

DERI Tutorials

Welcome!

Dr. Axel Polleres, DERI, NUI Galway

DERI Tutorials



- Series of lectures for

- Students
- Industrial Partners
- Colleagues from NUIG

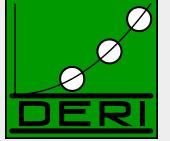
- First stage of Tutorials: between now and the Summer

- Fundamental lectures in the core topics of research units in DERI

- Goals:

- Bring everybody up-to-speed
- Create mutual understanding
- These first tutorials are **mainly intended for non-experts!**

Schedule



■ Biweekly

- Feb 26th 14:00 - 17:00: Principles of Publishing linked data
- March 12th, 14:00 - 17:00: Social Semantic Web: Introduction
- March 26th, 14:00-17:00: Annotation for the Semantic Web
- ...

■ Web site to be announced soon !!!!

- Video lectures – watch again at home, we can give short/tailored versions for our industry partners on specific aspects
- Further topics for stage two (advanced topics) being collected now

Introduction to Semantic Web, RDF, Ontologies (RDFS and OWL), SPARQL

An Introduction to the Semantic Web and its base Technologies

Dr. Axel Polleres
axel.polleres@deri.org

Digital Enterprise Research Institute (DERI)
National University of Ireland, Galway

DERI Tutorials – February 12, 2009

Outline

1. Motivation – Aggregating Linked Open Data by Rules & Ontologies
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/XML would be nice.

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Finding reviewers for a scientific Journal

Tim Berners-Lee, Dan Connolly, Lalana Kagal, Yosi Scharf, Jim Hendler:
N3Logic: A logical framework for the World Wide Web. Theory and Practice of Logic Programming (TPLP), Volume 8, p249-269.

Assume you are the editor of a scientific journal:

- Who are the right reviewers?
- Which qualified people do I know?
- How can I assess their expertise?
- Which reviewers are in conflict?
- Observation: Much of the necessary data is available on the Web!

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?

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Where is the data? 1/4

Top Left: TU KBS Knowledge-Based Systems Group staff page

Prof. Dr. Thomas Eiter
Professor of Computer Science
Head of the Institute of Information Systems
Head of the Institute of Information Systems

Office: +43 (1) 80 80 1840
Fax: +43 (1) 80 80 18405
Dienstel: +43 (1) 80 80 18405
DESKPHONE: Thu, 11:00 - 18:00

Top Right: Universität Regensburg homepage

O.B. Seery
Department of Mathematics and Computer Science, Universität Regensburg
Phone: +49 941 94 6430; Fax: +49 941 94 6410
E-mail: seery@mathematik.uni-regensburg.de

Associate Professor at the www.mathematik.uni-regensburg.de
Hausvorstand M2, Universität Regensburg, Germany

Bottom: Thomas Krennwalder's Wiki FrontPage

Obviously we do not want to leave zombies around – W. Robert Stevens

There is some personal information about me.

Publications:
See MyConfig for an incomplete list of my configuration files.

FrontPage (last edited 2007-03-26 13:03:44 by [ThomasKrennwalder](#))

Statistics:Powered Public:Powered Valid:HTML:4.01

A Logic-Agnostic Framework For the World Wide Web

The Semantic Web distinguishes between the first four generations of the Web:

- First Generation:** Hypertext (HTML)
- Second Generation:** Database (SQL)
- Third Generation:** XML
- Fourth Generation:** RDF

From the fifth generation of the Web, the Semantic Web is the most prominent example.

| Generation | Characteristics | Example |
|-------------------|------------------|---------|
| First Generation | Hypertext (HTML) | www |
| Second Generation | Database (SQL) | ERP |
| Third Generation | XML | WSDL |
| Fourth Generation | RDF | SPARQL |
| Fifth Generation | Reasoning | SW |

- A lot of Web data already available “out there” in a machine-readable format (RDF)
- More and more of it follows the *Linked Data principles*¹, i.e.:

1 Next DERI Tutorial!

Where is the data? 1/4

The screenshot shows a web browser with several tabs open, illustrating how data is scattered across the web:

- Tab 1:** TU Berlin Knowledge-Based Systems Group website for Prof. Dr. Thomas Elter.
- Tab 2:** Personal homepage for Thomas Elter at Universität Trier.
- Tab 3:** List of publications from the DOLPHIN Bibliography Server - EMQ.
- Tab 4:** Thomas Krennwallner's Wiki FrontPage.
- Search Results:** A Google search for "Thomas Elter" yields results from various sources, including his personal homepage, academic publications, and a wiki page.



- A lot of Web data already available "out there" in a machine-readable format (RDF)
- More and more of it follows the *Linked Data principles*¹, i.e.:

[Next DERI Tutorial!](#)

Where is the data? 1/4

The first screenshot shows the TU Berlin Knowledge-Based Systems Group website for Prof. Dr. Thomas Elter. It includes contact information (email, phone, fax, address) and research interests.

The second screenshot shows a personal homepage for Thomas Elter, featuring a photo, contact details, and a sidebar with links to various websites.

The third screenshot shows a list of publications from the DOLPHIN bibliography service, including titles, authors, and URLs.

The slide is titled "NLoge: A Logical Framework For the Web" and is presented by Thomas Elter. It includes a brief introduction, a diagram of the NLoge architecture, and a section on "Applications".

■ A lot of Web data already available “out there” in a machine-readable format (RDF)

■ More and more of it follows the *Linked Data* principles¹, i.e.:

- Use URIs as names for things
- Use HTTP dereferenceable URIs so that people can look up those names.
When someone looks up a URI, provide useful information.
- include links to other URIs so that they can discover more things.

¹ Next DERI Tutorial!

Where is the data? 1/4



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The first screenshot shows a TU Berlin Knowledge-Based Systems Group page for Prof. Dr. Thomas Elter. It includes contact information (email, phone, fax, address) and research interests. The second screenshot shows a University of Trier page for Thomas Elter, featuring a photo and a brief bio. The third screenshot is a list of publications from the DBLP Bibliography Server, showing titles, authors, and publication details.



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The first screenshot shows the TU Berlin Knowledge-Based Systems Group website for Prof. Dr. Thomas Elter. It includes contact information (email, phone, fax, address) and research interests. The second screenshot shows the University of Trier's homepage for Thomas Elter, featuring a photo and a brief bio. The third screenshot is a browser window displaying a list of 22 publications from the DBLP Bibliography Server, including titles like "Work-case Oriented Consecutive Query Answering for an Expressive Description Logic", "Sensor Error Classification in Action Descriptions: A Heuristic Approach", and "Conjunctive Query Answering in SH using Krom Description Logics".



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Where is the data? 1/4

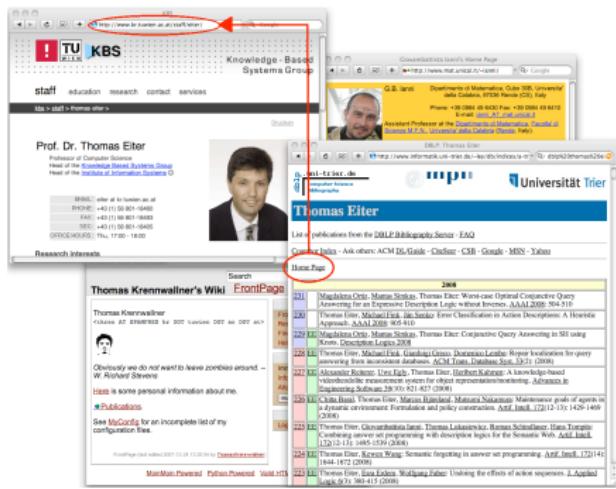
The figure shows three web pages. The top-left page is for 'Prof. Dr. Thomas Elter' at the TU KBS Knowledge-Based Systems Group. It includes a photo, contact information (email, phone, fax, address), and research interests. The top-right page is from the University of Trier, also featuring a photo and contact details. The bottom page is a DBLP bibliography for 'Thomas Elter', listing various academic publications with their URLs.



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Where is the data? 2/4

Obtaining Machine-Readable RDF data

(i) directly by the publishers, (ii) by GRDDL transformations, 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`)

Different Options:

RDFa [Adida *et al.*, 2008][Hausenblas *et al.*, 2008],

linking RDF/XML [Beckett and McBride (eds.), 2004] from (X)HTML, etc. Let's check,

e.g. <http://www.w3.org/People/Berners-Lee/>, or

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

Where is the data? 2/4

Obtaining Machine-Readable RDF data

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

The screenshot shows a web browser window with two panes. The left pane displays a FOAF card for "Giovambattista Ianni". It includes a photo, contact information (Phone: +39 0984 49 6430, Fax: +39 0984 49 6410, E-mail: ianni_AT_matunical.it), and a statement: "Io sono l'inizio e la fine di me stesso". Below this are sections for "Publications" (with links to Polaris Database and DBLP), "Biographical Sketch" (with a link to a page about Erdős numbers), "My FOAF card" (with a link to the RDF XML shown in the right pane), and "Teaching Activities" (with links to Operating Systems, Sistemi Operativi, and Computer Networks courses). The right pane shows the RDF XML generated from the FOAF card. A red arrow points from the "My FOAF card" link in the left pane to the RDF XML in the right pane.

```

<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:foaf="http://xmlns.com/foaf/0.1/"
    xmlns:admin="http://webns.net/mvcb/#"
    >
    <foaf:PersonalProfileDocument rdf:about="http://www.mat.unical.it/~ianni/foaf.rdf">
        <foaf:maker rdf:nodeID="n0"/>
        <foaf:primaryTopic rdf:nodeID="n1"/>
        <admin:generatorAgent rdf:resource="http://www.lddods.com/foaf/foaf-a-matic"/>
        <admin:errorReportsTo rdf:resource="mailto:leigh@lddods.com"/>
        <foaf:person rdf:nodeID="me">
            <foaf:name>Giovambattista Ianni</foaf:name>
            <foaf:givenName>Giovambattista</foaf:givenName>
            <foaf:familyName>ianni</foaf:family_name>
            <foaf:depiction rdf:resource="http://www.gibbi.com/L_G02.jpg"/>
            <foaf:phone rdf:resource="tel:+39-0984-496430"/>
            <foaf:workplaceHomepage rdf:resource="http://www.mat.unical.it/ianni"/>
            <foaf:knows>
                <foaf:Person>
                    <foaf:name>Axel Polleres</foaf:name>
                    <foaf:seeAlso>
                        <foaf:resource rdf:resource="http://www.polleres.net/foaf.rdf"/>
                    </foaf:seeAlso>
                </foaf:Person>
                <foaf:knows>
                    <foaf:Person>
                        <foaf:name>Wolfgang Faber</foaf:name>
                        <foaf:seeAlso>
                            <foaf:resource rdf:resource="http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf"/>
                        </foaf:seeAlso>
                    </foaf:Person>
                </foaf:knows>
            </foaf:knows>
        </foaf:person>
    </foaf:PersonalProfileDocument>

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Different Options:

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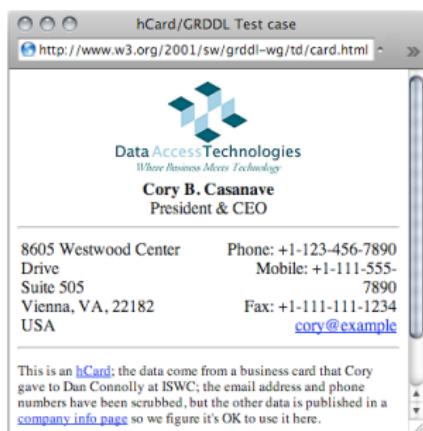
Obtaining Machine-Readable RDF data

(i) directly by the publishers, (ii) by GRDDL transformations, or (iii) by 3rd-party wrappers:

GRDDL (Gleaning Resource Descriptions from Dialects of Languages.) [Connolly (ed.), 2007]

Simple principle:

- extract RDF directly from HTML or XML files
- typically using XSLT transformations (other languages: XQuery, XSPARQL, etc.)
- useful for common Microformats , e.g. hCard, hCal:



hCard/GRDDL Test case
<http://www.w3.org/2001/sw/grddl-wg/td/card.html>

Data Access Technologies
Where Business Meets Technology

Cory B. Casanave
President & CEO

8605 Westwood Center Drive Suite 505 Vienna, VA, 22182 USA

Phone: +1-123-456-7890 Mobile: +1-111-555-7890 Fax: +1-111-111-1234 cory@example

This is an [hCard](#): the data come from a business card that Cory gave to Dan Connolly at ISWC; the email address and phone numbers have been scrubbed, but the other data is published in a [company info page](#) so we figure it's OK to use it here.

- profile <https://www.w3.org/2001/sw/grddl-wg/td/hcard.vcard> ...
- ... points to XSL transformation <http://www.w3.org/2006/vcard/hcard2vdt.xsl>
- ... which – executed on the original HTML file – extracts RDF

Where is the data? 3/4

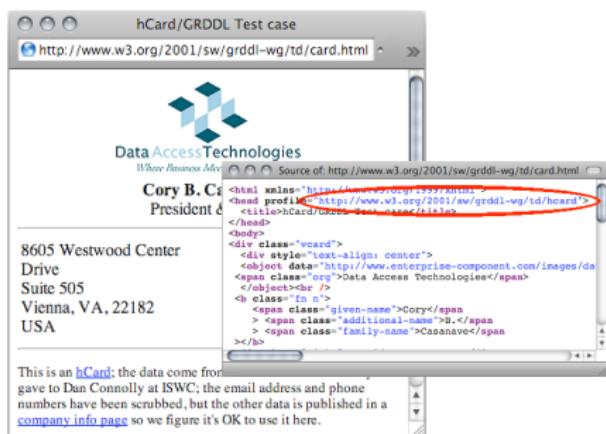
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The screenshot shows a web browser window titled "hCard/GRDDL Test case". The URL is <http://www.w3.org/2001/sw/grddl-wg/td/card.html>. The page content includes a logo for "Data Access Technologies" and contact information for "Cory B. Casanave". Below the contact info, there is a screenshot of the raw HTML code. A red circle highlights the XSLT transformation code in the head section:

```

<html xmlns="http://www.w3.org/1999/xhtml">
<head profile="http://www.w3.org/2001/sw/grddl-wg/td/hcard">
  <meta http-equiv="Content-Type" content="text/html; charset=UTF-8" />
  <title>vCard</title>
</head>
<body>
  <div style="text-align: center">
    <img alt="Data Access Technologies logo" data-bbox="245 485 305 525" />
    <span>Data Access Technologies</span>
    <br />
    <b>Cory B. Casanave</b>
    <br />
    President & CEO
  </div>
  <div class="vcard">
    <div>
      <span>8605 Westwood Center</span>
      <span>Drive</span>
      <span>Suite 505</span>
      <span>Vienna, VA, 22182</span>
      <span>USA</span>
    </div>
    <div>
      <span>8605 Westwood Center</span>
      <span>Drive</span>
      <span>Suite 505</span>
      <span>Vienna, VA, 22182</span>
      <span>USA</span>
    </div>
    <div>
      <span>Cory B. Casanave</span>
      <span>casanave@dataaccess.com</span>
    </div>
    <div>
      <span>+1 703 256 2222</span>
    </div>
  </div>
</body>

```

This is an [hCard](#); the data come from Dan Connolly at ISWC; the email address and phone numbers have been scrubbed, but the other data is published in a [company info page](#) so we figure it's OK to use it here.

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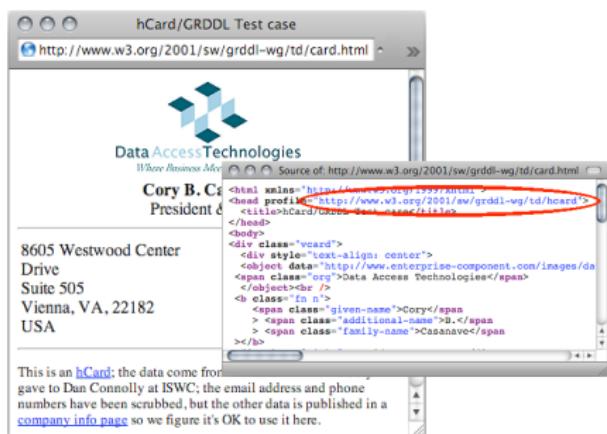
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The screenshot shows a web browser window with the title "hCard/GRDDL Test case". The URL in the address bar is <http://www.w3.org/2001/sw/grddl-wg/td/card.html>. The page content displays an hCard for "Cory B. Casanave" with the following details:
Name: Cory B. Casanave
Title: President & CEO
Organization: Data Access Technologies
Address: 8605 Westwood Center Drive Suite 505 Vienna, VA, 22182 USA
A note below states: "This is an [hCard](#); the data come from Dan Connolly at ISWC; the email address and phone numbers have been scrubbed, but the other data is published in a [company info page](#) so we figure it's OK to use it here."

The page source code is visible and includes the following XSLT transformation code, which is highlighted with a red circle:

```
<html xmlns="http://www.w3.org/1999/xhtml">
<head profile="http://www.w3.org/2001/sw/grddl-wg/td/hcard">
</head>
<body>
<div class="vcard">
<div style="text-align: center">
<img alt="Data Access Technologies logo" data-vcard="image">
<span class="org">Data Access Technologies</span>
<br />
<b>Cory B. Casanave</b>
<span class="title">President & CEO</span>
<span class="adr">
<span class="given-name">Cory</span>
<> <span class="additional-name">B.</span>
<> <span class="family-name">Casanave</span>
</span>
</div>
</div>
</body>
</html>
```

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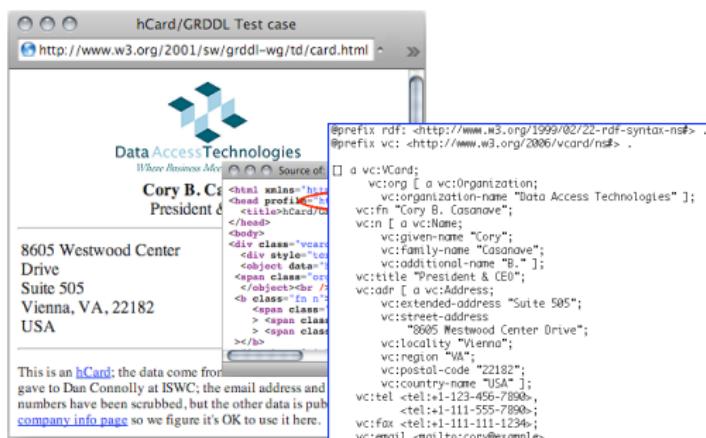
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```

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix vc: <http://www.w3.org/2006/vcard/ns#> .

d vc:VCard;
  vc:org [ a vc:Organization;
    vc:organization-name "Data Access Technologies" ];
  vc:fn "Cory B. Casanove";
  vc:n [ a vc:Name;
    vc:given-name "Cory";
    vc:family-name "Casanove";
    vc:additional-name "B." ];
  vc:title "President & CEO";
  vc:adr [ a vc:Address;
    vc:extended-address "Suite 505";
    vc:street-address "8605 Westwood Center Drive";
    vc:locality "Vienna";
    vc:region "VA";
    vc:postol-code "22182";
    vc:country-name "USA" ];
  vc:tel :tel1+1-123-456-7890;
    :tel1+1-111-555-7890;
  vc:fax <tel:+1-111-111-1234>;
  vc:email <mailto:cory@example.com> .
  
```

- profile [http://www.w3.org/2001/sw/grddl-wg/td/hcard...](http://www.w3.org/2001/sw/grddl-wg/td/hcard.html)
- ...points to XSL transformation
<http://www.w3.org/2006/vcard/hcard2rdf.xsl>
- ...which – executed on the original HTML file – extracts RDF.

Where is the data? 4/4

Obtaining Machine-Readable RDF data

(i) directly by the publishers, (ii) by GRDDL transformations, or (iii) by 3rd-party wrappers:

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

- 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/tplp/Berners-LeeCKSH08>, etc.
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- Other nice example: RDF+query interface for large parts of wikipedia:
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| Property | Value |
|------------------|---|
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/books/lmb/Subrahmanian2000> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/Bansal2005> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/Bawali2007> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/CavensicE00> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/ErgyETW00> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/EiterF98> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/EiterTW05> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/EiterM98> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/EiterM02> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/EiterW06> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/OhrzCE06> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/OhrzCE08> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/issi/PanzicaMP97> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/ijcai/Eiter06> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/ijcai/EiterP03> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/ijcai/BansalE04> |

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| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/CavensicE00> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/ErglyETW00> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/EiterF98b> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/EiterTW05> |
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| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/EiterM02> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/EiterW06> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/OhrzC06> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/PapadimitriouR05> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/PitkänenMP97> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/SinghS06> |
| is dc:creator of | <http://dblp.13s.de/d2r/resource/publications/conf/isa/EiterP03> |
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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? RDF Schema + OWL

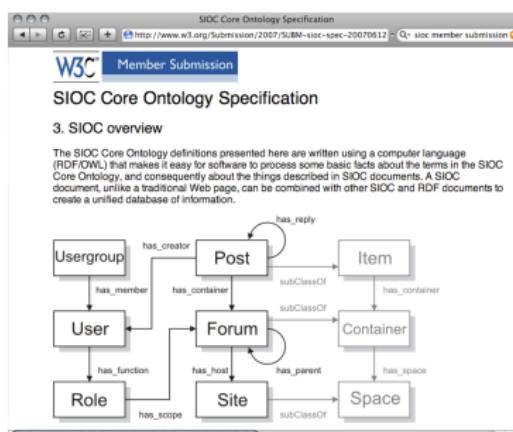
Data, i.e. the used *vocabulary* to write down RDF is described by *ontologies*, themselves published in RDF, e.g.:

- 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 | PersonalCollection | Project |

Properties: accountName | accountServiceHomepage | aimChatID | based_near | birthday | currentProject | depiction | depicts | dnsChecksum | family_name | firstName | fundedBy | geekode | gender | givenname | holdsAccount | homepage | icoChatID | img | interest | isPrimaryTopicOf | jabberID | knows | logo | made | maker | mbox | inbox | sha1sum | member | membershipClass | mensChatID | myensBraggs | name | nick | openid | page | pastProject | phone | plan | primaryTopic | publications | schoolHomepage | shal | sumname | theme | thumbnail | tipar | title | topic | topic_interest | weblog | workflowHomepage | workplaceHomepage | yahooChatID |



Outline

1. Motivation – Aggregating Linked Open Data by Rules & Ontologies
- 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?

Semantic Web Data: The Resource Description Framework (RDF)

- RDF is describing *resources* per triples/statements
Subject **Predicate** **Object**.
- “simplest possible database schema”, data just a set of triples:

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".

- 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)

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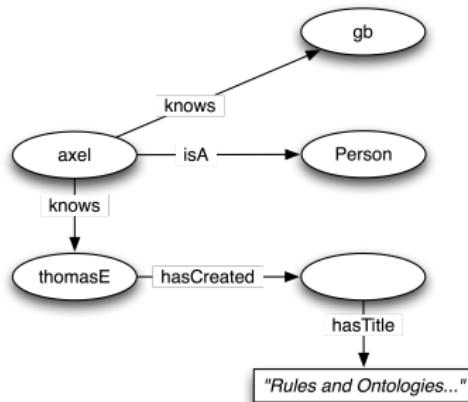
axel knows thomas.

$\exists X \text{ thomas hasCreated } X . X \text{ isA Article .}$

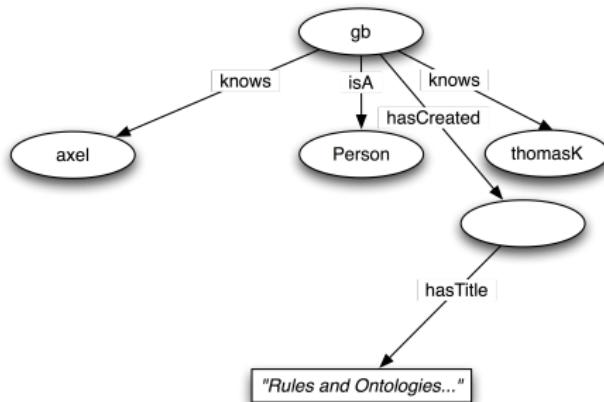
X hasTitle “Rules and Ontologies for the Semantic Web”.

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



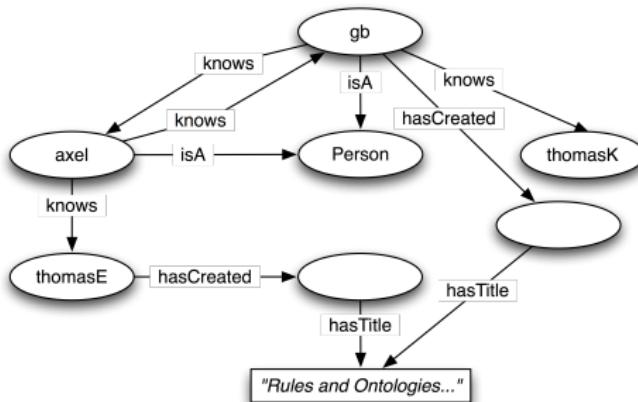
gb isA Person .
 gb knows axel .
 gb knows thomasK .
 gb hasCreated Y . Y isA Article .
 Y hasTitle "Rules and Ontologies..." .



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.

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

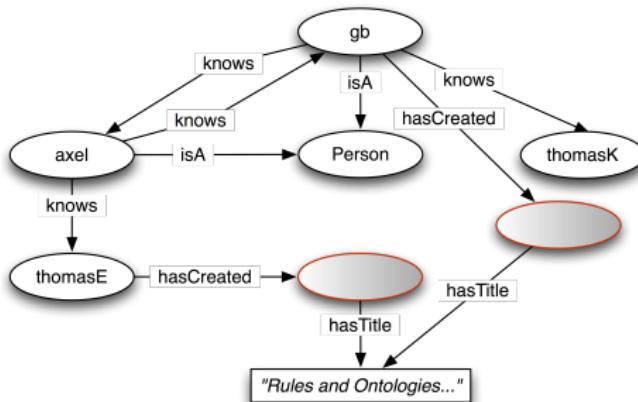
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A Syntax for RDF: Turtle

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)

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
- tools and APIs to convert from one syntax into the other, such as rapper (part of the Redland API, cf. <http://librdf.org/>), e.g.

```
rapper http://polleres.net/teaching/SemWebTech_2009/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, 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".
```

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 xsd: <http://www.w3.org/2001/XMLSchema#> .  
:me rdf:type foaf:Person .  
:me foaf:name "Axel Polleres" ; xsd:string .
```

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prefix xsd: <http://www.w3.org/2001/XMLSchema#> .  
:me rdf:type foaf:Person .  
:me foaf:name "Axel Polleres"^^xsd:string .
```

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axel hasName "Axel Polleres".*

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<http://polleres.net/foaf.rdf#me> <http://xmlns.com/foaf/0.1/name>
    "Axel Polleres"^^<http://www.w3.org/2001/XMLSchema#string>.
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@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
:me rdf:type foaf:Person .
:me foaf:name "Axel Polleres"^^xsd:string .
```

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```

More on RDF – Shortcuts in Turtle Syntax

```
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@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.13s.de/d2r/data/authors/Giovambattista_Ianni> .
:me foaf:knows <http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.13s.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`

■ 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.)

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/> .
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:me foaf:knows <http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> dc:creator _:x .
_:x rdf:type foaf:Document .
_:x dc:title "Rules and Ontologies for the Semantic Web".
```

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@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.13s.de/d2r/data/authors/Giovambattista_Ianni> ,
                <http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.13s.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`

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- (untyped literals with or without language tag are also called “plain” literals.)

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.13s.de/d2r/data/authors/Giovambattista_Ianni> ,
                <http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.13s.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`
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@prefix dc: <http://purl.org/dc/elements/1.1/> .

:me a foaf:Person;
    foaf:name "Axel Polleres";
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@prefix dc: <http://purl.org/dc/elements/1.1/> .

:me foaf:Person;
    foaf:name "Axel Polleres"^^xs:string;
    foaf:knows <http://dblp.13s.de/d2r/data/authors/Giovambattista_Ianni> ,
                <http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> .
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@prefix dc: <http://purl.org/dc/elements/1.1/> .

:me foaf:Person;
    foaf:name "Axel Polleres"^^xs:string;
    foaf:knows <http://dblp.13s.de/d2r/data/authors/Giovambattista_Ianni> ,
                <http://dblp.13s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.13s.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:
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More on RDF – Shortcuts in Turtle Syntax

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    foaf:knows <http://dblp.13s.de/d2r/data/authors/Giovambattista_Ianni> ,
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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++),² Jena (Java),³ 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/> .  
<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" ] .
```

²<http://librdf.org/>

³<http://jena.sourceforge.net/>

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```
@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" ] .
```

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

The screenshot shows a web browser window with two panes. The left pane displays a yellow-themed personal homepage for G.B. Ianni. It features a portrait photo, contact information (phone +39 0984 49 6430, fax +39 0984 49 6410), and a note about being an Assistant Professor at the Dipartimento di Matematica, Facoltà di Scienze M.F.N., Università della Calabria. Below this is a section titled "My FOAF card" with a link to "My FOAF card". The right pane shows the generated RDF code for this profile, starting with the prefix declarations and then listing various triples about the person.

```

<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:foaf="http://xmlns.com/foaf/0.1/"
    xmlns:mat="http://webmate.net/mwdb/#">
  <foaf:PersonalProfileDocument rdf:about="">
    <foaf:nick rdf:nodeID="me"/>
    <foaf:primaryTopic rdf:nodeID="me"/>
    <admin:generatorAgent rdf:resource="http://librdf.org/lodddo.com/foaf#foaf-a-matic"/>
    <admin:errorReportedBy rdf:resource="mailto:leight@lodddo.com"/>
    <foaf:PersonalProfileDocument>
      <foaf:Person rdf:nodeID="me">
        <foaf:name>Giovambattista Ianni</foaf:name>
        <foaf:givenName>Giovambattista</foaf:givenName>
        <foaf:family_name>Ianni</foaf:family_name>
        <foaf:homepage rdf:resource="http://www.gibbi.com"/>
        <foaf:depiction
          rdf:resource="http://www.gibbi.com/_l_002.jpg"/>
        <foaf:phone rdf:resource="tel:+39-0984-496430"/>
        <foaf:workplaceHomepage
          rdf:resource="http://www.mat.unical.it/ianni"/>
        <foaf:knows>
          <foaf:Person>
            <foaf:name>Xuel Polleres</foaf:name>
            <rdfs:seeAlso
              rdf:resource="http://www.polleres.net/foaf.rdf"/></foaf:Person></foaf:knows>
          <foaf:knows>
            <foaf:name>Wolfgang Faber</foaf:name>
            <rdfs:seeAlso
              rdf:resource="http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf"/></foaf:Person></foaf:knows>
        
```

foaf:name "Alessandra Martello"] .

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Outline

1. Motivation – Aggregating Linked Open Data by Rules & Ontologies
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, 2007] – based on graph pattern matching

| | | | |
|-----------|--------------------|---|--|
| Prologue: | P | PREFIX <i>prefix: <namespace-URI></i> | |
| Head: | C or S or A | CONSTRUCT { <i>template</i> } SELECT <i>variable list</i> ASK | ...construct a new RDF graph ...select matching resources/literals in a graph ...boolean query |
| Body: | D W M | FROM / FROM NAMED < <i>dataset-URI</i> > WHERE { <i>pattern</i> } ORDER BY <i>expression</i> LIMIT <i>integer</i> > 0 OFFSET <i>integer</i> > 0 | |

- 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

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- Let us start with SELECT queries and focus on the different **patterns**:
 - basic graph patterns (Conjunctive queries)
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 - 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
- all Turtle shortcuts allowed⁴
- 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
```

⁴ We assume here that the only people declared "known" in G.B.'s FOAF file are those known by him.

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"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 ] ]
}
```

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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 ]]  
}
```

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SELECT ?N  
WHERE {  
    [ foaf:knows  
        [ a foaf:Person; foaf:name ?N ]  
    }  
}
```

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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 ...
- ...i.e., we have to filter out the authors' names from the result.

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

“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.

UNIONs

“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.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.
- 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> |
| ... | |

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

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SELECT ?N ?L
FROM <http://www.polleres.net/foaf.rdf>
WHERE {<http://www.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" | |
| ... | |

OPTIONALs 2/2 – Set difference

“Select all names of persons known by Axel from his FOAF file who don’t have a rdfs:seeAlso links” query5.sparql

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

SELECT ?N
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 }
      FILTER ( ! bound(?L) )
    }
```

- OPTIONAL allows partial variable bindings in the solutions.
- The negated bound() function in the FILTER allows to suppress unbound values.
- This is similar to set difference (NOT EXISTS) in SQL or “negation as failure” in Logic Programming rules.
- Many more useful FILTER functions available in SPARQL.

OPTIONALs 2/2 – Set difference

“Select all names of persons known by Axel from his FOAF file who don’t have a rdfs:seeAlso links” query5.sparql

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

SELECT ?N
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 }
      FILTER ( ! bound(?L) )
    }
```

- OPTIONAL allows partial variable bindings in the solutions.
- The negated **bound()** function in the FILTER allows to suppress unbound values.
- This is similar to set difference (NOT EXISTS) in SQL or “negation as failure” in Logic Programming rules.
- Many more useful FILTER functions available in SPARQL

| ?N |
|--------------------------|
| "Alexandre Passant" |
| "Manfred Pfeiffenberger" |
| "Thomas Eiter" |

OPTIONALs 2/2 – Set difference

“Select all names of persons known by Axel from his FOAF file who don’t have a rdfs:seeAlso links” query5.sparql

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

SELECT ?N
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 }
       FILTER ( ! bound(?L) )
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```

- OPTIONAL allows partial variable bindings in the solutions.
- The negated bound() function in the FILTER allows to suppress unbound values.
- This is similar to set difference (NOT EXISTS) in SQL or “negation as failure” in Logic Programming rules.
- Many more useful FILTER functions available in SPARQL

| | |
|---|--------------------------|
| ? | N |
| | "Alexandre Passant" |
| | "Manfred Pfeiffenberger" |
| | "Thomas Eiter" |

OPTIONALs 2/2 – Set difference

“Select all names of persons known by Axel from his FOAF file who don’t have a rdfs:seeAlso links” query5.sparql

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

SELECT ?N
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 }
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GRAPH patterns

“Select all names of persons directly known by Axel or the names of persons appearing in the files linked by rdfs:seeAlso links.”

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

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

- named **GRAPH** patterns allow to match pattern in remote graphs
- the set of named graphs [Carroll *et al.*, 2005] typically needs to be statically declared in the dataset in current SPARQL implementations (`FROM NAMED` clause), details see [Prud'hommeaux and Seaborne, 2007], i.e. most SPARQL engines will not deliver the “expected” result here.
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SELECT ?N
FROM <http://www.polleres.net/foaf.rdf>
FROM NAMED???
WHERE {<http://www.polleres.net/foaf.rdf#me> foaf:knows ?X .
      { ?X foaf:name ?N .}
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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.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
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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> ?"`

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

- `<http://dblp.13s.de/d2r/resource/authors/Jim_Hendler> = <http://www.cs.rpi.edu/~hendler/foaf.rdf#jhendler>`

although, in `http://polleres.net/foaf.rdf` there is a triple:

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More on that later...

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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 but have not co-authored with any of the authors of

<http://dblp.13s.de/d2r/resource/publications/journals/tplp/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
- Extensions of SPARQL (updates (DELETE, INSERT, ...), aggregate functions (SUM, MAX, COUNT,...), etc.) currently being discussed in W3C, e.g. [esw-wiki,]
- 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, 2007])
- SPARQL itself may be viewed as a “rules language” (CONSTRUCT): Translation of SPARQL to rules [Schenk and Staab, 2008][Polleres, 2007]
- SPARQL only does RDF graph pattern matching, what about ontologies?
... Let’s take a look at this next!

Outline

1. Motivation – Aggregating Linked Open Data by Rules & Ontologies
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.
- By vocabulary, we mean here mostly:
 - *properties*, i.e., predicates
 - *classes*, i.e., objects of `rdf:type` triples
 - (*individuals*, i.e., concrete objects)⁵
- 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)*
 - *img is a relation between Persons and Images (domain/range)*
 - *knows is a relation between two Persons (domain/range)*
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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*⁶
 - *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)

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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.
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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 .  
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_:me foaf:knows [ a foaf:Person .  
    foaf:name "Alessandra Martello" ] .
```

The Semantics of RDF graphs:

Each RDF graph can “roughly” be viewed as a first-order formula:

```
∃me, 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 community favors unary/binary predicate representation:

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

- 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:

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

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

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Note 1:

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

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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

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

⋮

Data:

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

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

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

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

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```
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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 [Patel-Schneider *et al.*, 2004]
 - in terms of its RDF reading (OWL Full semantics), and
 - in terms of its Description Logics reading (OWL DL semantics)⁷

⁷ OWL DL puts restrictions on the use of the OWL and RDF vocabulary, e.g. classes may not be used as instances, etc., for instance `one rdf:type integer . integer rdf:type simpleDatatype .` would not be allowed.

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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 two slides: 1/2

Expressing property characteristics:

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

Expressing complex class descriptions:

| OWL complex class descriptions* | DL syntax | FOL short representation |
|---|-------------------------------|--|
| owl:Thing | \top | $x = x$ |
| owl:Nothing | \perp | $\neg x = x$ |
| $\text{owl:intersectionOf } (C_1 \dots C_n)$ | $C_1 \sqcap \dots \sqcap C_n$ | $C_1(x) \wedge \dots \wedge C_n(x)$ |
| $\text{owl:unionOf } (C_1 \dots C_n)$ | $C_1 \sqcup \dots \sqcup C_n$ | $C_1(x) \vee \dots \vee C_n(x)$ |
| $\text{owl:complementOf } (C)$ | $\neg C$ | $\neg C(x)$ |
| $\text{owl:oneOf } (o_1 \dots o_n)$ | $\{o_1, \dots, o_n\}$ | $x = o_1 \vee \dots \vee x = o_n$ |
| $\text{owl:restriction } (P \text{ owl:someValuesFrom } (C))$ | $\exists P.C$ | $\exists y. P(x, y) \wedge C(y)$ |
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| $\text{owl:restriction } (P \text{ owl:minCardinality } (n))$ | $\geqslant nP$ | $\exists y_1 \dots y_n. \bigwedge_{k=1}^n P(x, y_k) \wedge \bigwedge_{i < j} y_j \neq y_j$ |
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* For reasons of legibility, we use a variant of the OWL abstract syntax [Patel-Schneider *et al.*, 2004] in this table.

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OWL DL in two slides: 2/2

Relating Class descriptions:

$$\begin{array}{ll} C_1 \text{ rdfs:subClassOf } C_1 & C_1 \sqsubseteq C_2 \\ C_1 \text{ owl:equivalentClass } C_2 & C_1 \equiv C_2 \\ C_1 \text{ owl:disjointWith } C_2 & C_1 \sqcap C_2 \sqsubseteq \perp \end{array}$$

Relating individuals:

$$\begin{array}{ll} o_1 \text{ owl:sameAs } o_1 & o_1 = o_2 \\ o_1 \text{ owl:differentFrom } o_2 & o_1 \neq o_2 \end{array}$$

Examples:

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

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

... in OWL/RDF syntax:

```
foaf:homepage rdf:type owl:InverseFunctionalProperty .
```

... in DL syntax:

$$\top \sqsubseteq \leqslant 1 \text{homepage}^{-}$$

Example inference:

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```

$$\models$$

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

OWL Example: A simple ontology about reviewers

$\exists ex:title. \top \sqsubseteq ex:Paper$ (i)

$\exists ex:title^{-}. \top \sqsubseteq xsd:string$ (ii)

$ex:isAuthorOf^{-} \equiv dc:creator$ (iii)

$ex:Publication \equiv ex:Paper \sqcap \exists ex:publishedIn. \top$ (iv)

$\top \sqsubseteq \leqslant 1 ex:publishedIn^{-}$ (v)

$ex:Senior \equiv foaf:Person \sqcap \geqslant 10 ex:isAuthorOf \sqcap$ (vi)

$\exists ex:isAuthorOf.ex:Publication$

$ex:Club100 \equiv foaf:Person \sqcap \geqslant 100 ex:isAuthorOf$ (vii)

- A Publication is a Paper which has been published (iv)

`ex:Publication owl:intersectionOf (ex:Paper [a owl:Restriction; owl:onProperty ex:publishedIn ; owl:minCardinality 1]) .8`

- isAuthorOf is the opposite of Dublin Core's dc:creator Property (iii)

`ex:isAuthorOf owl:inverseOf dc:creator .`

- A Senior researcher is a foaf:Person who isAuthorOf 10+ Publications (vi)⁹

`ex:Senior owl:intersectionOf (foaf:Person [a owl:Restriction; owl:onProperty ex:isAuthorOf ; owl:minCardinality 10] [a owl:Restriction; owl:onProperty ex:isAuthorOf ; owl:someValuesFrom ex:Publication]) .`

- Each item can be publishedIn at most one venue (v)

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Reasoning with Ontologies

Tools:

- Special purpose DL reasoners:
Pellet [Sirin *et al.*, 2005], Racer [Haarslev and Möller, 2001], Fact++ [Tsarkov and Horrocks, 2006]
- General purpose FOL theorem provers:
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SPARQL & Ontologies

SPARQL on top of ontologies not (yet) entirely clear (cf. [Arenas *et al.*, , Unit 5b]):

- Problem 1: infinite RDFS/OWL inferences on a finite graph
- Problem 2: co-reference of blank nodes in SPARQL solutions
- Problem 3: SPARQL is SQL inspired (CWA), OWL/RDFS are (OWA):
e.g., OPTIONAL patterns are non-monotonic, RDFS+OWL inference are both monotonic, that can lead to query answers valid under simple RDF, but not under OWL entailment, etc.

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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)

Further tutorials available on request!

What's next? Further possible Tutorial topics

- Details on the semantics of RDF+RDFS
- Details on the semantics of SPARQL, and why SPARQL+RDFS is not trivial.
- Details on OWL, and sneak-preview on OWL2
- Sneak-preview on RIF (Rule Interchange Format)
- Practical applications of Reasoning about Web Data.

-  Ben Adida, Mark Birbeck, Shane McCarron, and Steven Pemberton (eds.).
Rdfa in xhtml: Syntax and processing, October 2008.
W3C Recommendation, available at <http://www.w3.org/TR/rdfa-syntax/>.
-  Marcelo Arenas, Claudio Gutierrez, Bijan Parsia, Jorge Pérez, Axel Polleres, and Andy Seaborne.
-  Tags for identifying languages, September 2006.
available at <http://www.rfc-editor.org/rfc/bcp/bcp47.txt>.
-  Dave Beckett and Tim Berners-Lee.
Turtle - Terse RDF Triple Language, January 2008.
W3C Team Submission, <http://www.w3.org/TeamSubmission/turtle/>.
-  Dave Beckett and Brian McBride (eds.).
Rdf/xml syntax specification (revised), February 2004.
W3C Recommendation, available at
<http://www.w3.org/TR/rdf-syntax-grammar/>.
-  Tim Berners-Lee and Dan Connolly.
Notation3 (N3): A readable RDF Syntax, January 2008.
W3C Team Submission, <http://www.w3.org/TeamSubmission/n3/>.
-  Uldis Bojārs, John G. Breslin, Diego Berrueta, Dan Brickley, Stefan Decker, Sergio Fernández, Christoph Görn, Andreas Harth, Tom Heath, Kingsley Idehen, Kjetil Kjernsmo, Alistair Miles, Alexandre Passant, Axel Polleres, Luis Polo, and Michael Sintek.
SIOC Core Ontology Specification, June 2007.
W3C member submission.

-  Dan Brickley and R.V. Guha (eds.).
RDF vocabulary description language 1.0: RDF Schema, February 2004.
W3C Recommendation, available at <http://www.w3.org/TR/rdf-schema/>.
-  Dan Brickley and Libby Miller.
FOAF Vocabulary Specification 0.91, November 2007.
<http://xmlns.com/foaf/spec/>.
-  Jeremy Carroll, Christian Bizer, Pat Hayes, and Patrick Stickler.
Named graphs.
Journal of Web Semantics, 3(4), 2005.
-  Dan Connolly (ed.).
Gleaning Resource Descriptions from Dialects of Languages (GRDDL), September 2007.
-  ESW Wiki: SPARQL.
List of useful links for SPARQL implementations and extensions,
<http://esw.w3.org/topic/SPARQL/>.
-  Claudio Gutiérrez, Carlos A. Hurtado, and Alberto O. Mendelzon.
Foundations of semantic web databases.
In *PODS*, pages 95–106, 2004.
-  V. Haarslev and R. Möller.
RACER System Description.
In *Proceedings of the First International Joint Conference on Automated Reasoning (IJCAR 2001)*, volume 2083 of *Lecture Notes in Computer Science (LNCS)*, pages 701–705. Springer Verlag, 2001.

-  Michael Hausenblas, Ivan Hermann, and Ben Adida.
Rdfa - bridging the web of documents and the web of data, 2008.
Tutorial given at ISWC2008, available at
<http://www.w3.org/2008/Talks/1026-ISCW-RDFa/RDFa-ISWC08.html>.
-  P. Hayes.
RDF semantics, 2004.
<http://www.w3.org/TR/rdf-mt/>.
-  Mikael Nilsson, Andy Powell, Pete Johnston, and Ambjörn Naeve.
Expressing dublin core metadata using the resource description framework (rdf), January 2008.
DCMI Recommendation.
-  Peter F. Patel-Schneider, Patrick Hayes, and Ian Horrocks.
OWL Web Ontology Language Semantics and Abstract Syntax, February 2004.
W3C Recommendation.
-  Jorge Pérez, Marcelo Arenas, and Claudio Gutierrez.
Semantics and complexity of sparql.
In *International Semantic Web Conference (ISWC 2006)*, pages 30–43, 2006.
-  Axel Polleres.
From SPARQL to rules (and back).
In *Proceedings of the 16th World Wide Web Conference (WWW2007)*, Banff, Canada, May 2007.
-  SPARQL Query Language for RDF, January 2007.

W3C Recommendation, available at

<http://www.w3.org/TR/2008/REC-rdf-sparql-query-20080115/>.



Alexandre Riazanov and Andrei Voronkov.

The design and implementation of vampire.

AI Communications, 15(2-3):91–110, 2002.



Simon Schenk and Steffen Staab.

Networked graphs: A declarative mechanism for sparql rules, sparql views and rdf data integration on the web.

In *Proceedings WWW-2008*, pages 585–594, 2008.



Evren Sirin, Bijan Parsia, Bernardo Cuenca Grau, Aditya Kalyanpur, and Yarden Katz.

Pellet: A practical OWL-DL reasoner.

Technical Report 68, UMIACS, University of Maryland, 2005.



Spass: An automated theorem prover for first-order logic with equality.

Available at <http://www.spass-prover.org/>.



Mark E. Stickel, Richard J. Waldinger, and Vinay K. Chaudhr.

A guide to snark.

Available at <http://www.ai.sri.com/snark/tutorial/tutorial.html>.



Dmitry Tsarkov and Ian Horrocks.

Fact++ Description Logic Reasoner: System Description.

In *Proceedings of the Third International Joint Conference on Automated Reasoning (IJCAR 2006)*, 2006.

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Some advanced SPARQL Examples

- Solution modifiers
- Blank nodes in Basic Graph patterns
- Blank nodes in CONSTRUCT queries
- Bag semantics, i.e. duplicates in solutions to SELECT queries
- Unsafe FILTERs
- FILTERs in OPTIONALs

Solution Modifiers

- LIMIT
- OFFSET
- ORDER BY

Example:

Give me the first 1000 Austrian scientists in DBpedia
([query_for_DBPEDIA_endpoint.sparql](#))

Blank nodes in Basic Graph patterns

Attention:

“The same blank node label may not be used in two separate basic graph patterns with a single query.”

This restriction allows us to treat all blank nodes just as variables, so no extra care for blank nodes is needed, normally.

Bottom line:

Preprocessing step 1:

Blank nodes in queries can be replaced equally using a unique, “fresh” variable for each blank node, the semantics of the query stays the same.

Blank nodes in Basic Graph patterns – Example

An example to illustrate this issue:

query⁹ : “*SELECT all persons known who have a homepage.*”

```
SELECT ?X  
FROM <http://www.polleres.net/foaf.rdf>  
WHERE { { _:b foaf:knows ?X } {?X foaf:homepage _:b}
```

That one would not be compliant with the current spec!

Blank nodes in Basic Graph patterns – Example

An example to illustrate this issue:

query 9b: “*SELECT all persons known who have a homepage.*”

```
SELECT ?X  
FROM <http://www.polleres.net/foaf.rdf>  
WHERE { _:b foaf:knows ?X . ?X foaf:homepage _:b }
```

Different meaning: *SELECT all persons known by their homepage.*

Blank nodes in Basic Graph patterns – Example

An example to illustrate this issue:

query9c: “*SELECT all persons known who have a homepage.*”

```
SELECT ?X  
FROM <http://www.polleres.net/foaf.rdf>  
WHERE { { _:b1 foaf:knows ?X } {?X foaf:homepage _:b2}
```

That one would work!

Blank nodes in Basic Graph patterns – Example

An example to illustrate this issue:

query 9d: “*SELECT all persons known who have a homepage.*”

```
SELECT ?X
FROM <http://www.polleres.net/foaf.rdf>
WHERE { { ?B1 foaf:knows ?X } { ?X foaf:homepage ?B2 }
```

That one is equivalent! Bnodes can be “treated” as variables

Blank nodes in CONSTRUCT queries

- CONSTRUCT queries allow an arbitrary basic graph pattern (set of triples with maybe variables) which is used to construct a new graph as the RDF merge, of all solution mappings applied to the construct template.

This semantics ensures that

- blank nodes in CONSTRUCT pattern are treated correctly (fresh bnode for each solution)
- only valid RDF triples are constructed ($UB \times U \times UBL$)

Some examples to understand this treatment...

Blank nodes in CONSTRUCT queries

- CONSTRUCT queries allow an arbitrary basic graph pattern (set of triples with maybe variables) which is used to construct a new graph as the RDF merge, of all solution mappings applied to the construct template.

This semantics ensures that

- blank nodes in CONSTRUCT pattern are treated correctly (fresh bnode for each solution)
- only valid RDF triples are constructed ($UB \times U \times UBL$)

Some examples to understand this treatment...

Blank nodes in CONSTRUCT queries – Example 1

query10: “Anonymizing the people Alice knows”

G_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .  
ex:alice foaf:name "Alice".  
ex:alice foaf:knows _:d.  
_:d foaf:name "Dorothy".
```

```
CONSTRUCT { ex:alice foaf:knows _:b }  
FROM  $G_{11}$   
WHERE { ex:alice foaf:knows ?X }
```

Result graph:

```
ex:alice foaf:knows _:genid1 .  
ex:alice foaf:knows _:genid2 .  
ex:alice foaf:knows _:genid3 .
```

The blank node labels, i.e., variable names, in the result graph can differ from implementation to implementation...

...in Turtle syntax also possible here: anonymous blank nodes.

Blank nodes in CONSTRUCT queries – Example 1

query10: “Anonymizing the people Alice knows”

G_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .  
ex:alice foaf:name "Alice".  
ex:alice foaf:knows _:d.  
_:d foaf:name "Dorothy".
```

```
CONSTRUCT { ex:alice foaf:knows _:b }  
FROM  $G_{11}$   
WHERE { ex:alice foaf:knows ?X }
```

Result graph:

```
ex:alice foaf:knows [] .  
ex:alice foaf:knows [] .  
ex:alice foaf:knows [] .
```

The blank node labels, i.e., variable names, in the result graph can differ from implementation to implementation...

...in Turtle syntax also possible here: **anonymous** blank nodes.

Blank nodes in CONSTRUCT queries – Example 2

query11 : “What is the node ex:alice connected to?”

G_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .  
ex:alice foaf:name "Alice".  
ex:alice foaf:knows _:d.  
_:d foaf:name "Dorothy".
```

```
CONSTRUCT { ex:alice ex:connectsTo ?N }  
FROM  $G_{11}$   
WHERE { ex:alice ?P ?N }
```

Result graph:

```
ex:alice ex:connectsTo ex:bob .  
ex:alice ex:connectsTo ex:charles .  
ex:alice ex:connectsTo [] .  
ex:alice ex:connectsTo "Alice".
```

In subject position, no literals allowed, the following “solution triple” is suppressed:
“Alice” ex:connectedTo ex:alice.

Note: the output graph can be *non-lean* (i.e. have redundant triples)!

Blank nodes in CONSTRUCT queries – Example 2

query11b: “What is the node `ex:alice` connected to?”

G_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .  
ex:alice foaf:name "Alice".  
ex:alice foaf:knows _:d.  
_:d foaf:name "Dorothy".
```

```
CONSTRUCT { ?N ex:isConnectedTo ex:alice }  
FROM  $G_{11}$   
WHERE { ex:alice ?P ?N }
```

Result graph:

```
ex:bob ex:isConnectedTo ex:alice .  
ex:charles ex:isConnectedTo ex:alice .  
[] ex:isConnectedTo ex:alice .
```

In subject position, no literals allowed, the following “solution triple” is suppressed:

`"Alice"` ex:connectedTo ex:alice.

Note: the output graph can be *non-lean* (i.e. have redundant triples)!

Bag semantics

Essentially:

- SPARQL allows duplicate solutions, these may arise from
 - UNION patterns
 - Projections (i.e., variables projected away in the result form)

Some examples on that...

Bag semantics – Example 1: Duplicates from UNION

query12 : “Who knows bob OR Charles”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
SELECT ?X  
FROM  $G_{11}$   
WHERE { { ?X foaf:knows ex:bob }  
        UNION { ?X foaf:knows ex:charles} }
```

Result:

| ?X |
|----------|
| ex:alice |
| ex:alice |

Bag semantics – Example 1: Duplicates from UNION

query12b: “Who knows bob OR Charles”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
SELECT DISTINCT ?X  
FROM  $G_{11}$   
WHERE { { ?X foaf:knows ex:bob }  
        UNION { ?X foaf:knows ex:charles} }
```

Result:

| | |
|----------|---|
| ? | X |
| ex:alice | |

Bag semantics – Example 1: Duplicates from UNION

`query12c`: “Who knows bob OR Charles”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
CONSTRUCT { ?X rdf:type ex:BobOrCharlesKnower }  
FROM  $G_{11}$   
WHERE { { ?X foaf:knows ex:bob }  
        UNION { ?X foaf:knows ex:charles} }
```

Result graph:

```
ex:alice rdf:type ex:BobOrCharlesKnower .
```

Bag semantics – Example 1: Duplicates from UNION

`query12d`: “Who knows bob OR Charles”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
CONSTRUCT { _:X rdf:type ex:BobOrCharlesKnower }  
FROM  $G_{11}$   
WHERE { { ?X foaf:knows ex:bob }  
        UNION { ?X foaf:knows ex:charles} }
```

Result graph:

```
_:genid1 rdf:type ex:BobOrCharlesKnower .  
_:genid2 rdf:type ex:BobOrCharlesKnower .
```

Note here: Blank nodes in CONSTRUCT also are affected by duplicate solutions!

Bag semantics – Example 1: Duplicates from UNION

query12d: “Who knows bob OR Charles”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
CONSTRUCT { _:Y rdf:type ex:BobOrCharlesKnower }  
FROM  $G_{11}$   
WHERE { { ?X foaf:knows ex:bob }  
        UNION { ?X foaf:knows ex:charles} }
```

Result graph:

```
_:genid1 rdf:type ex:BobOrCharlesKnower .  
_:genid2 rdf:type ex:BobOrCharlesKnower .
```

Note here: Blank nodes in CONSTRUCT also are affected by duplicate solutions!

The blank node id in a construct template is completely irrelevant

Bag semantics – Example 1: Duplicates from UNION

query12d: “Who knows bob OR Charles”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
CONSTRUCT { [] rdf:type ex:BobOrCharlesKnower }  
FROM  $G_{11}$   
WHERE { { ?X foaf:knows ex:bob }  
        UNION { ?X foaf:knows ex:charles} }
```

Result graph:

```
_:genid1 rdf:type ex:BobOrCharlesKnower .  
_:genid2 rdf:type ex:BobOrCharlesKnower .
```

Note here: Blank nodes in CONSTRUCT also are affected by duplicate solutions!

The blank node id in a construct template is completely irrelevant

Bag semantics – Example 2: Duplicates from projection

[query12e](#): “Who knows whom?”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
SELECT ?X ?Y  
FROM  $G_{11}$   
WHERE { ?X foaf:knows ?Y }
```

Result:

| ?X | ?Y |
|----------|------------|
| ex:alice | ex:bob |
| ex:alice | ex:charles |

Bag semantics – Example 2: Duplicates from projection

[query12f](#): “Who knows somebody?”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
SELECT ?X  
FROM  $G_{11}$   
WHERE { ?X foaf:knows ?Y }
```

Result:

| ?X |
|----------|
| ex:alice |
| ex:alice |

Bag semantics – Example 2: Duplicates from projection

[query12g](#): “Who knows somebody?”

G'_{11} :

```
ex:alice foaf:knows ex:bob .  
ex:alice foaf:knows ex:charles .
```

```
SELECT ?X  
FROM  $G_{11}$   
WHERE { ?X foaf:knows [] }
```

Result:

| ?X |
|----------|
| ex:alice |
| ex:alice |

Unsafe FILTERs and Errors in FILTERs

For patterns of the form $(P \text{ FILTER } R)$

- variables, appearing in R but not in P are problematic.
- complex filter expression, i.e. if R uses \neg , \wedge , \vee follow a 3-valued logic (\top , \perp , err)

Unsafe FILTER expression

Given a pattern $(P \text{ FILTER } R)$ we call R **unsafe** if it contains a variable not occurring in P .

Unsafe FILTERs – Examples

G₁₂:

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query13:

```
SELECT ?X ?H  
WHERE { ?X rdf:type foaf:Person. ?X foaf:homepage ?H .  
?X ex:age ?A FILTER( ?A > 30 ) }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:charles | ex:hp2 |

“Unsafe” variables in FILTERs just have to be treated as **unbound**, so the FILTER evaluates to “*unbound > 30*” which is an error, thus the FILTER expression always fails, independent of the input graph.

Unsafe FILTERs – Examples

G_{12} :

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query13b:

```
SELECT ?X ?H  
WHERE { ?X rdf:type foaf:Person. ?X foaf:homepage ?H .  
       FILTER( ?A > 30 ) }
```

Result:

| | |
|----|----|
| ?X | ?H |
|----|----|

“Unsafe” variables in FILTERs just have to be treated as **unbound**, so the FILTER evaluates to “*unbound* > 30” which is an error, thus the FILTER expression always fails, independent of the input graph.

Unsafe FILTERs – Examples

Note: unbound variables do not always yield the overall FILTER expression to fail!

G_{12} :

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query13c:

```
SELECT ?X ?H  
WHERE { ?X rdf:type foaf:Person. ?X foaf:homepage ?H  
      FILTER( ! bound(?A) ) }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:bob | ex:hp1 |
| ex:charles | ex:hp2 |

That one is no problem!

However, there are exceptions concerning unsafe FILTERs...

Unsafe FILTERs – Examples

Note: unbound variables do not always yield the overall FILTER expression to fail!

G_{12} :

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query13c:

```
SELECT ?X ?H  
WHERE { ?X rdf:type foaf:Person. ?X foaf:homepage ?H  
      FILTER( ! bound(?A) ) }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:bob | ex:hp1 |
| ex:charles | ex:hp2 |

That one is no problem!

However, there are **exceptions** concerning unsafe FILTERs...

“Unsafe” FILTERs – Exception 1: Filters within a group

[Prud'hommeaux and Seaborne, 2007, Section 5.2.2] “*A constraint, expressed by the keyword FILTER, is a restriction on solutions over the whole group in which the filter appears.*”

G_{12} :

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query14:

```
SELECT ?X ?H  
WHERE { ?X rdf:type foaf:Person. FILTER( isIRI(?H) ) ?X foaf:homepage ?H }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:bob | ex:hp1 |
| ex:charles | ex:hp2 |

“Unsafe” FILTERs – Exception 1: Filters within a group

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G_{12} :

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query14b:

```
SELECT ?X ?H  
WHERE { { ?X rdf:type foaf:Person. } FILTER( isIRI(?H) ) { ?X foaf:homepage ?H } }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:bob | ex:hp1 |
| ex:charles | ex:hp2 |

“Unsafe” FILTERs – Exception 1: Filters within a group

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```

query14c:

```
SELECT ?X ?H  
WHERE { ?X rdf:type foaf:Person. ?X foaf:homepage ?H FILTER( isIRI(?H) ) }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:bob | ex:hp1 |
| ex:charles | ex:hp2 |

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G_{12} :

```
ex:bob a foaf:Person; foaf:homepage ex:hp1; ex:age 20 .  
ex:charles a foaf:Person; foaf:homepage ex:hp2; ex:age 40 .
```

query14d: BUT:

```
SELECT ?X ?H  
WHERE { ( ?X rdf:type foaf:Person. FILTER( isIRI(?H) ) ) ?X foaf:homepage ?H }
```

Result:

| | |
|----|----|
| ?X | ?H |
|----|----|

“Unsafe” FILTERs – Exception 1: Filters within a group

Actually, this is not really an “exception”, but just a matter of translation to the relational syntax, where FILTERs are always moved last and are concatenated.

Normalization, i.e. exhaustive application of the following rules:

- $P_1 \text{ FILTER } R \ P_2 \Rightarrow ((P_1 \text{ AND } P_2) \text{ FILTER } R)$
- $(P \text{ FILTER } R_1) \text{ FILTER } R_2 \Rightarrow (P \text{ FILTER } (R_1 \wedge R_2))$

Intuitively: move FILTERs always to the end within a group, before evaluating the semantics.

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Intuitively: move FILTERs always to the end within a group, before evaluating the semantics.

Unsafe FILTERs – Exception 2: FILTERs in OPTIONALs

“select names, and homepages only of those older than 30”

G_{12} as before.

[query15](#):

```
SELECT ?X ?H
WHERE { ?X rdf:type foaf:Person. ?X ex:age ?A
        OPTIONAL { ?X foaf:homepage ?H FILTER( ?A > 30 ) } }
```

Result:

| ?X | ?H |
|------------|--------|
| ex:bob | |
| ex:charles | ex:hp2 |

$\{\mu_1 = \{X \rightarrow \text{bob}\}, \mu_2 = \{X \rightarrow \text{charles}, H \rightarrow \text{hp2}\}$

Complex FILTERs

Attention! \wedge ($&&$), \vee ($||$), \neg ($!$), in SPARQL FILTERs are not evaluated with respect to the usual boolean algebra, but (similar to SQL) in a 3-valued logic.

e.g. `eval("40"^^xs:integer > "30"^^xs:integer) = true,`
`eval("20"^^xs:integer > "20"^^xs:integer) = false,`
`eval("old" > "30"^^xs:integer) = err`

(cf. [query16](#), similar for [query13b](#) before)

Since a FILTER constraint R can result not only in *true* and *false*, but also in *err*, the semantics of FILTERs has to reflect that:

$eval(R)$:

| R | $\neg R$ |
|--------------|--------------|
| <i>true</i> | <i>false</i> |
| <i>false</i> | <i>true</i> |
| <i>err</i> | <i>err</i> |

| R_1 | R_2 | $R_1 \wedge R_2$ |
|--------------|--------------|------------------|
| <i>true</i> | <i>true</i> | <i>true</i> |
| <i>true</i> | <i>false</i> | <i>false</i> |
| <i>false</i> | <i>true</i> | <i>false</i> |
| <i>false</i> | <i>false</i> | <i>false</i> |
| <i>true</i> | <i>err</i> | <i>err</i> |
| <i>err</i> | <i>true</i> | <i>err</i> |
| <i>false</i> | <i>err</i> | <i>false</i> |
| <i>err</i> | <i>false</i> | <i>false</i> |
| <i>err</i> | <i>err</i> | <i>err</i> |

| R_1 | R_2 | $R_1 \vee R_2$ |
|--------------|--------------|----------------|
| <i>true</i> | <i>true</i> | <i>true</i> |
| <i>true</i> | <i>false</i> | <i>true</i> |
| <i>false</i> | <i>true</i> | <i>true</i> |
| <i>false</i> | <i>false</i> | <i>false</i> |
| <i>true</i> | <i>err</i> | <i>true</i> |
| <i>err</i> | <i>true</i> | <i>true</i> |
| <i>false</i> | <i>err</i> | <i>err</i> |
| <i>err</i> | <i>false</i> | <i>err</i> |
| <i>err</i> | <i>err</i> | <i>err</i> |

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| R | $\neg R$ |
|--------------|--------------|
| <i>true</i> | <i>false</i> |
| <i>false</i> | <i>true</i> |
| <i>err</i> | <i>err</i> |

| R_1 | R_2 | $R_1 \wedge R_2$ |
|--------------|--------------|------------------|
| <i>true</i> | <i>true</i> | <i>true</i> |
| <i>true</i> | <i>false</i> | <i>false</i> |
| <i>false</i> | <i>true</i> | <i>false</i> |
| <i>false</i> | <i>false</i> | <i>false</i> |
| <i>true</i> | <i>err</i> | <i>err</i> |
| <i>err</i> | <i>true</i> | <i>err</i> |
| <i>false</i> | <i>err</i> | <i>false</i> |
| <i>err</i> | <i>false</i> | <i>false</i> |
| <i>err</i> | <i>err</i> | <i>err</i> |

| R_1 | R_2 | $R_1 \vee R_2$ |
|--------------|--------------|----------------|
| <i>true</i> | <i>true</i> | <i>true</i> |
| <i>true</i> | <i>false</i> | <i>true</i> |
| <i>false</i> | <i>true</i> | <i>true</i> |
| <i>false</i> | <i>false</i> | <i>false</i> |
| <i>true</i> | <i>err</i> | <i>true</i> |
| <i>err</i> | <i>true</i> | <i>true</i> |
| <i>false</i> | <i>err</i> | <i>err</i> |
| <i>err</i> | <i>false</i> | <i>err</i> |
| <i>err</i> | <i>err</i> | <i>err</i> |

Complex FILTERs – Example

query17:

```
SELECT ?X ?A
WHERE { ?X rdf:type foaf:Person.    ?X ex:age ?A
        FILTER ( !(?A > ?X) && (?A > 20) ) }
```

Complex FILTERs – Example

query17:

```
SELECT ?X ?A  
WHERE { ?X rdf:type foaf:Person. ?X ex:age ?A  
        FILTER ( !(?A > ?X) && (?A > 20) ) }
```

This will not return a result, because comparison of a literal and a resource yields *err*:

$$\text{eval}(\neg \text{err} \wedge \text{true}) = \text{err}$$

$$\text{eval}(\neg \text{err} \wedge \text{false}) = \text{false}$$

$$\text{eval}(\neg \text{err} \wedge \text{err}) = \text{err}$$

Complex FILTERs – Example

query17b:

```
SELECT ?X ?A  
WHERE { ?X rdf:type foaf:Person. ?X ex:age ?A  
        FILTER ( !( ?A > ?X ) && (?A > 20) ) }
```

This one works for $\mu = \{?X \rightarrow \text{ex:bob}, ?A \rightarrow 20\}$:

| ?X | ?A |
|--------|----|
| ex:bob | 20 |

$$\text{eval}(\neg(\text{err} \wedge \text{false})) = \text{true}$$

Further information and slides, cf.

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

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