

Unit 1 – The Semantic Web - Lecture Overview and a “Bird’s Eye” View on RDF(S), OWL & SPARQL

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VU 184.729 Semantic Web Technologies

Unit Outline

1. Motivation – Aggregating Web Data
2. How can I publish data? RDF
3. How can I query that data? SPARQL
4. What does that data mean? Ontologies described in RDFS + OWL
5. What's next?

Prerequisites

- Some basic knowledge about first-order logics.
- Some basic knowledge about databases (SQL).
- Some basic knowledge about HTML.
- Some basic knowledge about XML would be nice.
- Who knows RDF, OWL, SPARQL already?
- Who knows Description Logics?
- Who knows Logic Programming (Datalog, Prolog, Answer Set Programming)?
- Who knows XQuery, RIF, FOAF, SIOC?

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- Who are the right reviewers?

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Questions:

- Where do I get the right data?
- What is the format & structure (schema) of this data?
- Which rules and query languages do I use to aggregate this data?
- Which systems are out there to support me?

Where is the data? 1/4

The image shows three overlapping browser windows. The top-left window displays a university website for 'TU/e' (Technische Universiteit Eindhoven) with a 'KBS' logo and navigation links for 'staff', 'education', 'research', and 'contact services'. The top-right window shows a faculty profile for 'D.B. Biers' at the University of Groningen, listing his position as Assistant Professor and contact information. The bottom window shows a Wikipedia page for 'Thomas Krennwallner', including a search bar, a 'FrontPage' button, and a profile picture.



Where is the data? 1/4

Prof. Dr. Thomas Eiter
Professor of Knowledge-Based Systems Group
Head of the Institute of Information Systems 11

Thomas Krennwallner's Wiki FrontPage
Thomas Krennwallner
Please do not edit this page without discussion on the talk page.

Publications
See MyCofix for an incomplete list of my configuration files.

Year	Publication
2008	Magdalena Ortiz, Martin Strohmann, Thomas Eiter: Worst-case Optimal Conjunctive Query Learning for an Expressive Description Logic without Inverse Roles. <i>AAAI</i> 2008, 964-970.
2008	Thomas Eiter, Michael Fink, Jiri Senkaj: Error Classification in Action Description: A Heuristic Approach. <i>AAAI</i> 2008, 400-410.
2008	Magdalena Ortiz, Martin Strohmann, Thomas Eiter: Conjunctive Query Answering in SH using Reason. <i>Description Logics</i> 2008.
2008	Thomas Eiter, Michael Fink, Gáborino Corso, Christian Lechner: Hybrid Involutions for query answering from inconsistent databases. <i>ACM Trans. Database Syst.</i> 33(2) (2008).
2008	Alexander Rottler, Uwe Fahl, Thomas Eiter, Herbert Rüchger: A knowledge-based independence reasoning system for object representation reasoning. <i>Advances in Engineering Software</i> 29(10): 821-827 (2008).
2008	Li Liu, Boris Voinea, Eiter, Mircea Ispănuș, Mariana Stoican: Maintenance goals of agents in a dynamic environment: Formulation and policy construction. <i>Artif. Intell.</i> 172(11-13): 1426-1449 (2008).
2008	Thomas Eiter, Chaitanya Sanyal, Thomas Lukasiewicz, Roman Schindlauer, Hans Tomerlin: Combining answer set programming with description logics for the Semantic Web. <i>Artif. Intell.</i> 172(11-13): 1485-1504 (2008).
2008	Thomas Eiter, Roman Wang: Semantic forgetting in answer set programming. <i>Artif. Intell.</i> 172(11-13): 1444-1472 (2008).
2008	Thomas Eiter, Enea Zaneni, Wolfgang Edel: Unleashing the effects of active sequences. <i>J. Applied Logic</i> 9(1): 98-113 (2008).

Thomas Eiter is the author of
NLogopic: A Logical Framework for the World Wide Web

Thomas Eiter, Peter Cimatti, Christian Bessière, Hans Tomerlin, Wolfgang Edel, Roman Wang, Enea Zaneni, and Enea Zavanato

Abstract
The answer set programming (ASP) paradigm has become a powerful tool for solving a wide range of problems in artificial intelligence. In this paper, we present NLogopic, a logical framework for the World Wide Web. NLogopic is a declarative language for specifying and solving problems in the domain of the Semantic Web. It is based on the ASP paradigm and provides a rich set of constructs for modeling and solving complex problems. NLogopic is designed to be a logical framework for the Semantic Web, and it is intended to be used as a tool for solving problems in this domain.

1. Introduction

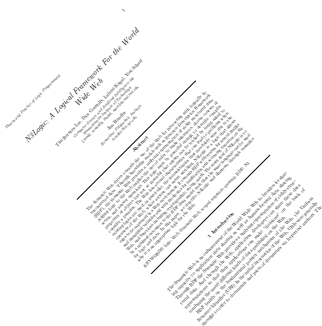
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Where is the data? 1/4



- A lot of Web data already available “out there”
- it's linked

Where is the data? 1/4



- A lot of Web data already available “out there”
- it’s linked
- More and more of it available in in a machine-readable format (RDF) following the *Linked Data* principles

Where is the data? 2/4

Obtaining Machine-Readable RDF data

(i) RDF directly by the publishers, (ii) as RDFa by content management systems, or (iii) by 3rd-party wrappers:

Where is the data? 2/4

Obtaining Machine-Readable RDF data

(i) **RDF directly by the publishers**, (ii) as RDFa by content management systems, or (iii) by 3rd-party wrappers:

FOAF/RDF linked from a home page: personal data (foaf:name, foaf:phone, etc.), relationships foaf:knows, rdfs:seeAlso)

The image shows two browser windows side-by-side. The left window displays the home page of G.B. Ianni, with a red circle around the 'My FOAF card' link. The right window shows the source code of the FOAF document, with a red arrow pointing from the link in the left window to the corresponding RDF code in the right window.

Different Options:

e.g. linking RDF/XML [Beckett and McBride (eds.), 2004] from (X)HTML,

Let's check, e.g. <http://www.w3.org/People/Berners-Lee/>,

<http://www.cs.rpi.edu/~hendler/>

Where is the data? 3/4

Obtaining Machine-Readable RDF data

(i) directly by the publishers, (ii) as RDFa by content management systems, or (iii) by 3rd-party wrappers:

Some sites provide RDF in terms of microformats, or RDFa (=RDF embedded in HTML), e.g. on <http://bestbuy.com>

- ... try using W3C's RDFa Distiller: <http://www.w3.org/2007/08/pyRdfa/>
- This RDFa is often generated directly by the underlying CMS (e.g. Drupal provides modules for RDFa)

Where is the data? 4/4

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Obtaining Machine-Readable RDF data

(i) directly by the publishers, (ii) as RDFa by content management systems,, or (iii) by 3rd-party wrappers:

L3S' RDF export of the DBLP citation index, see <http://dblp.l3s.de/d2r/>

The left screenshot shows a browser window with the URL <http://www.informatik.uni-trier.de/~ley/db/lin/>. The page title is "DBLP: Thomas Eiter" and it displays a list of publications from the DBLP Bibliography Server. The right screenshot shows the same author's page in RDF format, with the URL http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter/. The page title is "Thomas Eiter" and it displays a table of RDF triples for the author.

Left Screenshot (Human-readable):

DBLP: Thomas Eiter
<http://www.informatik.uni-trier.de/~ley/db/lin/>
 Universität Trier
Thomas Eiter
 List of publications from the DBLP Bibliography Server - FAQ
 Counter Index - Ask others: ACM DLGuide - CiteSeer - CSB - Google - MSN - Yahoo
 Home Page

2008	
231	Magdalena Ortiz, Mantas Simkas, Thomas Eiter: Worst-case Optimal Conjunctive Query Answering for an Expressive Description Logic without Inverses. AAAI 2008: 504-510
230	Thomas Eiter, Michael Fink, Jin Senko: Error Classification in Action Descriptions: A Heuristic Approach. AAAI 2008: 905-910
229	Magdalena Ortiz, Mantas Simkas, Thomas Eiter: Conjunctive Query Answering in SH using Knos. Description Logics 2008
228	Thomas Eiter, Michael Fink, Gianluigi Greco, Domenico Lembo: Repair localisation for query answering from inconsistent databases. ACM Trans. Database

Right Screenshot (RDF export):

Thomas Eiter | D2R Server publishing the ... Database, hosted at L3S Research Center
 Resource URI: http://dblp.l3s.de/d2r/resource/authors/Thomas_Eiter
 Home | Example Authors

Property	Value
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/books/it/Subramanian000>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/BarsiE205>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/BrewkaE07>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/DelvauxE067>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EgyptE200>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterFS08>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterPTW05>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterM08>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterM02>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterW06>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/OrtizCE06>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/OrtizE08>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/ijcgt/EiterMPS97>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/ijcgt/EiterLS96>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/ijcgt/EiterP03>
foaf:creator	<http://dblp.l3s.de/d2r/resource/publications/conf/ijcgt/BarsiE04>

Where is the data? 4/4

Obtaining Machine-Readable RDF data

(i) directly by the publishers, (ii) as RDFa by content management systems,, or (iii) by 3rd-party wrappers:

L3S' RDF export of the DBLP citation index, see <http://dblp.l3s.de/d2r/>

The left screenshot shows the DBLP website for Thomas Eiter, with a red arrow pointing to the right screenshot. The right screenshot shows the RDF export page for Thomas Eiter, displaying a table of RDF triples.

Property	Value
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/books/it/Substanzmar000>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/BasilEZ05>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/BasilEZ07>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/CdmanaveE07>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EgyET08>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterFS00>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterFT05>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterFM06>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterMS03>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterW06>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/OrtaCE06>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/OrtaSE07>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterMS07>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/EiterP03>
is:dc:creator of	<http://dblp.l3s.de/id/resource/publications/conf/aaai/BasilE04>

- Gives unique URIs to authors, documents, etc. on DBLP! E.g., http://dblp.l3s.de/d2r/resource/authors/Thomas_Eiter, http://dblp.l3s.de/d2r/resource/authors/Tim_Berners-Lee, <http://dblp.l3s.de/d2r/resource/publications/journals/tlp/Berners-LeeCKSH08>, etc.
- Provides RDF version of all DBLP data + query interface!
- Other nice example: RDF+query interface for large parts of wikipedia: <http://dbpedia.org/>

How can I query that data? SPARQL

SPARQL – W3C approved standardized query language for RDF:

- look-and-feel of “SQL for the Web”
- allows to ask queries like
- *“All documents created by Thomas Eiter”*
- *“Names of all persons who co-authored with authors of the present paper”*
- *“Names of persons who know Tim Berners-Lee or who are known by Tim Berners-Lee”*
- *“All people who have published in TPLP but have not co-authored with any of the authors of the present paper”*

Example ([query1.sparql](#)):

```
SELECT ?D
FROM <http://dblp.13s.de/d2r/data/authors/Thomas_Eiter>
WHERE {?D dc:creator <http://dblp.13s.de/d2r/resource/authors/Thomas_Eiter>}
```

What does the data mean?

Data, i.e. the used *vocabulary* to write down RDF is described by *ontologies*, themselves published in RDF, e.g.:

- Friend-of-a-Friend (FOAF) [Brickley and Miller, 2007]
- Socially-Interlinked-Online-Communities (SIOC) [Bojārs *et al.*, 2007]
- Dublin Core [Nilsson *et al.*, 2008]

FOAF Vocabulary Specification 0.91
 Namespace Document 2 November 2007 - OpenID Edition
 FOAF at a glance
 An a-z index of FOAF terms, by class (categories or types) and by property.

Classes: | Agent | Document | Group | Image | OnlineAccount | OnlineChatAccount | OnlineCommerceAccount | OnlineGamingAccount | Organization | Person | PersonalProfileDocument | Project |

Properties: | accountName | accountService | homepage | aimChatID | based_near | birthday | currentProject | depiction | decimals | dnaChecksum | family_name | firstName | fundedBy | geekcode | gender | givenname | holdsAccount | homepage | ircChatID | img | interest | isPrimaryTopicOf | jabberID | knows | logo | made | maker | mbox | max_sharesum | member | membershipClass | nrsChatID | myersBriggs | name | nick | openid | page | pastProject | phone | plan | primaryTopic | publications | schoolHomepage | sha1 | surname | theme | thumbnail | tipjar | title | topic | topic_interest | weblog | workInfoHomepage | workplaceHomepage | yahooChatID |

SIOC Core Ontology Specification
 Member Submission
 SIOC Core Ontology Specification
 3. SIOC overview
 The SIOC Core Ontology definitions presented here are written using a computer language (RDF/OWL) that makes it easy for software to process some basic facts about the terms in the SIOC Core Ontology, and consequently about the things described in SIOC documents. A SIOC document, unlike a traditional Web page, can be combined with other SIOC and RDF documents to create a unified database of information.

```

graph TD
    Usergroup -- has_creator --> Post
    Usergroup -- has_member --> User
    Usergroup -- has_member --> Role
    Usergroup -- has_creator --> Forum
    Usergroup -- has_creator --> Site
    User -- has_function --> Role
    Role -- has_scope --> Site
    Site -- has_host --> Forum
    Site -- has_parent --> Space
    Forum -- has_creator --> Post
    Forum -- has_container --> Post
    Forum -- has_container --> Container
    Post -- has_reply --> Post
    Post -- subClassOf --> Item
    Post -- subClassOf --> Container
    Item -- has_container --> Container
    Container -- has_splice --> Space
  
```

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- RDF is describing *resources* per triples/statements
Subject Predicate Object.

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axel isA Person .

axel hasName “Axel Polleres”.

axel knows gb .

axel knows thomas.

thomas hasCreated an Article

titled “Rules and Ontologies for the Semantic Web”.

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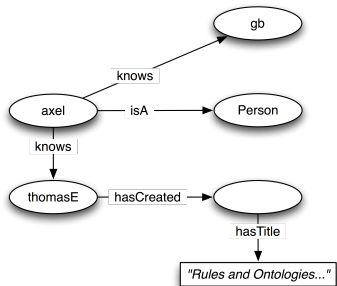
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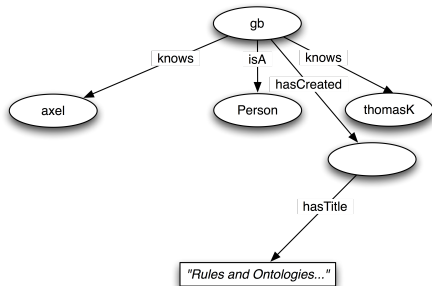
X hasTitle “Rules and Ontologies for the Semantic Web”.

- abstracts away from tables (RDBMS) or tree-like (XML) schemas
- triples can be viewed as edges of a labeled, directed graph.
- main advantage: Graphs are easy to merge! (Trees, Tables aren't)

axel isA Person .
 axel knows gb .
 axel knows thomasE.
 thomasE hasCreated X . X isA Article .
 X hasTitle "Rules and Ontologies..." .



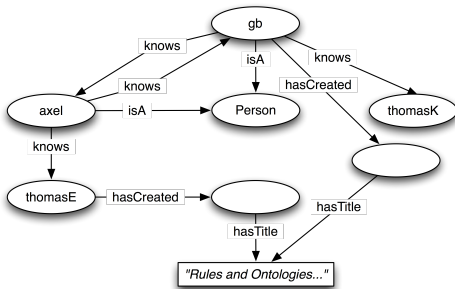
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Observe: the "existential variables" became "blank" nodes in the Graph.

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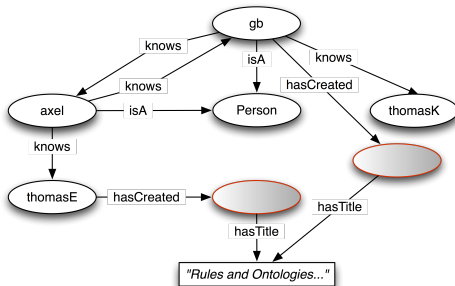
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Observe: the "existential variables" became "blank" nodes in the Graph. **Note that we have no reason to assume that the two blank nodes are the same.**

A Syntax for RDF: Turtle

There are different syntaxes for RDF

- RDF/XML [Beckett and McBride (eds.), 2004]
- Turtle [Beckett and Berners-Lee, 2008], N3 [Berners-Lee and Connolly, 2008]
- RDFa [Adida *et al.*, 2008] (i.e., RDF “embedded” in (X)HTML)
- RDF in JSON

We'll use Turtle syntax in this lecture:

- it is a subset of Notation 3 [Berners-Lee and Connolly, 2008]
- sufficient to write all RDF
- almost human-readable
- also the basis for SPARQL
- upcoming W3C standard
- tools and APIs to convert from one syntax into the other, such as `raper` (part of the Redland API, cf. <http://librdf.org/>), e.g.

```
raper http://polleres.net/teaching/SemWebTech_2012/testdata/foaf.ttl -i turtle -o rdfxml
```

Resources in RDF, Turtle Syntax

- Resources are identified by URIs (to encourage web-wide unique identifiers)
- There are special URIs, defined in vocabularies (FOAF, SIOC, RDF, etc.)
- Objects can be literals,

axel isA Person .

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```
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```

becomes:

```
<http://polleres.net/foaf.rdf#me> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>  
    <http://xmlns.com/foaf/0.1/Person>.  
<http://polleres.net/foaf.rdf#me> <http://xmlns.com/foaf/0.1/name>  
    "Axel Polleres".
```

Resources in RDF, Turtle Syntax

- Resources are identified by URIs (to encourage web-wide unique identifiers)
- There are special URIs, defined in vocabularies (FOAF, SIOC, RDF, etc.)
- Objects can be literals, **occasionally with a datatype**

axel isA Person .

axel hasName "Axel Polleres".

becomes:

```
<http://polleres.net/foaf.rdf#me> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
    <http://xmlns.com/foaf/0.1/Person>.
<http://polleres.net/foaf.rdf#me> <http://xmlns.com/foaf/0.1/name>
    "Axel Polleres"^^<http://www.w3.org/2001/XMLSchema#string>.
```

Resources in RDF, Turtle Syntax

- Resources are identified by URIs (to encourage web-wide unique identifiers)
- There are special URIs, defined in vocabularies (FOAF, SIOC, RDF, etc.)
- Objects can be literals, occasionally with a datatype

```
axel isA Person .
axel hasName "Axel Polleres".
```

becomes:

```
<http://polleres.net/foaf.rdf#me> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
    <http://xmlns.com/foaf/0.1/Person>.
<http://polleres.net/foaf.rdf#me> <http://xmlns.com/foaf/0.1/name>
    "Axel Polleres"^^<http://www.w3.org/2001/XMLSchema#string>.
```

Ugly to read... more compact syntaxes like Turtle [Beckett and Berners-Lee, 2008] allow prefix definitions à la XML:

```
@prefix : <http://polleres.net/foaf.rdf#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix xs: <http://www.w3.org/2001/XMLSchema#> .
:me rdf:type foaf:Person .
:me foaf:name "Axel Polleres"^^ xs:string.
```

More on RDF – Shortcuts in Turtle Syntax

```
@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me rdf:type foaf:Person .
:me foaf:name "Axel Polleres" .
:me foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> .
:me foaf:knows <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator X .
X rdf:type foaf:Document .
X dc:title "Rules and Ontologies for the Semantic Web".
```


More on RDF – Shortcuts in Turtle Syntax

```
@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me rdf:type foaf:Person .
:me foaf:name "Axel Polleres" .
:me foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> .
:me foaf:knows <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator _:X .
_:X rdf:type foaf:Document .
_:X dc:title "Rules and Ontologies for the Semantic Web".
```

- Blank nodes in Turtle are written as `_:Varname`

More on RDF – Shortcuts in Turtle Syntax

```

@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me rdf:type foaf:Person ;
    foaf:name "Axel Polleres" ;
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
               <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator _:X .
_:X rdf:type foaf:Document ;
    dc:title "Rules and Ontologies for the Semantic Web" .

```

- Blank nodes in Turtle are written as `_:Varname`
- Turtle allows shortcuts:
 - Same subject triples can be grouped together with `' ; ' , ' , ' , '`

More on RDF – Shortcuts in Turtle Syntax

```
@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .

:me rdf:type foaf:Person;
    foaf:name "Axel Polleres";
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
               <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
    rdf:type foaf:Document ;
    dc:title "Rules and Ontologies for the Semantic Web" ] .
```

- Blank nodes in Turtle are written as `_:` *Varname*
- Turtle allows shortcuts:
 - Same subject triples can be grouped together with `' ; ' , ' , ' ,'`
 - Blank nodes can be grouped/replaced using "bracket syntax" `' [,] '`

More on RDF – Shortcuts in Turtle Syntax

```
@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me a foaf:Person;
    foaf:name "Axel Polleres";
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
               <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
    a foaf:Document ;
    dc:title "Rules and Ontologies for the Semantic Web" ] .
```

- Blank nodes in Turtle are written as `_:Varname`
- Turtle allows shortcuts:
 - Same subject triples can be grouped together with `',' , ','`
 - Blank nodes can be grouped/replaced using "bracket syntax" `'[,]'`
 - `rdf:type` is often abbreviated with `a`.

More on RDF – Shortcuts in Turtle Syntax

```

@prefix : <http://polleres.net/foaf.rdf#>
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@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me foaf:Person;
    foaf:name "Axel Polleres"^^xs:string;
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
               <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
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```

- Blank nodes in Turtle are written as `_:Varname`
- Turtle allows shortcuts:
 - Same subject triples can be grouped together with `',' , ','`
 - Blank nodes can be grouped/replaced using "bracket syntax" `'[,]'`
 - `rdf:type` is often abbreviated with `a`.
 - typed literals `l` of type `dt` are written as `l^^dt`.

More on RDF – Shortcuts in Turtle Syntax

```

@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me foaf:Person;
    foaf:name "Axel Polleres"^^xs:string;
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
               <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
    a foaf:Document ;
    dc:title "Rules and Ontologies for the Semantic Web"Gen ] .

```

- Blank nodes in Turtle are written as `_:Varname`
- Turtle allows shortcuts:
 - Same subject triples can be grouped together with `' ; ' , ' , '`
 - Blank nodes can be grouped/replaced using "bracket syntax" `' [, '] '`
 - `rdf:type` is often abbreviated with `a`.
 - typed literals `l` of type `dt` are written as `l^^dt`.
 - untyped literals can have a **language tag** [BCP-47, 2006].

More on RDF – Shortcuts in Turtle Syntax

```

@prefix : <http://polleres.net/foaf.rdf#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
:me foaf:Person;
    foaf:name "Axel Polleres"^^xs:string;
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
               <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
    a foaf:Document ;
    dc:title "Rules and Ontologies for the Semantic Web"@en ] .

```

- Blank nodes in Turtle are written as `_:Varname`
- Turtle allows shortcuts:
 - Same subject triples can be grouped together with `','`
 - Blank nodes can be grouped/replaced using "bracket syntax" `'['`, `']'`
 - `rdf:type` is often abbreviated with `a`.
 - typed literals `l` of type `dt` are written as `l^^dt`.
 - untyped literals can have a language tag [BCP-47, 2006].
 - (untyped literals with or without language tag are also called "plain" literals.)

Collecting RDF from the Web

- For us this is enough so far to “read” RDF on the Web.

¹<http://librdf.org/>

²<http://jena.sourceforge.net/>

Collecting RDF from the Web

- For us this is enough so far to “read” RDF on the Web.
- For published RDF data there exists a machine-readable XML syntax. Lots of tools and APIs to read/process/convert this data (Redland (C++),¹ Jena (Java),² etc.)

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix : <http://www.gibbi.com/foaf.rdf#> .

<http://www.gibbi.com/foaf.rdf> a foaf:PersonalProfileDocument.
<http://www.gibbi.com/foaf.rdf> foaf:maker :me .
<http://www.gibbi.com/foaf.rdf> foaf:primaryTopic :me .
:me a foaf:Person .
:me foaf:name "Giovambattista Ianni" .
:me foaf:homepage <http://www.gibbi.com> .
:me foaf:knows [ a foaf:Person ;
                 foaf:name "Wolfgang Faber" ;
                 rdfs:seeAlso <http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf> ].
:me foaf:knows [ a foaf:Person .
                 foaf:name "Axel Polleres" ;
                 rdfs:seeAlso <http://www.polleres.net/foaf.rdf> ].
:me foaf:knows [ a foaf:Person .
                 foaf:name "Thomas Eiter" ] .
:me foaf:knows [ a foaf:Person .
                 foaf:name "Alessandra Martello" ] .
```

¹<http://librdf.org/>

²<http://jena.sourceforge.net/>

Collecting RDF from the Web

- For us this is enough so far to “read” RDF on the Web.
- For published RDF data there exists a machine-readable XML syntax. Lots of tools and APIs to read/process/convert this data (Redland (C++),¹ Jena (Java),² etc.)

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix : <http://www.gibbi.com/foaf.rdf#> .
```

The screenshot shows a browser window with the URL `http://www.mat.unical.it/~ianni/`. The page content includes a header for G.B. Ianni, contact details, and a 'My FOAF card' section. A red circle highlights the FOAF card icon, and a red arrow points to the source page's XML code. The XML code shows a foaf:PersonalProfileDocument with various properties like name, email, and homepage.

```
foaf:name "Alessandra Martello" J .
```

¹<http://librdf.org/>

²<http://jena.sourceforge.net/>

Unit Outline

1. Motivation – Aggregating Web Data
2. How can I publish data? RDF
3. How can I query that data? SPARQL
4. What does that data mean? Ontologies described in RDFS + OWL
5. What's next?

How can I query/aggregate RDF data? SPARQL

- First “ingredient”: a standardized query language – SPARQL [Prud’hommeaux and Seaborne, 2008] – based on graph pattern matching

Prologue:	P	PREFIX <i>prefix</i> : <namespace-URI>
Head:	C or	CONSTRUCT { <i>template</i> }
	S or	SELECT <i>variable list</i>
	A	ASK
Body:	D	FROM / FROM NAMED <dataset-URI>
	W	WHERE { <i>pattern</i> }
	M	ORDER BY <i>expression</i>
		LIMIT <i>integer</i> > 0
		OFFSET <i>integer</i> > 0

- ... construct a new RDF graph
- ... select matching resources/literals in a graph
- ... boolean query

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- ... construct a new RDF graph
- ... select matching resources/literals in a graph
- ... boolean query

- Let us start with SELECT queries and focus on the different **patterns**:
 - basic graph patterns (Conjunctive queries)
 - FILTERS
 - UNIONS of patterns
 - OPTIONAL Patterns
 - GRAPH Patterns

Basic Graph Patterns (Conjunctive queries)

“select all names of persons known by G.B. from his FOAF file”

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
FROM <http://www.mat.unical.it/~ianni/foaf.rdf>
WHERE {
    <http://www.mat.unical.it/~ianni/foaf.rdf#me> foaf:knows ?X .
    ?X a foaf:Person . ?X foaf:name ?N .
}
```

- graph patterns (WHERE part) allow Turtle syntax

Basic Graph Patterns (Conjunctive queries)

“select all names of persons known by G.B. from his FOAF file”

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
FROM <http://www.mat.unical.it/~ianni/foaf.rdf>
WHERE {
  [ foaf:knows
    [ a foaf:Person; foaf:name ?N ] ]
}
```

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed³

³We assume here that the only people declared “known” in G.B.’s FOAF file are those known by him.

Basic Graph Patterns (Conjunctive queries)

“select all names of persons known by G.B., Axel, and Thomas K. from their FOAF files”

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
FROM <http://www.mat.unical.it/~ianni/foaf.rdf>
FROM <http://www.polleres.net/foaf.rdf>
FROM <http://www.postsubmeta.net/foaf>
WHERE {
    [ foaf:knows
      [ a foaf:Person; foaf:name ?N ] ]
}
```

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed³
- merge of several graphs can be queried at once

Basic Graph Patterns (Conjunctive queries)

“select all names of persons known by G.B., Axel, and Thomas K. from their FOAF files”

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
WHERE {
    [ foaf:knows
      [ a foaf:Person; foaf:name ?N ] ]
}
```

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed³
- merge of several graphs can be queried at once
- **Try it!** E.g. using ARQ (<http://jena.sourceforge.net/ARQ/>)
arq -query
http://www.polleres.net/teaching/SemWebTech_2009/testdata/query2.sparql

FILTERs in Basic Graph Patterns

“select all names of persons known by GB, Thomas, and Axel from their FOAF files” (query3.sparql)

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
WHERE {
  [ foaf:knows
    [a foaf:Person ; foaf:name ?N] ]
}
```

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed
- Dataset can also be implicit, depending on the implementation...
so, let's assume we have a Web crawl of FOAF data ...

FILTERs in Basic Graph Patterns

“select all names of persons known by GB, Thomas, and Axel from their FOAF files” (query3.sparql)

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
WHERE {
  [ foaf:knows
    [a foaf:Person ; foaf:name ?N] ]
  FILTER ( ?N != "Giovambattista Ianni" &&
          ?N != "Thomas Krennwallner" && ?N != "Axel Polleres" )
}
```

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed
- Dataset can also be implicit, depending on the implementation...
so, let's assume we have a Web crawl of FOAF data ...
- ...i.e., we have to filter out the authors' names from the result.

UNIONS (Disjunction)

*“Names of persons who know Axel Polleres **or** who are known by Axel Polleres”*

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
FROM ...
WHERE {
  { [ foaf:name "Axel Polleres" ] foaf:knows [foaf:name ?N ] }
  UNION
  { [ foaf:name ?N ] foaf:knows [foaf:name "Axel Polleres" ] }
}
```

UNIONS (Disjunction)

*“Names of persons who know Axel Polleres **or** who are known by Axel Polleres”*

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?N
FROM ...
WHERE {
  { [ foaf:name "Axel Polleres" ] foaf:knows [foaf:name ?N ] }
  UNION
  { [ foaf:name ?N ] foaf:knows [foaf:name "Axel Polleres" ] }
}
```

- **UNION** s allow alternative matching of several patterns, similar to UNIONS in SQL.

OPTIONALS 1/2 – Partial Matching

“Select all names of persons known by Axel from his FOAF file and – if available – their `rdfs:seeAlso` links” `query4.sparql`

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>

SELECT ?N ?L
FROM <http://www.polleres.net/foaf.rdf>
WHERE {<http://www.polleres.net/foaf.rdf#me> foaf:knows ?X .
      ?X foaf:name ?N . ?X rdfs:seeAlso ?L
      }
```

- “Normal” basic graph pattern doesn’t work here, returns only those ?X with a `rdfs:seeAlso` link.

?N	?L
"Dan Brickley"	<http://danbri.org/foaf.rdf>
"Ruben Lara Hernandez"	<http://nets.ii.uam.es/~rlara/foaf.rdf>
...	

OPTIONALS 1/2 – Partial Matching

“Select all names of persons known by Axel from his FOAF file and – if available – their `rdfs:seeAlso` links” `query4.sparql`

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>

SELECT ?N ?L
FROM <http://www.polleres.net/foaf.rdf>
WHERE {<http://www.polleres.net/foaf.rdf#me> foaf:knows ?X .
      ?X foaf:name ?N . OPTIONAL { ?X rdfs:seeAlso ?L }
      }
```

- “Normal” basic graph pattern doesn’t work here, returns only those ?X with a `rdfs:seeAlso` link.
- OPTIONAL allows **partial variable bindings** in the solutions.

?N	?L
"Dan Brickley"	<http://danbri.org/foaf.rdf>
"Ruben Lara Hernandez"	<http://nets.ii.uam.es/~rlara/foaf.rdf>
...	
"Thomas Eiter"	
...	

CONSTRUCT

CONSTRUCT queries in SPARQL allow to generate new RDF graphs from the results of a query, e.g.

“Create a graph which establishes ‘foaf:knows relations for all persons who I have co-authored with according to DBLP.’ (query7.sparql)”

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
PREFIX: <http://dblp.l3s.de/d2r/resource/authors/>
CONSTRUCT { <http://polleres.net/foaf.rdf#me> foaf:knows ?Y }
WHERE { ?D dc:creator :Axel_Polleres;
        dc:creator ?Y . FILTER( ?Y != :Axel_Polleres )
      }
```


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“Create a graph which establishes ‘foaf:knows relations for all persons who I have co-authored with according to DBLP.’ (query7.sparql)”

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
PREFIX: <http://dblp.13s.de/d2r/resource/authors/>
CONSTRUCT { <http://polleres.net/foaf.rdf#me> foaf:knows ?Y }
WHERE { ?D dc:creator :Axel_Polleres;
        dc:creator ?Y . FILTER( ?Y != :Axel_Polleres )
      }
```

- “Output pattern” is a basic graph pattern
- similar to “views” in SQL
- May be viewed as a “rules language” itself.

ASK

ASK queries are “yes/no” queries without explicit output, e.g.

“Does Axel know one of the co-authors of

<<http://dblp.13s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>>?”

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
```

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
```

```
PREFIX dc: <http://purl.org/dc/elements/1.1/>
```

ASK

```
FROM <http://polleres.net/foaf.rdf>
```

```
FROM <http://dblp.13s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
```

```
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
```

```
    <http://dblp.13s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>  
        dc:creator ?A }
```

ASK

ASK queries are “yes/no” queries without explicit output, e.g.

“Does Axel know one of the co-authors of

<http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>?”

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
```

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
```

```
PREFIX dc: <http://purl.org/dc/elements/1.1/>
```

ASK

```
FROM <http://polleres.net/foaf.rdf>
```

```
FROM <http://dblp.l3s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
```

```
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
        <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>
          dc:creator ?A }
```

Interestingly, this query returns “no”... why? Because SPARQL doesn't know that

- `<http://dblp.l3s.de/d2r/resource/authors/Jim_Hendler> =`
`<http://www.cs.rpi.edu/hendler/foaf.rdf#jhendler>`

ASK

ASK queries are “yes/no” queries without explicit output, e.g.

“Does Axel know one of the co-authors of

<http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>?”

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
```

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
```

```
PREFIX dc: <http://purl.org/dc/elements/1.1/>
```

ASK

```
FROM <http://polleres.net/foaf.rdf>
```

```
FROM <http://dblp.l3s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
```

```
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
        <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>
          dc:creator ?A }
```

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```
http://polleres.net/foaf.rdf#me> foaf:knows <http://www.cs.rpi.edu/handler/foaf.rdf#jhendler>
```

More on that later...

Exercise

Using the SPARQL interface to DBLP at <http://dblp.13s.de/d2r/snorql/> write a query that outputs the following:

Task

Names of people who have published in TPLP or have co-authored with any of the authors of

<http://dblp.13s.de/d2r/resource/publications/journals/tlp/Berners-LeeCKSH08>

- Can you do it in one query?
- Which of the constructs discussed do you need?

SPARQL summary

- We have only “scratched the surface” here
- Particularly, we didn't treat SPARQL1.1 ... more on that in later lectures:
- Extensions of SPARQL (updates (DELETE, INSERT, ...), aggregate functions (SUM, MAX, COUNT, ...), etc.) currently being standardized
- Rigid investigation of SPARQL's semantics and complexity [Pérez *et al.*, 2006; Gutiérrez *et al.*, 2004]
- Peculiarities in SPARQL's semantics (multiset semantics, joins over unbound variables, etc. [Prud'hommeaux and Seaborne, 2008])
- SPARQL only does RDF graph pattern matching, what about ontologies? ... Let's take a look at this next!

Unit Outline

1. Motivation – Aggregating Web Data
2. How can I publish data? RDF
3. How can I query that data? SPARQL
4. What does that data mean? Ontologies described in RDFS + OWL
5. What's next?

What does RDF data mean?

- *Ontologies* are formal descriptions of what the *vocabulary* used in an RDF document means.

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- By vocabulary, we mean here mostly:
 - *properties*, i.e., predicates
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 - (*individuals*, i.e., concrete objects)⁴

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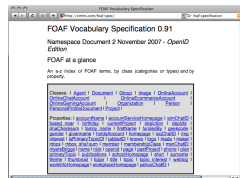
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- Ontologies describe **relations** among properties, classes and individuals (subclasses, subproperties, equivalence, domain, range, etc.)
- The W3C has published two standards to describe ontologies, namely *RDF Schema (RDFS)* [Brickley and Guha (eds.), 2004] and the *Web Ontology language (OWL)* [Patel-Schneider *et al.*, 2004]
 - **RDFS** ... simple schema language with minimal expressivity, mostly expressible in simple forward chaining inference rules (*Horn Rules*)
 - **OWL** ... higher expressivity, foundations in *Description Logics*
 - both RDFS and OWL ontologies are RDF graphs themselves, i.e., OWL and RDFS provide “an RDF vocabulary to describe RDF vocabularies”

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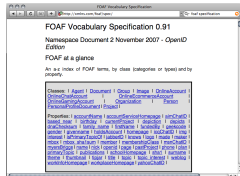
Example Vocabulary 1 – The FOAF ontology:

- **Properties:** name, knows, homepage, primaryTopic etc.
- **Classes:** Person, Agent, Document, Organisation, etc.
- **Relations:** e.g.
 - *Each Person is a Agent* (subclass)
 - *The img property is more specific than depiction* (subproperty)



Example Vocabulary 1 – The FOAF ontology:

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 - *Each Person is a Agent* (subclass)
 - *The img property is more specific than depiction* (subproperty)
 - *img is a relation between Persons and Images* (domain/range)
 - *knows is a relation between two Persons* (domain/range)
 - *homepage denotes **unique** homepage of an Agent* (uniquely identifying property)
 -
 -



Examples 2 – A simple ontology about reviewers:

- **Properties:** title, isAuthorOf, publishedIn, etc.
- **Classes:** Senior, Paper, Publication, etc.
- **Relations:**
 - *A Publication is a Paper which has been published* (subclass + existential condition on property)

⁵reuse of external ontologies!

Examples 2 – A simple ontology about reviewers:

- **Properties:** title, isAuthorOf, publishedIn, etc.
- **Classes:** Senior, Paper, Publication, etc.
- **Relations:**
 - *A Publication is a Paper which has been published* (subclass + existential condition on property)
 - *isAuthorOf is the opposite of Dublin Core's dc:creator Property*⁵

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Examples 2 – A simple ontology about reviewers:

- **Properties:** title, isAuthorOf, publishedIn, etc.
- **Classes:** Senior, Paper, Publication, etc.
- **Relations:**
 - *A Publication is a Paper which has been published* (subclass + existential condition on property)
 - *isAuthorOf is the opposite of Dublin Core's dc:creator Property*⁵
 - *A Senior researcher is a foaf:Person who isAuthorOf 10+ Publications* (subclass + condition on cardinality)

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Examples 2 – A simple ontology about reviewers:

- **Properties:** title, isAuthorOf, publishedIn, etc.
- **Classes:** Senior, Paper, Publication, etc.
- **Relations:**
 - *A Publication is a Paper which has been published* (subclass + existential condition on property)
 - *isAuthorOf is the opposite of Dublin Core's dc:creator Property*⁵
 - *A Senior researcher is a foaf:Person who isAuthorOf 10+ Publications* (subclass + condition on cardinality)
 - *Each item can be publishedIn at most one venue* (functional property)
 -
 -
 -

⁵reuse of external ontologies!

RDF(S) vocabulary: RDF and RDFS themselves are vocabularies!

- **Properties:** `rdf:type`, `rdfs:domain`, `rdfs:range`, `rdf:subClassOf`, `rdf:subPropertyOf`, `rdf:first`, `rdf:rest` etc.
- **Classes:** `rdf:XMLLiteral`, `rdf:Literal`, `rdfs:Resource`, `rdfs:Property`, `rdfs:Class`, `rdf:List`, etc.
- **Relations:**

RDF(S) vocabulary: RDF and RDFS themselves are vocabularies!

- **Properties:** `rdf:type`, `rdfs:domain`, `rdfs:range`, `rdf:subClassOf`, `rdf:subPropertyOf`, `rdf:first`, `rdf:rest` etc.
- **Classes:** `rdf:XMLLiteral`, `rdf:Literal`, `rdfs:Resource`, `rdfs:Property`, `rdfs:Class`, `rdf:List`, etc.
- **Relations:** The semantics of the RDFS vocabulary is defined in [Hayes, 2004]; it is a “meta vocabulary” used to define the semantics of other vocabularies

The Semantics of RDF graphs:

```

@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
<http://www.mat.unical.it/~ianni/foaf.rdf> a foaf:PersonalProfileDocument.
<http://www.mat.unical.it/~ianni/foaf.rdf> foaf:maker _:me .
<http://www.mat.unical.it/~ianni/foaf.rdf> foaf:primaryTopic _:me .
:me a foaf:Person .
:me foaf:name "Giovambattista Ianni" .
:me foaf:homepage <http://www.gibbi.com> .
:me foaf:phone <tel:+39-0984-496430> .
:me foaf:knows [ a foaf:Person ;
                 foaf:name "Wolfgang Faber" ;
                 rdfs:seeAlso <http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf>].
:me foaf:knows [ a foaf:Person .
                 foaf:name "Axel Polleres" ;
                 rdfs:seeAlso <http://www.polleres.net/foaf.rdf>].
:me foaf:knows [ a foaf:Person .
                 foaf:name "Thomas Eiter" ] .
:me foaf:knows [ a foaf:Person .
                 foaf:name "Alessandra Martello" ] .

```


The Semantics of RDF graphs:

As we will see in the next Units, each RDF graph can “roughly” be viewed as a first-order formula:

```

∃b1, b2, b3, b4
(triple(foaf.rdf, rdf:type, PersonalProfileDocument)
 ^ triple(foaf.rdf, maker, me)
 ^ triple(foaf.rdf, primaryTopic, me)
 ^ triple(me, rdf:type, Person)
 ^ triple(me, name, "Giovambattista Ianni")
 ^ triple(me, homepage, http://www.gibbi.com)
 ^ triple(me, phone, tel:+39-0984-496430)
 ^ triple(me, knows, b2) ^ triple(b1, type, Person)
 ^ triple(b1, name, "Wolfgang Faber")
 ^ triple(b1, rdfs:seeAlso, http://www.kr.tuwien...)
 ^ triple(me, knows, b1) ^ triple(b1, rdf:type, Person)
 ^ triple(b2, name, "Axel Polleres")
 ^ triple(b2, rdfs:seeAlso, http://www.polleres...)
 ^ triple(me, knows, b3) ^ triple(b1, rdf:type, Person)
 ^ triple(b3, name, "Thomas Eiter")
 ^ triple(me, knows, b4) ^ triple(b1, type, Person)
 ^ triple(b4, name, "Alessandra Martello"))

```

The Semantics of RDF graphs:

Alternatively, especially the OWL favors unary/binary predicate representation:

```

$$\begin{aligned} & \exists me, b1, b2, b3, b4 (\text{PersonalProfileDocument}(\text{foaf.rdf}) \\ & \wedge \text{maker}(\text{foaf.rdf}, me) \\ & \wedge \text{primaryTopic}(\text{foaf.rdf}, me) \\ & \wedge \text{Person}(me) \wedge \dots) \end{aligned}$$

```

- unary predicates for `rdf:type` predicates
- binary predicates for all other predicates

The Semantics of the RDFS vocabulary:

The formal semantics of RDF(S) [Hayes, 2004] is accompanied by a set of (informative) entailment rules ... can be written down roughly as the following first-order formulas:

$$\begin{aligned}
&\forall S, P, O (triple(S, P, O) \supset triple(S, rdf:type, rdfs:Resource)) \\
&\forall S, P, O (triple(S, P, O) \supset triple(P, rdf:type, rdf:Property)) \\
&\forall S, P, O (triple(S, P, O) \supset triple(O, rdf:type, rdfs:Resource)) \\
&\forall S, P, O (triple(S, P, O) \wedge triple(P, rdfs:domain, C) \supset triple(S, rdf:type, C)) \\
&\forall S, P, O, C (triple(S, P, O) \wedge triple(P, rdfs:range, C) \supset triple(O, rdf:type, C)) \\
&\forall C (triple(C, rdf:type, rdfs:Class) \supset triple(C, rdfs:subClassOf, rdfs:Resource)) \\
&\forall C_1, C_2, C_3 (triple(C_1, rdfs:subClassOf, C_2) \wedge \\
&\quad triple(C_2, rdfs:subClassOf, C_3) \supset triple(C_1, rdfs:subClassOf, C_3)) \\
&\forall S, C_1, C_2 (triple(S, rdf:type, C_1) \wedge triple(C_1, rdfs:subClassOf, C_2) \supset triple(S, rdf:type, C_2)) \\
&\forall S, C (triple(S, rdf:type, C) \supset triple(C, rdf:type, rdfs:Class)) \\
&\forall C (triple(C, rdf:type, rdfs:Class) \supset triple(C, rdfs:subClassOf, C)) \\
&\forall P_1, P_2, P_3 (triple(P_1, rdfs:subPropertyOf, P_2) \wedge \\
&\quad triple(P_2, rdfs:subPropertyOf, P_3) \supset triple(P_1, rdfs:subPropertyOf, P_3)) \\
&\forall S, P_1, P_2, O (triple(S, P_1, O) \wedge triple(P_1, rdfs:subPropertyOf, P_2) \supset triple(S, P_2, O)) \\
&\forall P (triple(P, rdf:type, rdf:Property) \supset triple(P, rdfs:subPropertyOf, P))
\end{aligned}$$

plus the axiomatic triples from [Hayes, 2004, Sections 3.1 and 4.1].

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$$\forall S, P, O (triple(S, P, O) \supset triple(O, rdf:type, rdfs:Resource))$$

$$\forall S, P, O (triple(S, P, O) \wedge triple(P, rdfs:domain, C) \supset triple(S, rdf:type, C))$$

$$\forall S, P, O, C (triple(S, P, O) \wedge triple(P, rdfs:range, C) \supset triple(O, rdf:type, C))$$

$$\forall C (triple(C, rdf:type, rdfs:Class) \supset triple(C, rdfs:subClassOf, rdfs:Resource))$$

$$\forall C_1, C_2, C_3 (triple(C_1, rdfs:subClassOf, C_2) \wedge$$

$$triple(C_2, rdfs:subClassOf, C_3) \supset triple(C_1, rdfs:subClassOf, C_3))$$

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Writing entailment rules in unary/binary representation would yield second order, e.g.:

$$\forall S, C_1, C_2 (triple(S, rdf:type, C_1) \wedge triple(C_1, rdfs:subClassOf, C_2) \supset triple(S, rdf:type, C_2))$$

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All those rules were Datalog expressible, i.e. no negation, no function symbols.

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Writing entailment rules in unary/binary representation would yield second order, e.g.:

$$\forall S, C_1, C_2 (C_1(S) \wedge \text{rdfs:subClassOf}(C_1, C_2) \supset C_2(S))$$

RDFS Semantics Example: The FOAF ontology

FOAF Ontology:

- *Each Person is a Agent* (subclass)
- *The img property is more specific than depiction* (subproperty)
- *img is a relation between Persons and Images* (domain/range)
- *knows is a relation between two Persons* (domain/range)
- *homepage denotes **unique** homepage of an Agent* (uniquely identifying property)

⋮

RDFS: Semantics

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⋮

Data:

```
:me rdf:type foaf:Person .
```


RDFS Semantics Example: The FOAF ontology

FOAF Ontology in RDF:

- `foaf:Person rdfs:subClassOf foaf:Agent .`
- `foaf:img rdfs:subPropertyOf foaf:depiction .`
- `foaf:img rdfs:domain foaf:Person ; rdfs:range foaf:Image .`
- `foaf:knows rdfs:domain foaf:Person ; rdfs:range foaf:Person .`
- ???

⋮

RDFS: Semantics

⋮
 $\forall S, C_1, C_2 (triple(S, rdf:type, C_1) \wedge triple(C_1, rdfs:subClassOf, C_2) \supset triple(S, rdf:type, C_2))$
 ⋮

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- `foaf:img rdfs:domain foaf:Person ; rdfs:range foaf:Image .`
- `foaf:knows rdfs:domain foaf:Person ; rdfs:range foaf:Person .`
- *homepage denotes unique homepage of an Agent ???*

⋮

RDFS: Semantics

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⋮

Data:

```
:me rdfs:type foaf:Person .
:me rdfs:type foaf:Agent .
```

The OWL vocabulary:

- *homepage* denotes **unique** homepage of an *Agent* (uniquely identifying property)

For expressing this, we need more than the RDFS vocabulary. **OWL** is again an RDF vocabulary, extending RDF(S), fixed semantics that adds more expressivity on top of RDFS:

- **Properties:** `owl:sameAs`, `owl:differentFrom`, `owl:inverseOf`, `owl:onProperty`, `owl:allValuesFrom`, `owl:someValuesFrom`, `owl:minCardinality`, `owl:maxCardinality` etc.
- **Classes:** `owl:Restriction`, `owl:DatatypeProperty`, `owl:ObjectProperty`, `owl:FunctionalProperty`, `owl:InverseFunctionalProperty`, `owl:SymmetricProperty` etc.
- **Relations:** The semantics of OWL is defined in
 - in terms of its RDF reading (RDF-based-semantics), and

⁶direct semantics puts some restrictions on the use of the OWL and RDF vocabulary, fragment sometimes called OWL DL

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- **Relations:** The semantics of OWL is defined in
 - in terms of its RDF reading (RDF-based-semantics), and
 - in terms of its Description Logics reading (direct semantics)⁶

⁶direct semantics puts some restrictions on the use of the OWL and RDF vocabulary, fragment sometimes called OWL DL

The Semantics of the OWL vocabulary (DL reading):

Description Logics:

- syntactic variant of first-order logic with equality
- especially tailored for talking about concepts (classes, sets) and roles (properties)
- dedicated symbols for class membership and subclass/subproperty relation:

`foaf:Person` `rdfs:subClassOf` `foaf:Agent`

$Person \sqsubseteq Agent$

`:me` `rdf:type` `foaf:Person`

$me \in Person$

OWL DL in one slide

Expressing property characteristics:

OWL property axioms as RDF triples	DL syntax	FOL short representation
$P \text{ rdfs:domain } C .$	$\top \sqsubseteq \forall P^- . C$	$\forall x, y. P(x, y) \supset C(x)$
$P \text{ rdfs:range } C .$	$\top \sqsubseteq \forall P . C$	$\forall x, y. P(x, y) \supset C(y)$
$P \text{ owl:inverseOf } P_0 .$	$P \equiv P_0^-$	$\forall x, y. P(x, y) \equiv P_0(y, x)$
$P \text{ rdf:type owl:SymmetricProperty.}$	$P \equiv P^-$	$\forall x, y. P(x, y) \equiv P(y, x)$
$P \text{ rdf:type owl:FunctionalProperty.}$	$\top \sqsubseteq \leq 1P$	$\forall x, y, z. P(x, y) \wedge P(x, z) \supset y = z$
$P \text{ rdf:type owl:InverseFunctionalProperty.}$	$\top \sqsubseteq \leq 1P^-$	$\forall x, y, z. P(x, y) \wedge P(z, y) \supset x = z$
$P \text{ rdf:type owl:TransitiveProperty.}$	$P^+ \sqsubseteq P$	$\forall x, y, z. P(x, y) \wedge P(y, z) \supset P(x, z)$

OWL DL in one slide

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$P \text{ rdfs:range } C .$	$\top \sqsubseteq \forall P . C$	$\forall x, y. P(x, y) \supset C(y)$
$P \text{ owl:inverseOf } P_0 .$	$P \equiv P_0^-$	$\forall x, y. P(x, y) \equiv P_0(y, x)$
$P \text{ rdf:type owl:SymmetricProperty.}$	$P \equiv P^-$	$\forall x, y. P(x, y) \equiv P(y, x)$
$P \text{ rdf:type owl:FunctionalProperty.}$	$\top \sqsubseteq \leq 1P$	$\forall x, y, z. P(x, y) \wedge P(x, z) \supset y = z$
$P \text{ rdf:type owl:InverseFunctionalProperty.}$	$\top \sqsubseteq \leq 1P^-$	$\forall x, y, z. P(x, y) \wedge P(z, y) \supset x = z$
$P \text{ rdf:type owl:TransitiveProperty.}$	$P^+ \sqsubseteq P$	$\forall x, y, z. P(x, y) \wedge P(y, z) \supset P(x, z)$

Expressing complex class descriptions:

OWL complex class descriptions*	DL syntax	FOL short representation
owl:Thing	\top	$x = x$
owl:Nothing	\perp	$\neg x = x$
$\text{owl:intersectionOf } (C_1 \dots C_n)$	$C_1 \sqcap \dots \sqcap C_n$	$C_1(x) \wedge \dots \wedge C_n(x)$
$\text{owl:unionOf } (C_1 \dots C_n)$	$C_1 \sqcup \dots \sqcup C_n$	$C_1(x) \vee \dots \vee C_n(x)$
$\text{owl:complementOf } (C)$	$\neg C$	$\neg C(x)$
$\text{owl:oneOf } (o_1 \dots o_n)$	$\{o_1, \dots, o_n\}$	$x = o_1 \vee \dots \vee x = o_n$
$\text{owl:restriction } (P \text{ owl:someValuesFrom } (C))$	$\exists P . C$	$\exists y. P(x, y) \wedge C(y)$
$\text{owl:restriction } (P \text{ owl:allValuesFrom } (C))$	$\forall P . C$	$\forall y. P(x, y) \supset C(y)$
$\text{owl:restriction } (P \text{ owl:value } (o))$	$\exists P . \{o\}$	$P(x, o)$
$\text{owl:restriction } (P \text{ owl:minCardinality } (n))$	$\geq nP$	$\exists y_1 \dots y_n . \bigwedge_{k=1}^n P(x, y_k) \wedge \bigwedge_{i < j} y_i \neq y_j$
$\text{owl:restriction } (P \text{ owl:maxCardinality } (n))$	$\leq nP$	$\forall y_1 \dots y_{n+1} . \bigwedge_{k=1}^{n+1} P(x, y_k) \supset \bigvee_{i < j} y_i = y_j$

*For reasons of legibility, we use a variant of the OWL abstract syntax [Patel-Schneider et al., 2004] in this table.

OWL DL in two slides: 2/2

Relating Class descriptions:

 C_1 rdfs:subClassOf C_2 $C_1 \sqsubseteq C_2$ C_1 owl:equivalentClass C_2 $C_1 \equiv C_2$ C_1 owl:disjointWith C_2 $C_1 \sqcap C_2 \sqsubseteq \perp$

Relating individuals:

 o_1 owl:sameAs o_2 $o_1 = o_2$ o_1 owl:differentFrom o_2 $o_1 \neq o_2$

OWL DL in two slides: 2/2

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Examples:

```
<http://www.polleres.net/foaf.rdf#me> owl:sameAs
  <http://dblp.13s.de/d2r/resource/authors/Axel_Polleres> .

<http://polleres.net/foaf.rdf#me> owl:differentFrom
  <http://www.mat.unical.it/~ianni/foaf.rdf#me> .
```

OWL DL in two slides: 2/2

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Many more features in OWL2 (2009) ... wouldn't have fit in 2 slides ;-)

OWL Example: The FOAF ontology

- *homepage* denotes **unique** homepage of an *Agent* (uniquely identifying property)

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Example inference:

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  <http://www.polleres.net/> .

⊨
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  <http://dblp.13s.de/d2r/resource/authors/Axel_Polleres> .
```

Reasoning with Ontologies

Tools:

- Special purpose DL reasoners:
Pellet [Sirin *et al.*, 2005], Racer [Haarslev and Möller, 2001], Fact++ [Tsarkov and Horrocks, 2006], Hermit [Motik *et al.*, 2007]
- General purpose FOL theorem provers:
SNARK [Stickel *et al.*,], SPASS [SPASS,], Vampire [Riazanov and Voronkov, 2002]
- For special fragments of OWL [?]:
 - **Rule/LP engines** (OWL RL)
 - **Relational databases** (OWL QL)

SPARQL & Ontologies

SPARQL on top of ontologies not trivial:

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W3C's SPARQL1.1 WG has defined Entailment regimes for OWL, stay tuned for later lectures.

Unit Outline

1. Motivation – Aggregating Web Data
2. How can I publish data? RDF
3. How can I query that data? SPARQL
4. What does that data mean? Ontologies described in RDFS + OWL
5. What's next?

Summary

- We should all have a rough idea about where to find RDF now.
- We should all have a rough idea about how to read RDF now.
- We should all have a rough idea of how to query RDF (SPARQL).
- We should all have an idea of how the semantics of RDF vocabularies and data can be described (RDFS + OWL)

Details to come!

What's next?

- Details on the semantics of RDF+RDFS
- Details on the semantics of SPARQL,
- SPARQL 1.1
- OWL2 and efficient reasoning for some fragments
- SPARQL1.1 + RDFS + OWL
- Towards the end of the lecture: practical applications on Reasoning about Web Data.

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