalProperty			TRUE			TRUE			TRUE			TRUE
	owl:InverseFunctionalProperty			TRUE			TRUE			TRUE			TRUE
	owl:ObjectProperty			TRUE			TRUE			TRUE			TRUE
	o wi:On to lo gy			TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
	owl:On to logyProperty						TRUE			TRUE			TRUE
	o wl:Restrictio n			TRUE			TRUE			TRUE			TRUE
	owl:SymmetricProperty			TRUE			TRUE			TRUE			TRUE
	owl:TransitiveProperty			TRUE			TRUE			TRUE			TRUE
	rd fXMLLiteral				TRUE			TRUE			TRUE		
0 7 0	owl:Nothing			TRUE			TRUE			TRUE			TRUE
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ie ie	o wi:in compatibleWith						TRUE			TRUE			TRUE
s	owl:priorVersion						TRUE			TRUE			TRUE
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	r d fin il			TRUE	TRUE		TRUE	TRUE		TRUE	TRUE		TRUE

Let's put these on a Timeline

	1999-2002			2001-2004			2012-2014		:
First F	Recommenc	lations		RDF 1.0		RD	OWL2	1	
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...
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~2014 ... and RDF1.2 adding a couple more as we speak ;-)

	rdf:first				TRUE	TRU	E		TRUE	TRUE		TRUE
	rdf:object		TRUE	TRUE						TRUE		
	rdf:predicate		TRUE	TRUE		TRU	E			TRUE		
	rdf:rest				TRUE	TRU	E		TRUE	TRUE		
	rdf:subject		TRUE	TRUE	FALSE	TRU	E			TRUE		
	rdf:type		TRUE	TRUE	TRUE	TRU	E	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:comment		TRUE	TRUE	TRUE	TRU	C	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:comment			TRUE	TRUE	TRU	E E	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:isDefinedBy			THUE	TRUE	TRU	E	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:label			TRUE	TRUE	TRU	F	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:member		-	THOL	THOL	1110		TRUE	more	11102	TRUE	THOL
	rdfs:range			TRUE	TRUE	TBU	E	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:seeAlso			TRUE	TRUE	TRU	E	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:subClassOf			TRUE	TRUE	TRU	E	TRUE	TRUE	TRUE	TRUE	TRUE
	rdfs:subPropertyOf			TRUE	TRUE			TRUE	TRUE			
	owcallValuesFrom				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:datatypeComplementO	f										TRUE
S	owl:differentFrom											TRUE
ë	owl: disjointUnionOf				TRUE	_			FALSE			TRUE
E	owcalsjointWith				TRUE				TRUE			TRUE
e	owcastinctmembers								TOUE			TRUE
р	owcequivalentClass								TRUE			TPUE
ž	ow/cequivalentProperty								TRUE			TRUE
-	owl:hasSelf											TRUE
	owthasValue				TRUE				TRUE			TRUE
	owtintersectionOf				TRUE				TRUE			TRUE
	owt inverseOf				TRUE				TRUE			TRUE
	owt:maxCardinality				TRUE				TRUE			TRUE
	owtmaxQualifiedCardinality											TRUE
	owtmembers											TRUE
	owl: minCardinality				TRUE				TRUE			TRUE
	owtminQualifiedCardinality											TRUE
	owtonClass											TRUE
	owl:onDataRange											TRUE
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	owt onProperty				TRUE				TRUE			TRUE
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	owcpropertyChainAxiom											TRUE
	owl:propertyDisjointWith											TRUE
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	owt:sameAs owt:someValuesFrom owt:sourceIndividual				TRUE				TRUE			TRUE TRUE TRUE TRUE
	owt:sameAs owt:someValuesFrom owt:sourceIndividual owt:targetIndividual owt:targetValue				TRUE				TRUE			TRUE TRUE TRUE TRUE TRUE TRUE
	owt:sameAs owt:someValuesFrom owt:sourceIndividual owt:targetIndividual owt:targetIvalue owt:unionOf				TRUE				TRUE			TRUE TRUE TRUE TRUE TRUE TRUE TRUE
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	owt:sameAs owt:someValuesFrom owt:sourceIndividual owt:targetHolidual owt:targetHolidual owt:uninOf owt:withRestrictions rdf:All rdf:Bag rdf:List rdf:Property		TRUE TRUE TRUE	TRUE TRUE TRUE	TRUE TRUE FALSE FALSE TRUE TRUE	TRU TRU TRU TRU	E E E	FALSE FALSE FALSE TRUE	TRUE TRUE FALSE FALSE TRUE TRUE	TRUE TRUE TRUE TRUE TRUE	FALSE FALSE FALSE TRUE	TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE
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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 🔻	
	rdf:object	TRUE	TRUE		
	rdf:predicate	TRUE	TRUE		
<i>(</i> ^	rdf:subject	TRUE	TRUE	FALSE	
d)	rdf:type	TRUE	TRUE	TRUE	
Ę	rdf:value	TRUE	TRUE	TRUE	
С С	rdfs:comment		TRUE	TRUE	
ă	rdfs:domain		TRUE	TRUE	
0	rdfs:label		TRUE	TRUE	
5	rdfs:range		TRUE	TRUE	
	rdfs:seeAlso		TRUE	TRUE	
	rdfs:subClassOf		TRUE	TRUE	
	rdfs:subPropertyOf		TRUE	TRUE	
S	rdf:Alt	TRUE	TRUE	FALSE	
Ğ	rdf:Bag	TRUE	TRUE	FALSE	
SS	rdf:Property	TRUE	TRUE	TRUE	
ä	rdf:Seq	TRUE	TRUE	FALSE	
- E	rdf:Statement	TRUE	TRUE	FALSE	
0	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":
 - <u>https://www.w3.org/2007/OWL/wiki/Fragments</u>

OWL "ter Horst" (2005)



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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

Jos de Bruijn Digital Enterprise Research Institute (DERI) University of Innsbruck, Austria jos.debruijn@deri.org

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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 Tao¹, Evren Sirin², Jie Bao¹, Deborah L. McGuinness¹

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?

Axel Polleres Birte Glimm Aidan Hogan Markus Krötzsch Ulm University, Institute of Siemens AG Österreich. **Digital Enterprise** University of Oxford, Siemensstrasse 90, 1210 Research Institute, Department of Computer Artificial Intelligence, 89069 Ulm, Germany National University of Science, OX1 3QD Vienna, Austria Ireland Galway, Ireland Oxford, United Kingdom

RDF | RDFS | OWL | OWL 2

- 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



OWL LD (2012)

Mostly single-triple

 \rightarrow Essential idea:

expressible axioms

OWL: Yet to arrive on the Web of Data?

Axel Polleres Birte Glimm Aidan Hogan Markus Krötzsch Siemens AG Österreich. Ulm University, Institute of **Digital Enterprise** University of Oxford, Research Institute, Department of Computer Siemensstrasse 90, 1210 Artificial Intelligence, 89069 Ulm, Germany National University of Science, OX1 3QD Vienna, Austria Ireland Galway, Ireland Oxford, United Kingdom

- 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



RDFS- (2007)

Minimal Deductive Systems for RDF

Sergio Muñoz¹, Jorge Pérez^{2,3}, and Claudio Gutierrez⁴

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 Muñoz¹, Jorge Pérez^{2,3}, and Claudio Gutierrez⁴

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)	$(\mathcal{A}, \mathtt{sp}, \mathcal{B})$ $(\mathcal{B}, \mathtt{sp}, \mathcal{C})$	(h)	$(\mathcal{A}, \mathtt{sp}, \mathcal{B})$ $(\mathcal{X}, \mathcal{A}, \mathcal{Y})$
(u)	$(\mathcal{A}, \mathtt{sp}, \mathcal{C})$	(0)	$(\mathcal{X},\mathcal{B},\mathcal{Y})$

3. Subclass:

$$(a) \ \frac{(\mathcal{A}, \mathtt{sc}, \mathcal{B}) \ (\mathcal{B}, \mathtt{sc}, \mathcal{C})}{(\mathcal{A}, \mathtt{sc}, \mathcal{C})} \qquad \qquad (b) \ \frac{(\mathcal{A}, \mathtt{sc}, \mathcal{B}) \ (\mathcal{X}, \mathtt{type}, \mathcal{A})}{(\mathcal{X}, \mathtt{type}, \mathcal{B})}$$

4. Typing:

$$(a) \quad \frac{(\mathcal{A}, \mathtt{dom}, \mathcal{B}) \quad (\mathcal{X}, \mathcal{A}, \mathcal{Y})}{(\mathcal{X}, \mathtt{type}, \mathcal{B})} \qquad \qquad (b) \quad \frac{(\mathcal{A}, \mathtt{range}, \mathcal{B}) \quad (\mathcal{X}, \mathcal{A}, \mathcal{Y})}{(\mathcal{Y}, \mathtt{type}, \mathcal{B})}$$

- 5. Implicit Typing:
 - $(a) \quad \frac{(\mathcal{A}, \mathtt{dom}, \mathcal{B}) \quad (\mathcal{C}, \mathtt{sp}, \mathcal{A}) \quad (\mathcal{X}, \mathcal{C}, \mathcal{Y})}{(\mathcal{X}, \mathtt{type}, \mathcal{B})} \qquad \qquad (b) \quad \frac{(\mathcal{A}, \mathtt{range}, \mathcal{B}) \quad (\mathcal{C}, \mathtt{sp}, \mathcal{A}) \quad (\mathcal{X}, \mathcal{C}, \mathcal{Y})}{(\mathcal{Y}, \mathtt{type}, \mathcal{B})}$

(d)

6. Subproperty Reflexivity:

$$\begin{array}{l} (a) \quad \frac{(\mathcal{X}, \mathcal{A}, \mathcal{Y})}{(\mathcal{A}, \mathrm{sp}, \mathcal{A})} \\ (b) \quad \frac{(\mathcal{A}, \mathrm{sp}, \mathcal{B})}{(\mathcal{A}, \mathrm{sp}, \mathcal{A}) \quad (\mathcal{B}, \mathrm{sp}, \mathcal{B})} \end{array}$$

7. Subclass Reflexivity:

(a)

$$rac{(\mathcal{A},\mathtt{sc},\mathcal{B})}{(\mathcal{A},\mathtt{sc},\mathcal{A}) \ \ (\mathcal{B},\mathtt{sc},\mathcal{B})}$$

$$rac{(\mathcal{A}, p, \mathcal{P})}{(\mathcal{A}, \mathrm{sp}, \mathcal{A})} \quad \textit{for } p \in \{\texttt{dom}, \texttt{range}\}$$

(c) $\frac{1}{(p,p,p)}$ for $p \in \rho df$

 $) \ rac{(\mathcal{X}, p, \mathcal{A})}{(\mathcal{A}, \mathtt{sc}, \mathcal{A})} \quad \textit{for} \ p \in \{\mathtt{dom}, \mathtt{range}, \mathtt{type}\}$

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	R	DF1.2
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)!