DERI Tutorials

Welcome!

Dr. Axel Polleres, DERI, NUI Galway

National University of Ireland, Galway
Ollscoil na hÉireann, Gaillimh

science foundation ireland
fondúireacht eolaíochta éireann

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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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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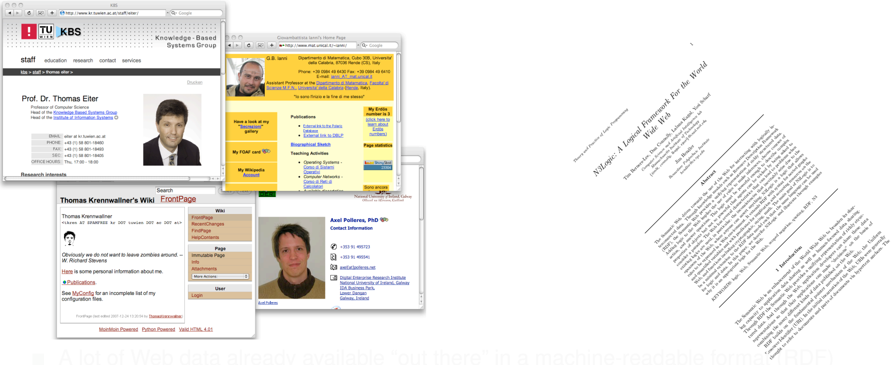

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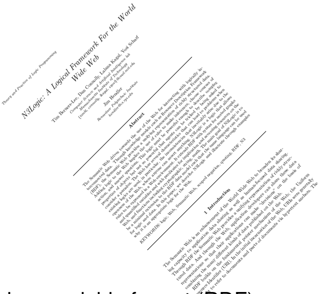

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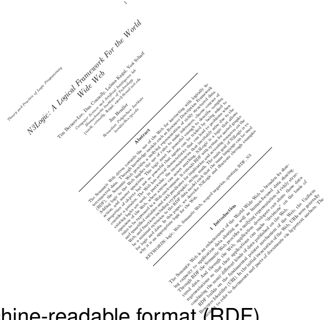

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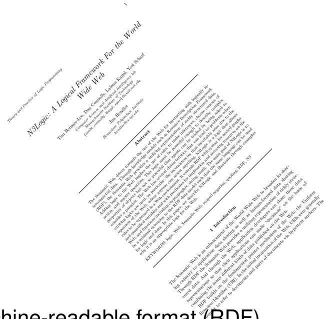

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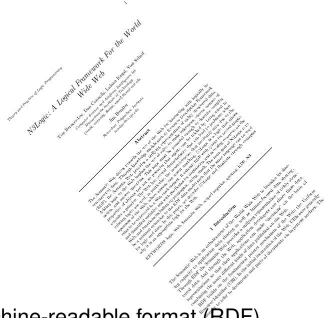

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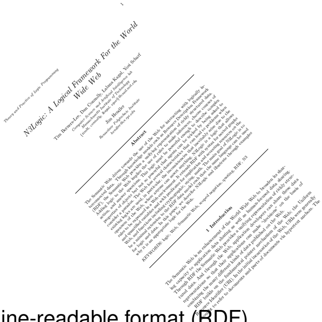

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Obtaining Machine-Readable RDF data
(i) directly by the publishers, (ii) by GRDDL transformations, or (iii) by 3rd-party wrappers:

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,

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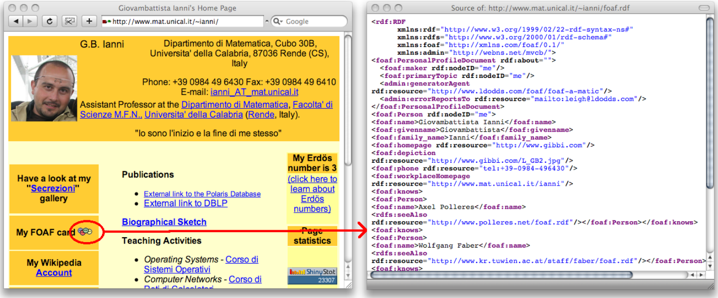

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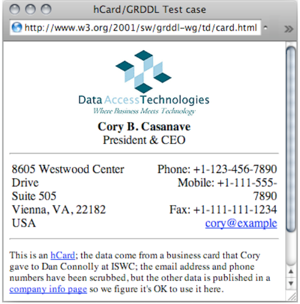
GRDDL (**G**leaning **R**esource **D**escriptions from **D**ialects of **L**anguages.) [Connolly (ed.), 2007]

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:



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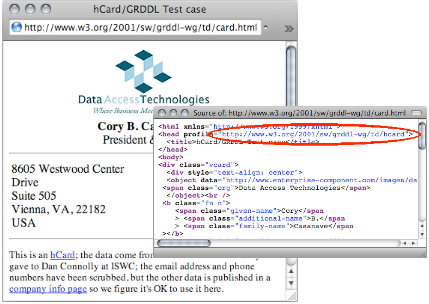

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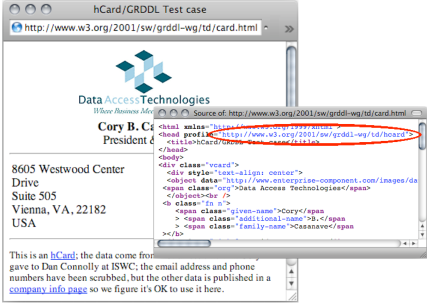

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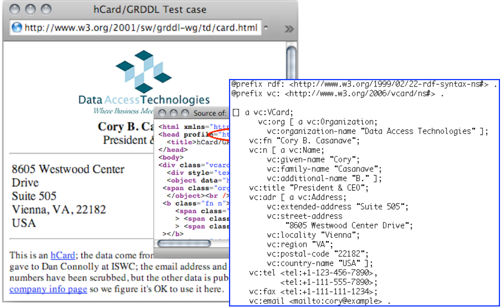

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L3S' RDF export of the DBLP citation index, see http://dblp.l3s.de/d2r/

- 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.
- Provides RDF version of all DBLP data + query interface!
- Other nice example: RDF+query interface for large parts of wikipedia: http://dbpedia.org/

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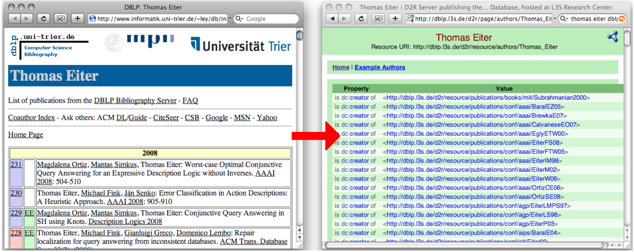

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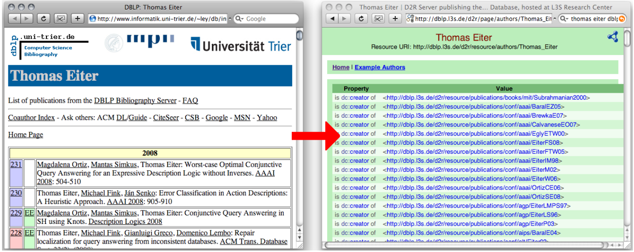

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How can I query that data? SPARQL

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*”

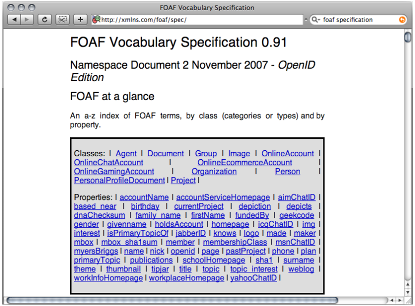
Example (**query1.sparql**):

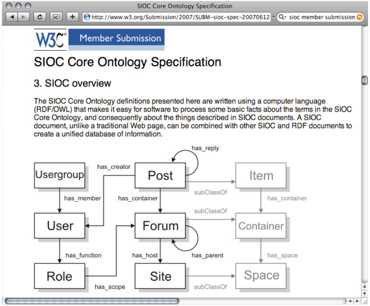
```
SELECT ?D
FROM <http://dblp.l3s.de/d2r/data/authors/Thomas_Eiter>
WHERE {?D dc:creator
          <http://dblp.l3s.de/d2r/resource/authors/Thomas_Eiter>}
```

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]





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Semantic Web Data: The Resource Description Framework (RDF)

- RDF is describing *resources* per triples/statements

  Subject **P**redicate **O**bject.

- “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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  $\exists X$ *thomas hasCreated* X *.* X *isA Article .*
  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)

Semantic Web Data: The Resource Description Framework (RDF)

- RDF is describing *resources* per triples/statements

  Subject **P**redicate **O**bject.
- "simplest possible database schema", data just a set of triples:

  axel isA Person .
  axel hasName "Axel Polleres".
  axel knows gb .
  axel knows thomas.
  $\exists X$ *thomas hasCreated* X *.* X *isA Article .*
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- abstracts away from tables (RDBMS) or tree-like (XML) schemas
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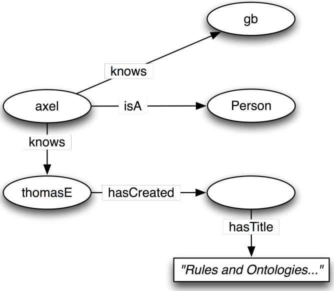
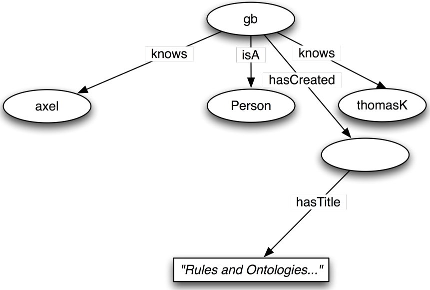
axel isA Person .
axel knows gb .
axel knows thomasE.
thomasE hasCreated X . X isA Article
.
X hasTitle “Rules and Ontologies. . . ”.

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.

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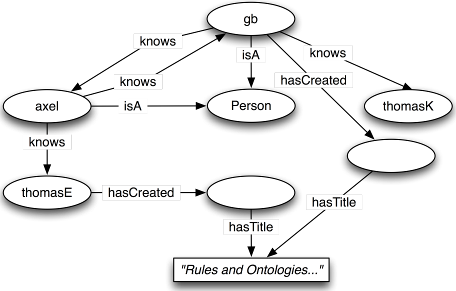

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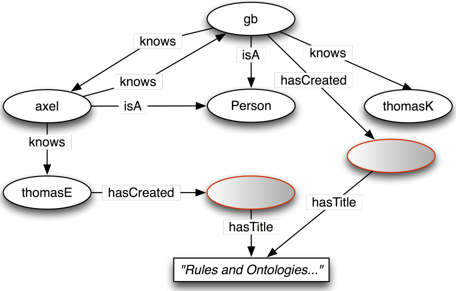

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A Syntax for RDF: Turtle

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 á la XML:

```
@prefix :  <http://polleres.net/foaf.rdf#> .
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@prefix foaf:  <http://xmlns.com/foaf/0.1/> .
@prefix xs:  <http://www.w3.org/2001/XMLSchema#> .
:me rdf:type foaf:Person .
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```

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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.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*
- Turtle allows shortcuts:
  - Same subject triples can be grouped together with ';' , ','
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  - `rdf:type` is often abbreviated with `a`.
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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#> .
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<http://www.mat.unical.it/~ianni/foaf.rdf> foaf:primaryTopic _:me .
_:me a foaf:Person .
_:me foaf:name "Giovambattista Ianni" .
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_:me foaf:phone <tel:+39-0984-496430> .
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```

[2] http://librdf.org/

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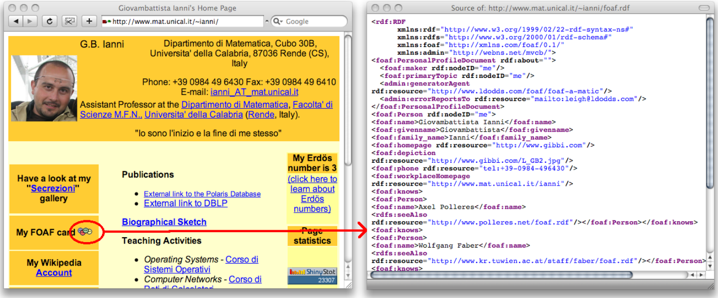


```
      foaf:name "Alessandra Martello" ] .
```

---

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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` *prefix*: <*namespace-URI*>	
Head:	**C** or	`CONSTRUCT` { *template* }	. . . construct a new RDF graph
	S or	`SELECT` *variable list*	. . . select matching resources/literals in a graph
	A	`ASK`	. . . boolean query
Body:	**D**	`FROM` / `FROM NAMED` <*dataset-URI*>	
	W	`WHERE` { *pattern* }	
	M	`ORDER BY` *expression*	
		`LIMIT` *integer* > 0	
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- Let us start with `SELECT` queries and focus on the different patterns:
  - basic graph patterns (Conjunctive queries)
  - `FILTER`s
  - `UNION`s of patterns
  - `OPTIONAL` Patterns
  - `GRAPH` Patterns

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

- Let us start with `SELECT` queries and focus on the different patterns:
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  - `UNION`s of patterns
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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 allowed[4]
- 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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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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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
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- 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

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```
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
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- . . . 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 {
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       UNION
       { [ foaf:name ?N ] foaf:knows [foaf:name "Axel Polleres" ] }
      }
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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/r̃lara/foaf.rdf>
...	

OPTIONALs 1/2 – Partial Matching

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WHERE {<http://www.www.polleres.net/foaf.rdf#me> foaf:knows ?X .
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...	
"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#>
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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

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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."

```
PREFIX rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
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SELECT ?N
FROM <http://www.polleres.net/foaf.rdf>
WHERE {<http://www.polleres.net/foaf.rdf#me> foaf:knows ?X .
       { { ?X foaf:name ?N .}
        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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FROM NAMED???
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       { { ?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.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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```

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

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

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

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More on that later...

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

Using the SPARQL interface to DBLP at `http://dblp.l3s.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.l3s.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

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* `Person`*s and* `Imgage`*s* (domain/range)
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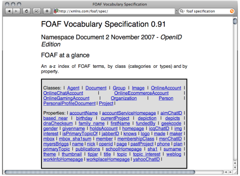
  - `homepage` *denotes* ***unique*** *homepage of an* `Agent` (uniquely identifying property)

⋮



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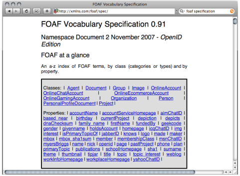

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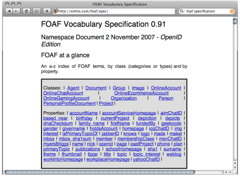

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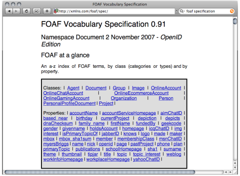

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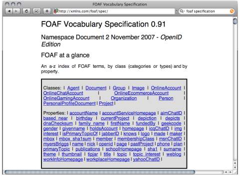

Examples 2 – A simple ontology about reviewers:

- **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)
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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.
- **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

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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 .
                  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:

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

$$
\begin{array}{l}
\exists \mathit{me}, \mathit{b1}, \mathit{b2}, \mathit{b3}, \mathit{b4} \\
(\mathit{triple}(\texttt{foaf.rdf}, \texttt{rdf:type}, \texttt{PersonalProfileDocument}) \\
\wedge\ \mathit{triple}(\texttt{foaf.rdf}, \texttt{maker}, \mathit{me}) \\
\wedge\ \mathit{triple}(\texttt{foaf.rdf}, \texttt{primaryTopic}, \mathit{me}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{rdf:type}, \texttt{Person}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{name}, \texttt{"Giovambattista Ianni"}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{homepage}, \texttt{http://www.gibbi.com}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{phone}, \texttt{tel:+39-0984-496430}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{knows}, \mathit{b2}) \wedge\ \mathit{triple}(\mathit{b1}, \texttt{type}, \texttt{Person}) \\
\wedge\ \mathit{triple}(\mathit{b1}, \texttt{name}, \texttt{"Wolfgang Faber"}) \\
\wedge\ \mathit{triple}(\mathit{b1}, \texttt{rdfs:seeAlso}, \texttt{http://www.kr.tuwien...}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{knows}, \mathit{b1}) \wedge\ \mathit{triple}(\mathit{b1}, \texttt{rdf:type}, \texttt{Person}) \\
\wedge\ \mathit{triple}(\mathit{b2}, \texttt{name}, \texttt{"Axel Polleres"}) \\
\wedge\ \mathit{triple}(\mathit{b2}, \texttt{rdfs:seeAlso}, \texttt{http://www.polleres...}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{knows}, \mathit{b3}) \wedge\ \mathit{triple}(\mathit{b1}, \texttt{rdf:type}, \texttt{Person}) \\
\wedge\ \mathit{triple}(\mathit{b3}, \texttt{name}, \texttt{"Thomas Eiter"}) \\
\wedge\ \mathit{triple}(\mathit{me}, \texttt{knows}, \mathit{b4}) \wedge\ \mathit{triple}(\mathit{b1}, \texttt{type}, \texttt{Person}) \\
\wedge\ \mathit{triple}(\mathit{b4}, \texttt{name}, \texttt{"Alessandra Martello"}))
\end{array}
$$

The Semantics of RDF graphs:

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

$$\exists \mathit{me}, \mathit{b1}, \mathit{b2}, \mathit{b3}, \mathit{b4}\ (\texttt{PersonalProfileDocument}(\texttt{foaf.rdf})$$
$$\land\ \texttt{maker}(\texttt{foaf.rdf}, \mathit{me})$$
$$\land\ \texttt{primaryTopic}(\texttt{foaf.rdf}, \mathit{me})$$
$$\land\ \texttt{Person}(\mathit{me}) \land \cdots)$$

- 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:

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

$$\forall S, P, O\ (triple(S, P, O) \supset triple(P, \texttt{rdf:type}, \texttt{rdf:Property}))$$

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

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

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

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

$$\forall C_1, C_2, C_3\ (triple(C_1, \texttt{rdfs:subClassOf}, C_2) \wedge triple(C_2, \texttt{rdfs:subClassOf}, C_3) \supset triple(C_1, \texttt{rdfs:subClassOf}, C_3))$$

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

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Note 1:
All those rules were Datalog expressible, i.e. no negation, no function symbols.

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RDFS Semantics Example: The FOAF ontology

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RDFS: Semantics

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Data:

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

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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 .`
- ???

$\vdots$

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- *homepage denotes* ***unique*** *homepage of an Agent* ???

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RDFS: Semantics

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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:InverseFuncionalProperty`, `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.

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:InverseFuncionalProperty`, `owl:SymmetricProperty` etc.
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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
:me rdf:type  foaf:Person
```

$Person \sqsubseteq Agent$

$me \in Person$

OWL DL in two slides: 1/2

Expressing property characteristics:

OWL property axioms as RDF triples	DL syntax	FOL short representation
P `rdfs:domain` C .	$\top \sqsubseteq \forall P^{-}.C$	$\forall x, y.P(x, y) \supset C(x)$
P `rdfs:range` C .	$\top \sqsubseteq \forall P.C$	$\forall x, y.P(x, y) \supset C(y)$
P `owl:inverseOf` P_0 .	$P \equiv P_0^{-}$	$\forall x, y.P(x, y) \equiv P_0(y, x)$
P `rdf:type owl:SymmetricProperty`.	$P \equiv P^{-}$	$\forall x, y.P(x, y) \equiv P(y, x)$
P `rdf:type owl:FunctionalProperty`.	$\top \sqsubseteq \leqslant 1P$	$\forall x, y, z.P(x, y) \wedge P(x, z) \supset y = z$
P `rdf:type owl:InverseFunctionalProperty`.	$\top \sqsubseteq \leqslant 1P^{-}$	$\forall x, y, z.P(x, y) \wedge P(z, y) \supset x = z$
P `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`	$\bot$	$\neg x = x$
`owl:intersectionOf` $(C_1 \ldots C_n)$	$C_1 \sqcap \cdots \sqcap C_n$	$C_1(x) \wedge \cdots \wedge C_n(x)$
`owl:unionOf` $(C_1 \ldots C_n)$	$C_1 \sqcup \cdots \sqcup C_n$	$C_1(x) \vee \cdots \vee C_n(x)$
`owl:complementOf` (C)	$\neg C$	$\neg C(x)$
`owl:oneOf` $(o_1 \ldots o_n)$	$\{o_1, \ldots, o_n\}$	$x = o_1 \vee \cdots \vee x = o_n$
`owl:restriction` (P `owl:someValuesFrom` (C))	$\exists P.C$	$\exists y.P(x, y) \wedge C(y)$
`owl:restriction` (P `owl:allValuesFrom` (C))	$\forall P.C$	$\forall y.P(x, y) \supset C(y)$
`owl:restriction` (P `owl:value` (o))	$\exists P.\{o\}$	$P(x, o)$
`owl:restriction` (P `owl:minCardinality` (n))	$\geqslant nP$	$\exists y_1 \ldots y_n . \bigwedge_{k=1}^{n} P(x, y_k) \wedge \bigwedge_{i<j} y_j \neq y_j$
`owl:restriction` (P `owl:maxCardinality` (n))	$\leqslant nP$	$\forall y_1 \ldots y_{n+1} . \bigwedge_{k=1}^{n+1} P(x, y_k) \supset \bigvee_{i<j} y_i = y_j$

* 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: 1/2

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OWL DL in two slides: 2/2

Relating Class descriptions:

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

Relating individuals:

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

Examples:

```
<http://www.polleres.net/foaf.rdf#me> owl:sameAs
       <http://dblp.l3s.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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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:

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

Example inference:

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<http://www.polleres.net/foaf.rdf#me> foaf:homepage
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```

$$\models$$

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$$\exists ex{:}title.\top \sqsubseteq ex{:}Paper \quad \text{(i)}$$

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

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

$$ex{:}Publication \equiv ex{:}Paper \sqcap \exists ex{:}publishedIn.\top \quad \text{(iv)}$$

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

$$ex{:}Senior \equiv foaf{:}Person \sqcap \geqslant 10\ ex{:}isAuthorOf \sqcap \exists ex{:}isAuthorOf.ex{:}Publication \quad \text{(vi)}$$

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  `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)

  `ex:publishedIn a owl:FunctionalProperty .`

[8] `( ... )` is a shortcut for `rdf:List`s, expand to `rdf:first`, `rdf:rest`, `rdf:nil` triples.

[9] (vi) is not exactly that, qualified number restrictions will likely be in OWL 2, though.

OWL Example: A simple ontology about reviewers

$$\exists ex{:}title.\top \sqsubseteq ex{:}Paper \quad \text{(i)}$$

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

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

$$ex{:}Publication \equiv ex{:}Paper \sqcap \exists ex{:}publishedIn.\top \quad \text{(iv)}$$

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

$$ex{:}Senior \equiv foaf{:}Person \sqcap \geqslant 10\ ex{:}isAuthorOf \sqcap \exists ex{:}isAuthorOf.ex{:}Publication \quad \text{(vi)}$$

$$ex{:}Club100 \equiv foaf{:}Person \sqcap \geqslant 100\ ex{:}isAuthorOf \quad \text{(vii)}$$

- *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)
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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:
  SNARK [Stickel *et al.*,], SPASS [SPASS,], Vampire [Riazanov and Voronkov, 2002]
- Rule/LP engines: dlvhex, Triple, cwm, SWI-Prolog, Jena Rules

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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.

W3C's OWL2 WG tries to define SPARQL DL . . . stay tuned!

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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?

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 descibed (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.

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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:

query9b: "*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 _:b.
```

That one would work!

Blank nodes in Basic Graph patterns – Example

An example to illustrate this issue:

query9d: “*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 mayb 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 mayb 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

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- 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 G11
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”

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```

```
CONSTRUCT { ex:alice foaf:knows _:b }
FROM G11
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 G11
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 surpressed:
`"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 G11
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 surpressed:
`"Alice" ex:connectedTo ex:alice.`

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

Bag semantics

Essentially:

- SPARQL allows dublicate 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 G11
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 G11
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 G11
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 G11
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 G11
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 G11
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 G11
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 G11
WHERE { ?X foaf:knows [] }
```

Result:

?X
ex:alice
ex:alice

Unsafe FILTERs and Errors in FILTERs

For patterns of the form (P 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 ($\top$, $\bot$, err)

Unsafe FILTER expression

Given a pattern (P FILTER R) we call R unsafe if it contains a variable not occurring in P.

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 .
```

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

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

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!

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?X	?H
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That one is no problem!

Hovever, 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.*"

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```

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

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```

query14b:

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

Result:

?X	?H
ex:bob	ex:hp1
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```
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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:

- $P1$ FILTER R $P2 \Rightarrow$ (($P1$ AND $P2$) FILTER R)
- (P FILTER $R1$) FILTER $R2 \Rightarrow$ (P FILTER ($R1 \wedge R2$))

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

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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

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

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	$\neg R$
true	*false*
false	*true*
err	*err*

R_1	R_2	$R_1 \wedge R_2$
true	*true*	*true*
true	*false*	*false*
false	*true*	*false*
false	*false*	*false*
true	*err*	*err*
err	*true*	*err*
false	*err*	*false*
err	*false*	*false*
err	*err*	*err*

R_1	R_2	$R_1 \vee R_2$
true	*true*	*true*
true	*false*	*true*
false	*true*	*true*
false	*false*	*false*
true	*err*	*true*
err	*true*	*true*
false	*err*	*err*
err	*false*	*err*
err	*err*	*err*

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eval `("old" > "30"^^xs:integer)` = *err*
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R_1	R_2	$R_1 \wedge R_2$
true	*true*	*true*
true	*false*	*false*
false	*true*	*false*
false	*false*	*false*
true	*err*	*err*
err	*true*	*err*
false	*err*	*false*
err	*false*	*false*
err	*err*	*err*

R_1	R_2	$R_1 \vee R_2$
true	*true*	*true*
true	*false*	*true*
false	*true*	*true*
false	*false*	*false*
true	*err*	*true*
err	*true*	*true*
false	*err*	*err*
err	*false*	*err*
err	*err*	*err*

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*:

$$eval(\neg err \wedge true) = err$$

$$eval(\neg err \wedge false) = false$$

$$eval(\neg err \wedge err) = err$$

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 $\mu = \{?X \rightarrow \texttt{ex:bob}, ?A \rightarrow 20\}$:

?X	?A
ex:bob	20

$$eval(\neg(err \wedge false) = true$$

Further information and slides, cf.

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

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