Unit 1 – Preliminaries
RDF, RDFS, OWL & SPARQL

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DERI, National University of Ireland, Galway

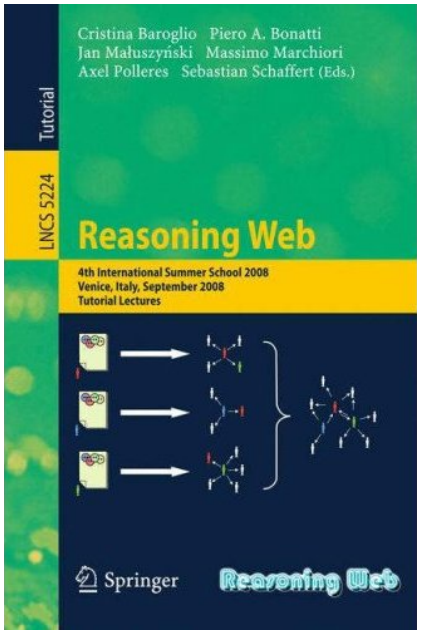
Reasoning Web Summer School 2008

Unit Outline

1. Motivation – Aggregating Linked Open Data by Rules
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?

Building a review panel for our book

- You want to publish a book containing the lectures of this Summer School...



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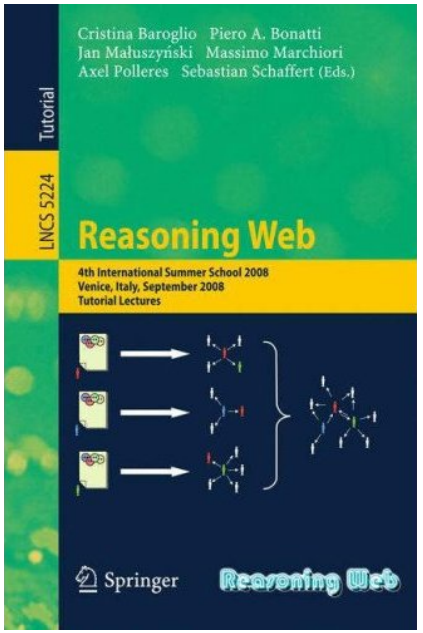

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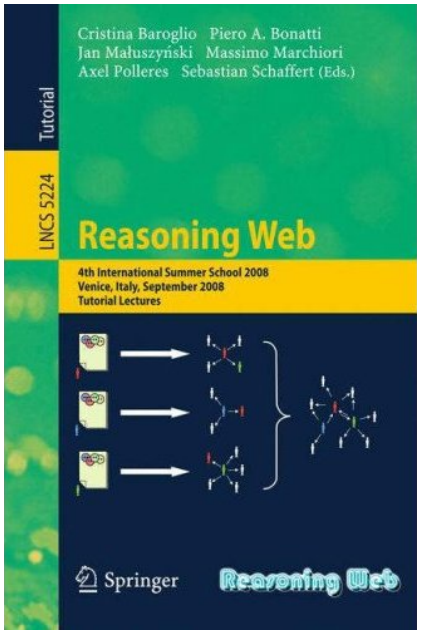

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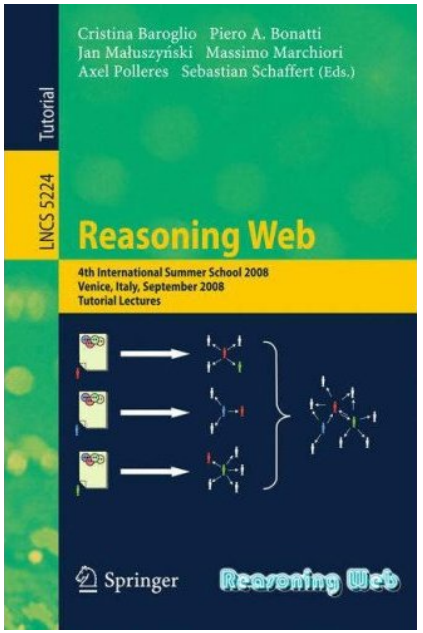

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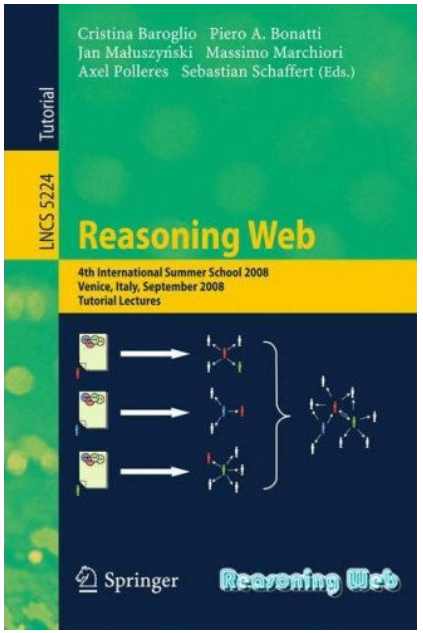

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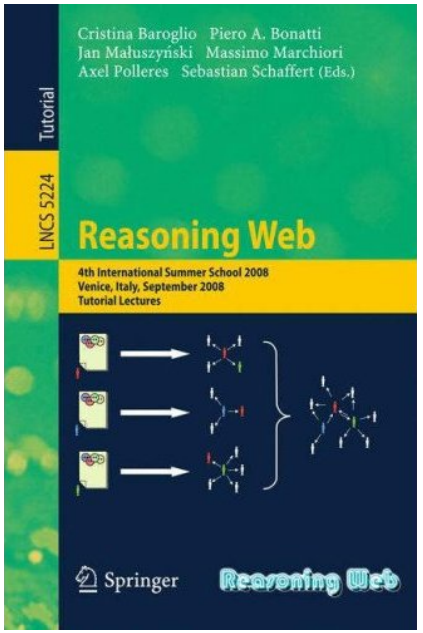
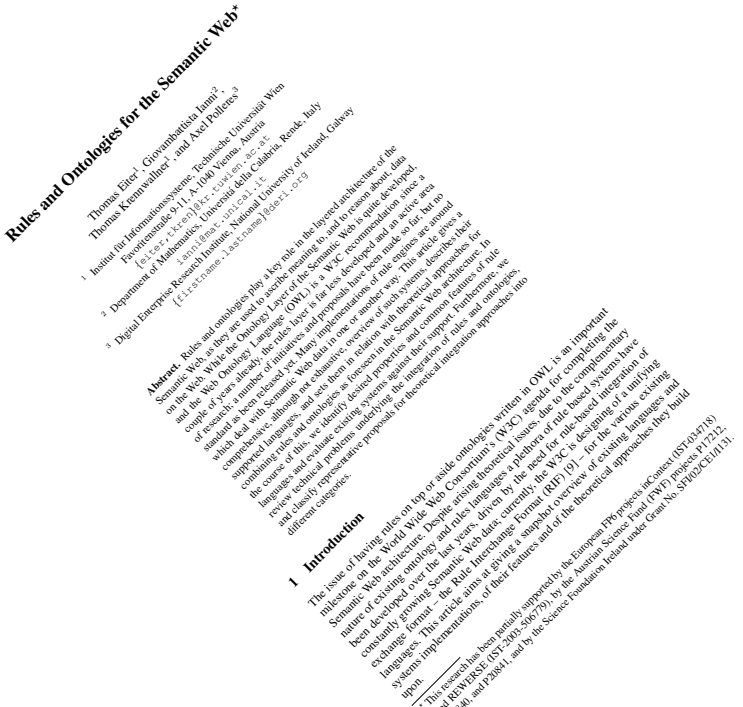


Questions:

- Where do I get the right data?
- Which rules and query languages do I use to aggregate this data?
- Which systems are out there to support me?

Where is the data? 1/4



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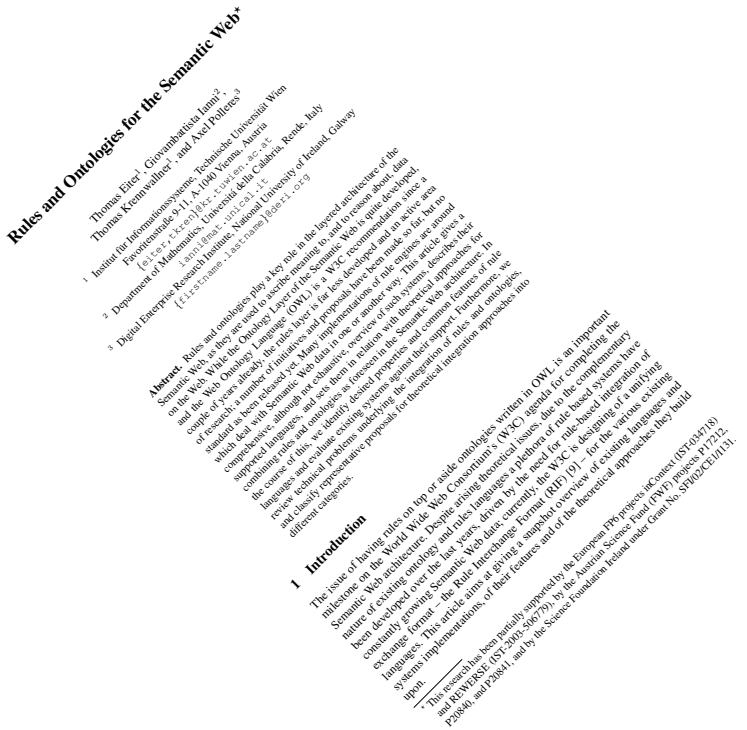

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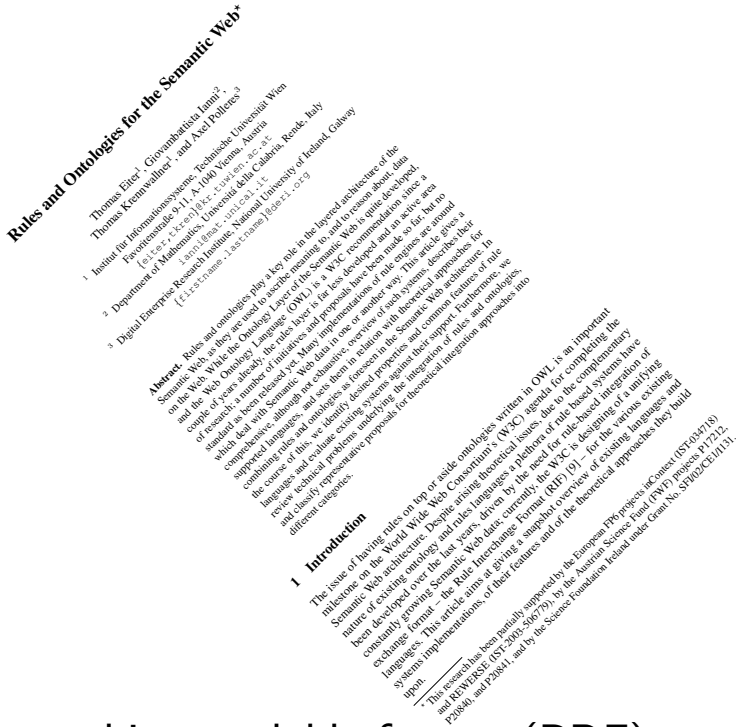

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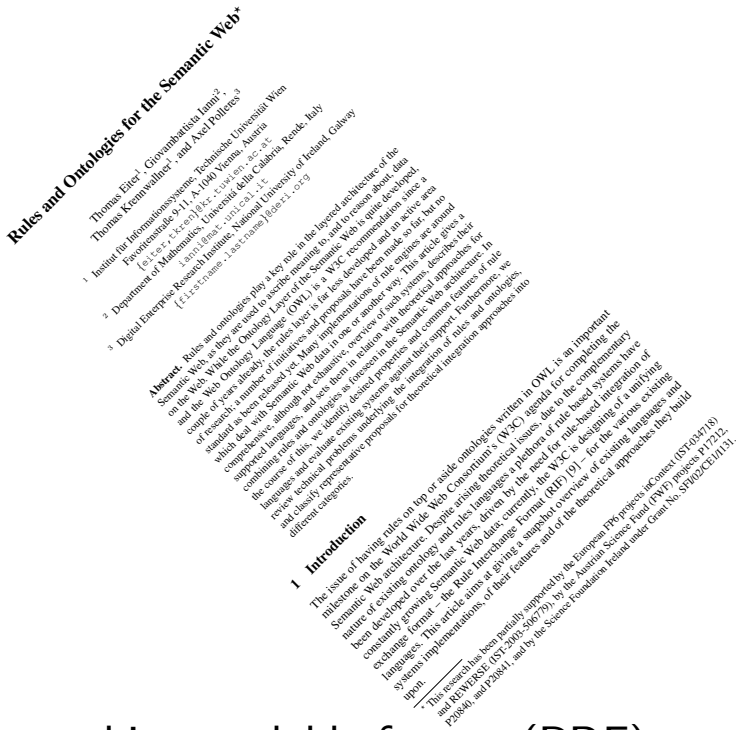

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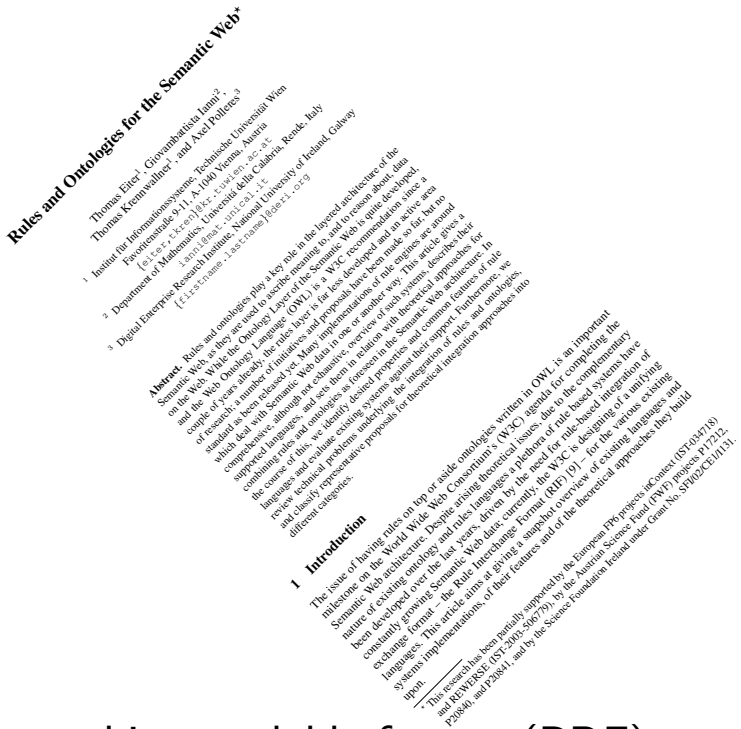

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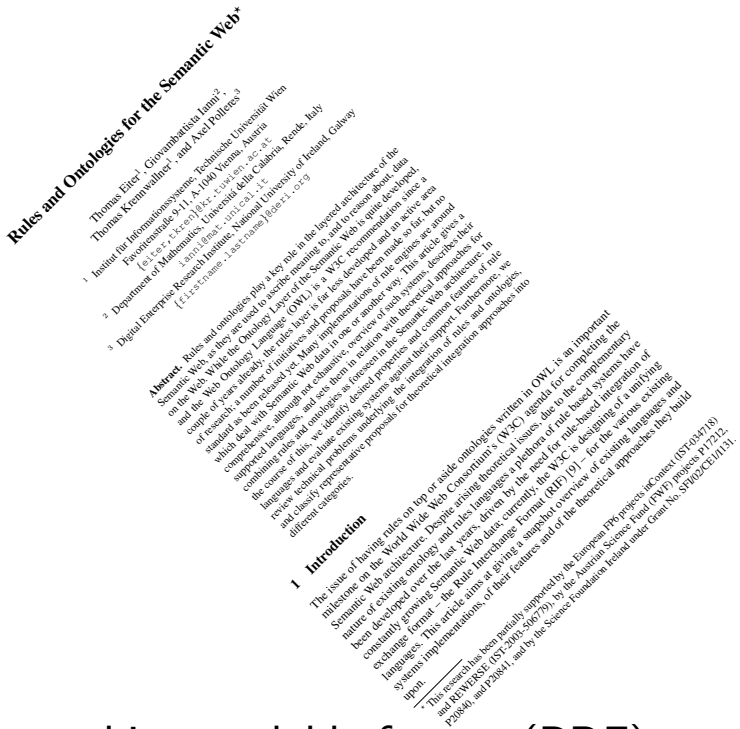

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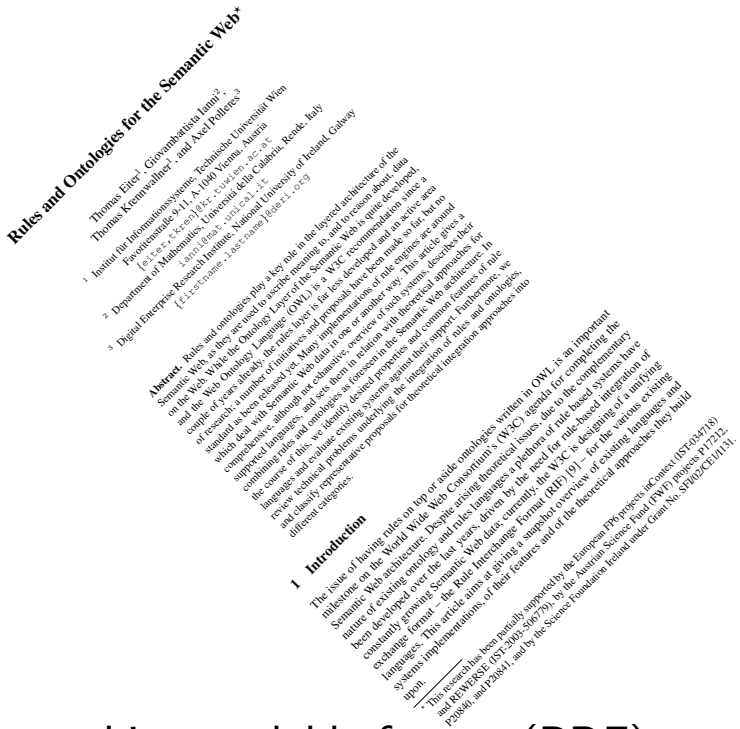

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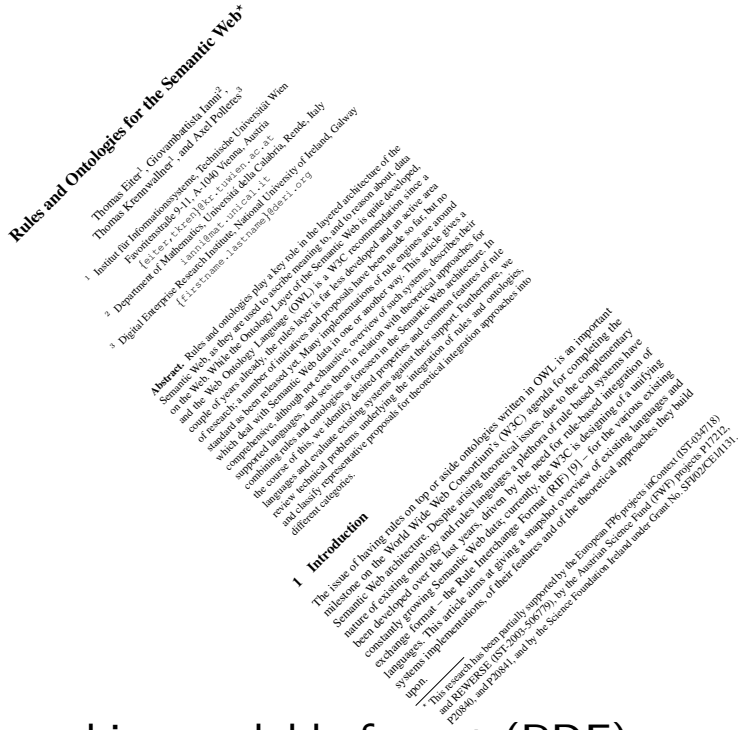

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  3. When someone looks up a URI, provide useful information.
  4. Include links to other URIs so that they can discover more things.

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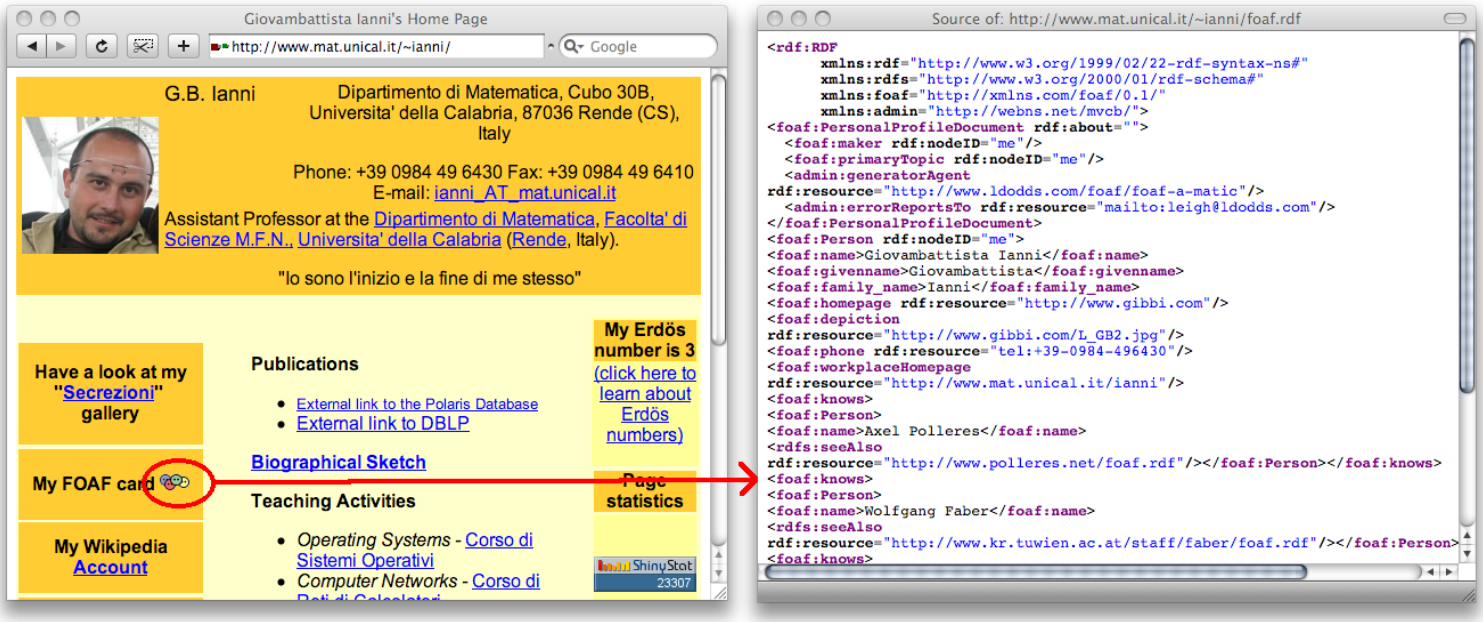
FOAF/RDF linked from a home page: personal data (`foaf:name`, `foaf:phone`, etc.), relationships `foaf:knows`, `rdfs:seeAlso`)



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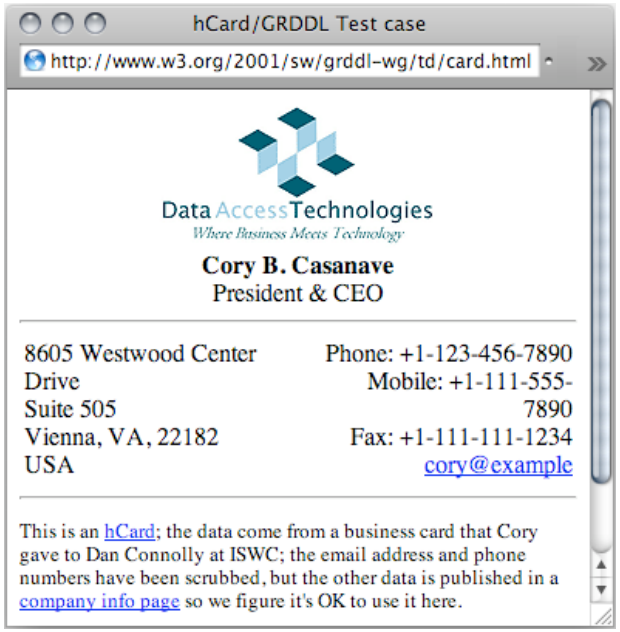

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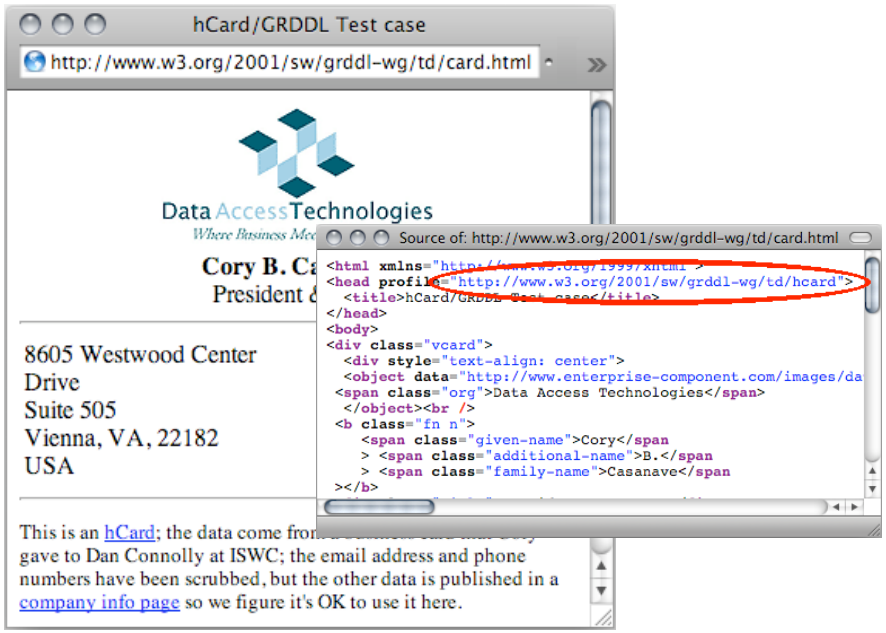

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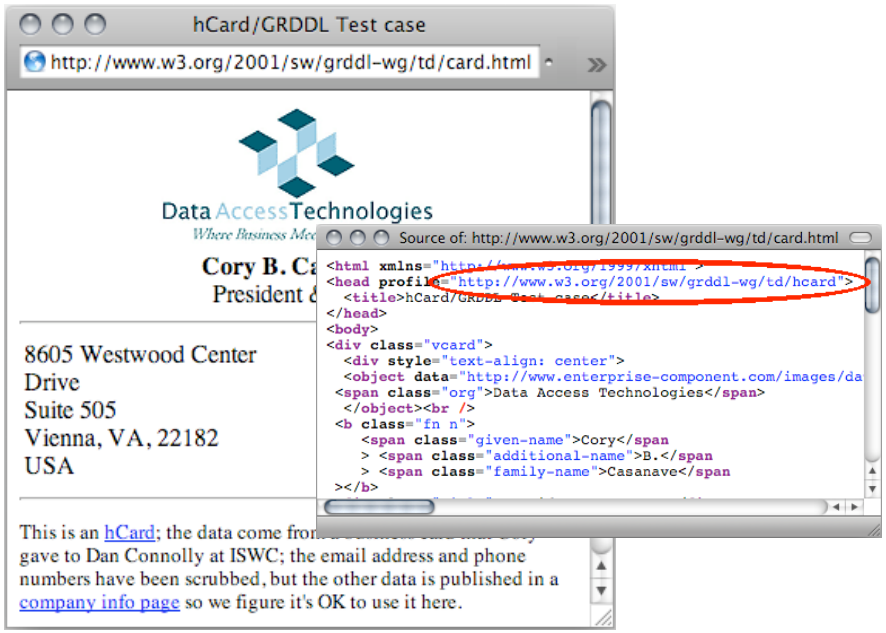

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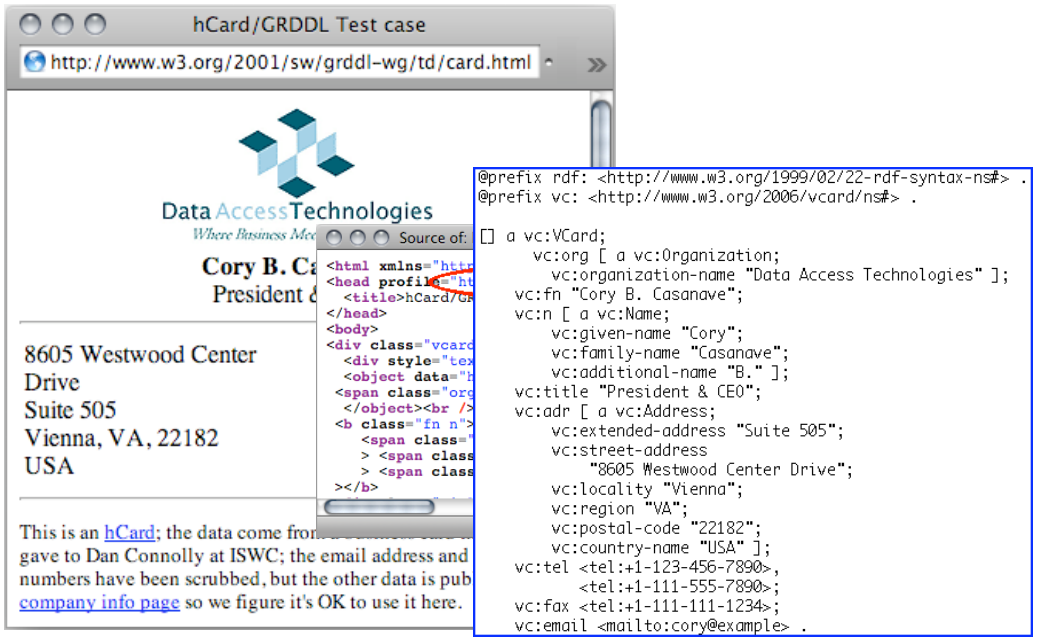

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[2] `http://dblp.l3s.de/d2r/`

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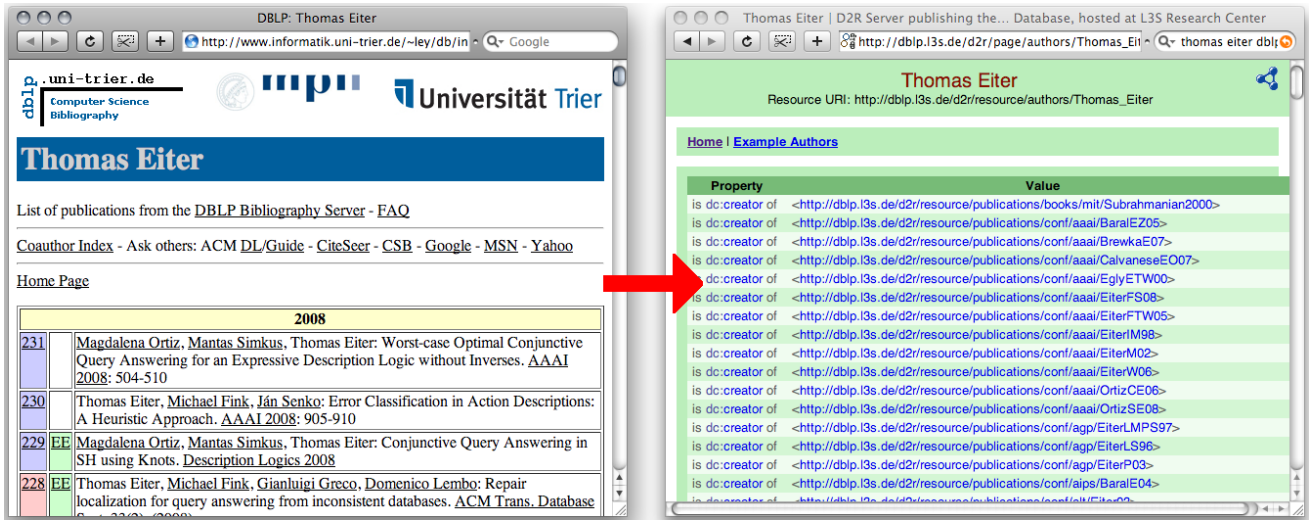

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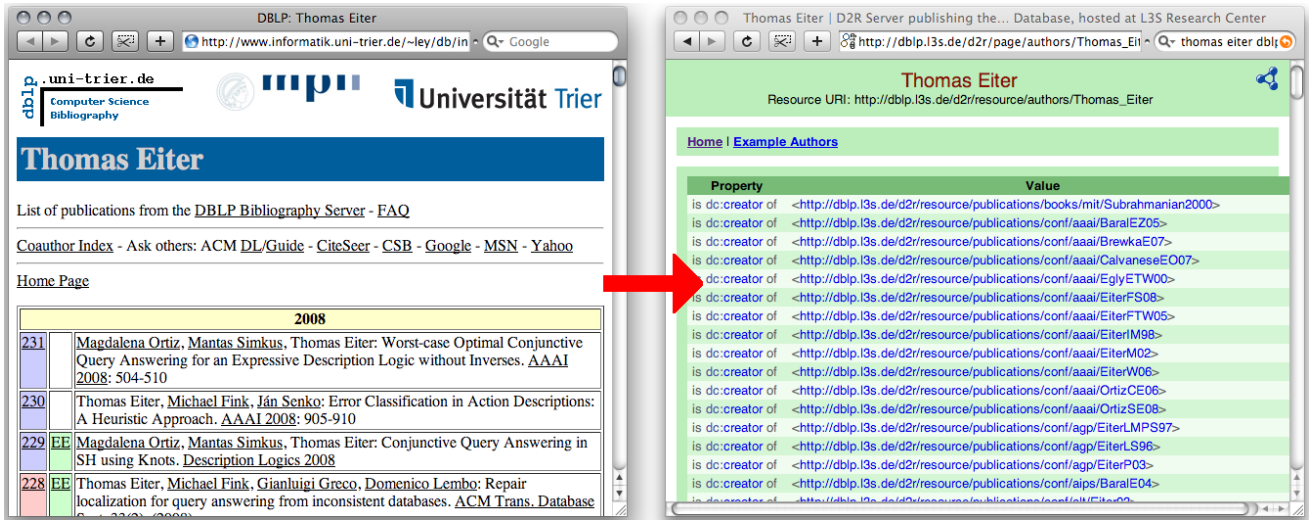


- Gives unique URIs to authors, documents, etc. on DBLP! E.g., http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter, http://dblp.l3s.de/d2r/page/publications/conf/rweb/EiterIKP08
- Provides RDF version of all DBLP data + query interface!

[2] http://dblp.l3s.de/d2r/

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 Axel Polleres or who are known by Axel Polleres*"
- "*All people who have published in the Reasoning Web Series but have not co-authored with any of the authors of the present paper*"

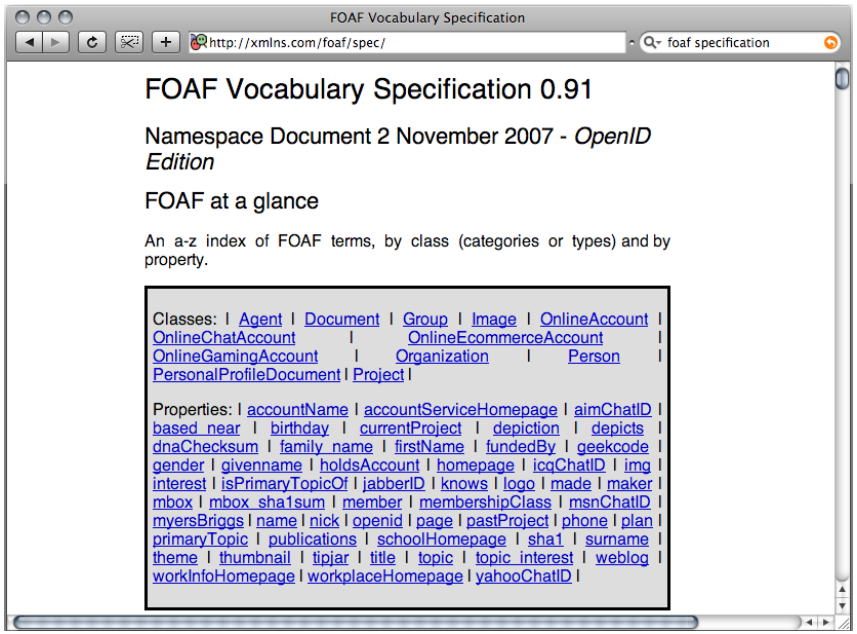
Example:

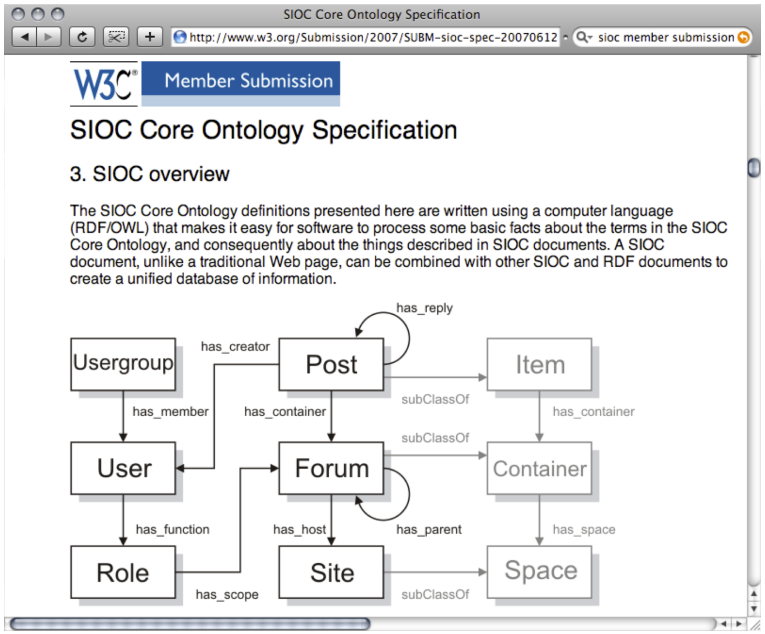
```
SELECT ?D
FROM <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter>
WHERE {?D dc:creator <http://dblp.l3s.de/d2r/resource/authors/Thomas_Eiter>}
```

What does the data mean? 2/2

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]





Unit Outline

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- 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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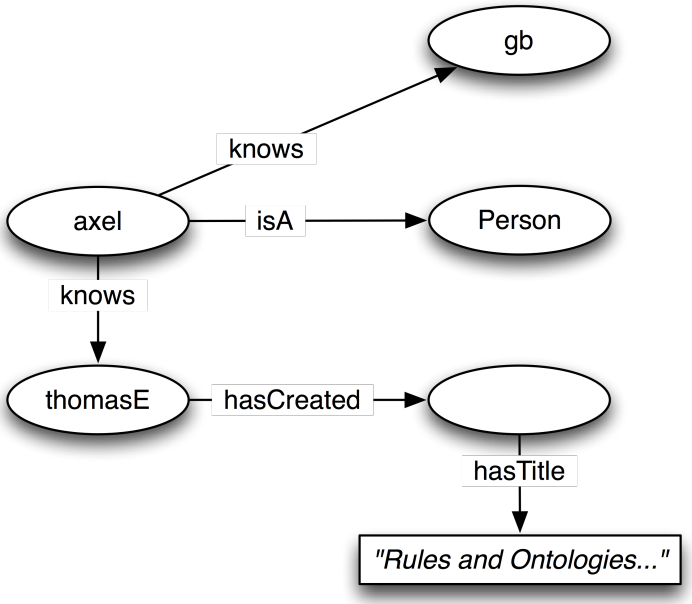

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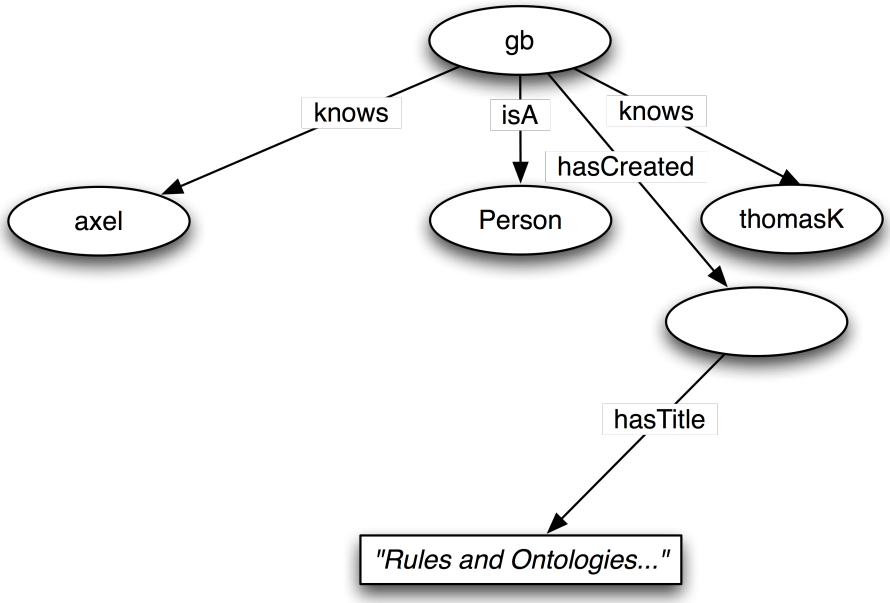

Observe: the "existential variables" became "blank" nodes in the Graph.

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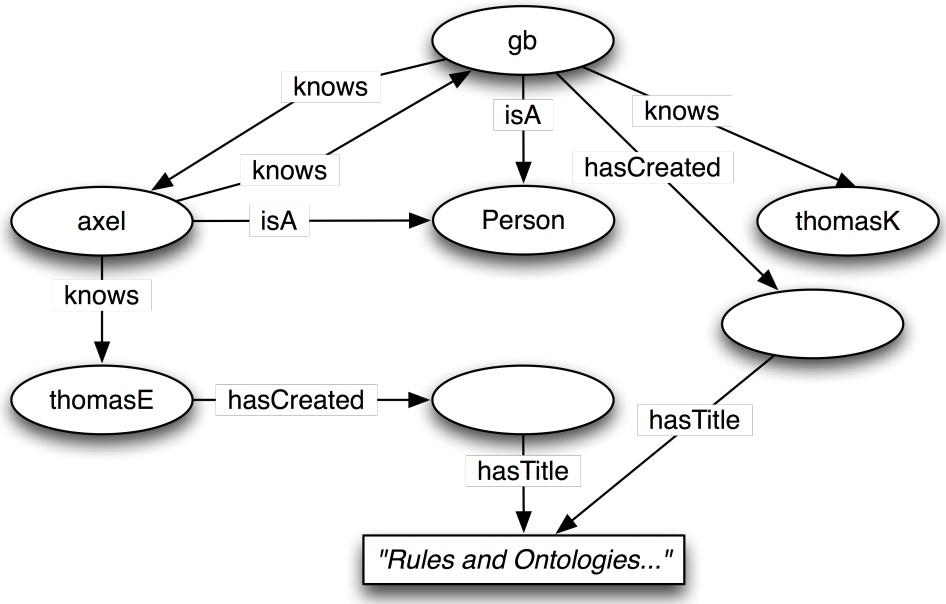

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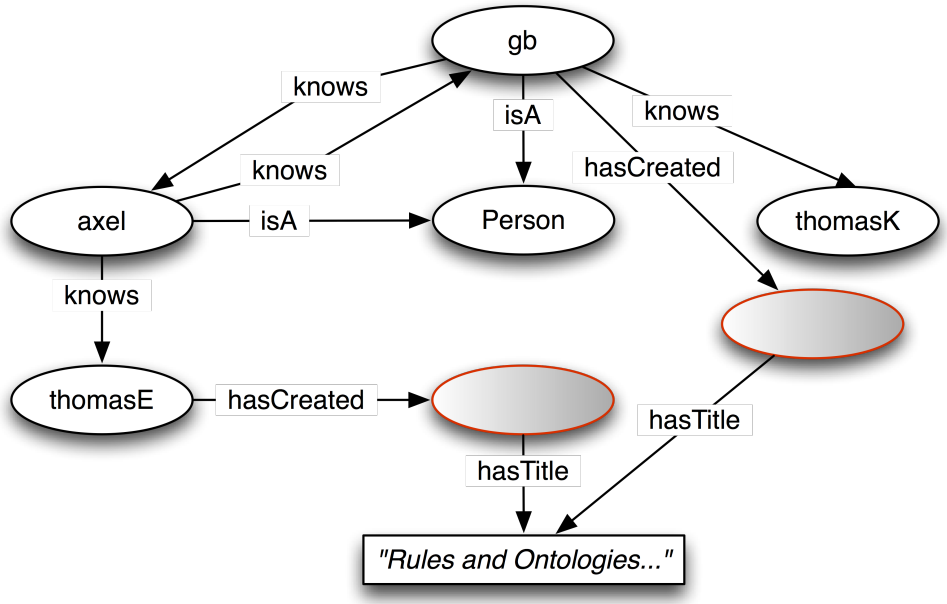

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Resources in RDF, Syntax

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- There are special URIs, defined in vocabularies (FOAF, SIOC, RDF, etc.)
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becomes:

```
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```

Resources in RDF, Syntax

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

axel isA Person .
axel hasName "Axel Polleres".

becomes:

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

Ugly to read. . . more compact syntaxes like Turtle [Beckett, 2007] allow prefix definitions á la XML:

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

More on RDF – Shortcuts in Turtle Syntax

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

More on RDF – Shortcuts in Turtle Syntax

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

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

More on RDF – Shortcuts in Turtle Syntax

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

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

More on RDF – Shortcuts in Turtle Syntax

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

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

More on RDF – Shortcuts in Turtle Syntax

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

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

Collecting RDF from the Web

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

[3] http://librdf.org/
[4] http://jena.sourceforge.net/

Collecting RDF from the Web

- For us this is enough so far to "read" RDF on the Web.
- For published RDF data there exists a machine-readable XML syntax. Lots of tools and APIs to read/process/convert this data (Redland (C++),[3] Jena (Java),[4] 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" ] .
```

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- For us this is enough so far to "read" RDF on the Web.
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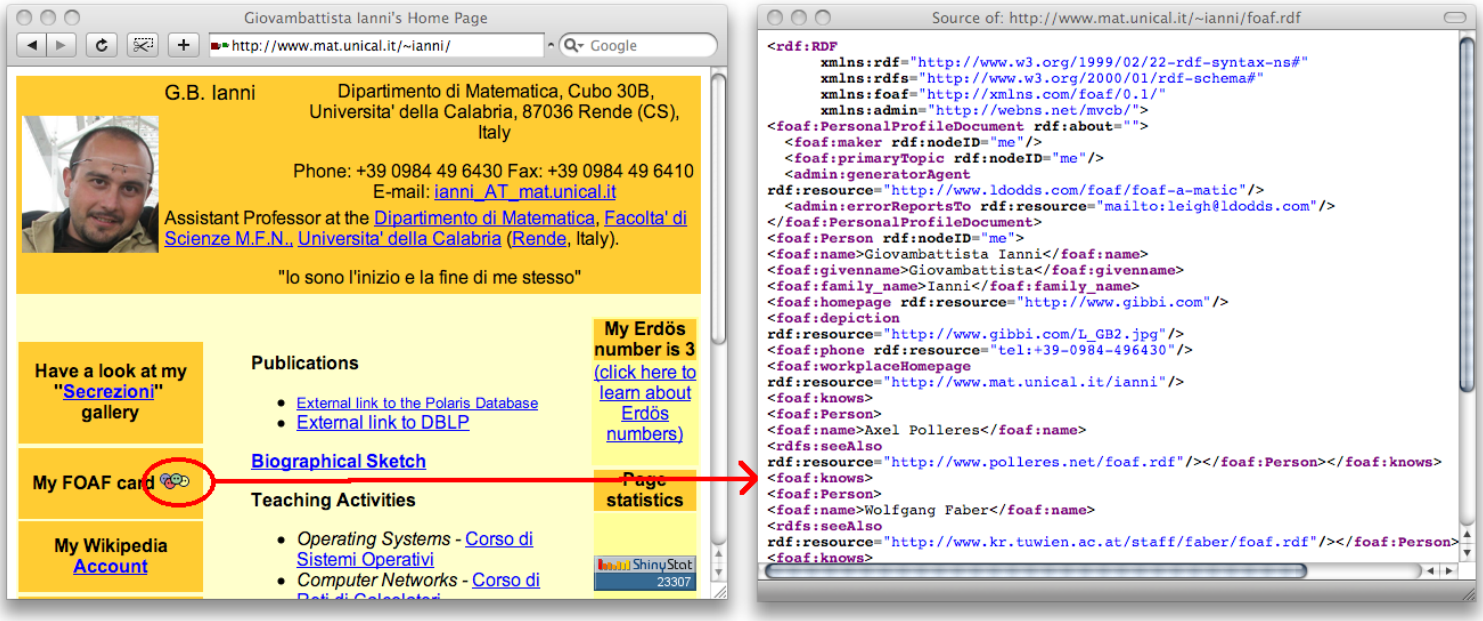
```
@prefix rdfs:  <http://www.w3.org/2000/01/rdf-schema#> .
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf:  <http://xmlns.com/foaf/0.1/> .
```




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

[3] http://librdf.org/

[4] http://jena.sourceforge.net/

Unit Outline

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	`construct { ` *template* ` }`	. . . construct a new RDF graph
	S	`select` *variable list*	. . . select matching resources fin 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	

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	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:
  - basic graph patterns (Conjunctive queries)
  - `filters`
  - `unions` of patterns
  - `optional` Patterns
  - `graph` Patterns

Basic Graph Patterns (Conjunctive queries)

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

```
prefix foaf:  <http://xmlns.com/foaf/0.1/>
select ?N
from <http://www.mat.unical.it/~ianni/foaf.rdf>
where {
       <http://www.mat.unical.it/~ianni/foaf.rdf#me> foaf:knows ?X .
       ?X a foaf:Person .  ?X foaf:name ?N .
      }
```

- graph patterns (`where` part) allow Turtle syntax

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

Basic Graph Patterns (Conjunctive queries)

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

```
prefix foaf:  <http://xmlns.com/foaf/0.1/>
select ?N
from <http://www.mat.unical.it/~ianni/foaf.rdf>
where {
       [ foaf:knows
         [ a foaf:Person; foaf:name ?N ]]
      }
```

- graph patterns (`where` part) allow Turtle syntax
- all Turtle shortcuts allowed[5]

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

Basic Graph Patterns (Conjunctive queries)

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

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

select ?N
from <http://www.mat.unical.it/~ianni/foaf.rdf>
from <http://www.polleres.net/foaf.rdf>
from <http://www.postsubmeta.net/foaf>
where {
       [ foaf:knows
         [ a foaf:Person; foaf:name ?N ]]
      }
```

- graph patterns (`where` part) allow Turtle syntax
- all Turtle shortcuts allowed[5]
- merge of several graphs can be queried at once

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

FILTERs in Basic Graph Patterns

"select all names of persons known by the authors from their FOAF files"

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

select ?N
where {
       [ foaf:knows
         [a foaf:Person ; foaf:name ?N] ]
      }
```

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

FILTERs in Basic Graph Patterns

"select all names of persons known by the authors from their FOAF files"

```
prefix foaf:  <http://xmlns.com/foaf/0.1/>
select ?N
where {
       [ foaf:knows
        [a foaf:Person ; foaf:name ?N] ]
       filter ( ?N != "Thomas Eiter" && ?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" ] }
      }
```

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 G.B. from his FOAF file and – if available – their `rdfs:seeAlso` links"

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

select ?N ?L
from <http://www.mat.unical.it/~ianni/foaf.rdf>
where {<http://www.mat.unical.it/~ianni/foaf.rdf#me> foaf:knows ?X .
       ?X foaf:name ?N . ?X rdfs:seeAlso ?L
      }
```

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

?N	?L
"Wolfgang Faber"	<http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf>
"Axel Polleres"	<http://www.polleres.net/foaf.rdf>

OPTIONALs 1/2 – Partial Matching

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prefix foaf:  <http://xmlns.com/foaf/0.1/>

select ?N ?L
from <http://www.mat.unical.it/~ianni/foaf.rdf>
where {<http://www.mat.unical.it/~ianni/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
"Wolfgang Faber"	<http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf>
"Axel Polleres"	<http://www.polleres.net/foaf.rdf>
"Thomas Eiter"	
"Alessandra Martello"	

OPTIONALs 2/2 – Set difference

"Select all names of persons known by G.B. from his FOAF file who don't have a `rdfs:seeAlso` links"

```
prefix rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
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 foaf:name ?N . optional { ?X rdfs:seeAlso ?L }
       filter ( !  bound(L) )
      }
```

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where {<http://www.mat.unical.it/~ianni/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.

?N
"Thomas Eiter"
"Alessandra Martello"

OPTIONALs 2/2 – Set difference

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select ?N
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where {<http://www.mat.unical.it/~ianni/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.
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- This is similar to set difference (NOT EXISTS) in SQL or "negation as failure" in Logic Programming rules.

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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 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
"Thomas Eiter"
"Alessandra Martello"

GRAPH patterns

"Select all names of persons directly known by G.B. or the names of persons appearing in the files linked by `rdfs:seeAlso` links."

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

GRAPH patterns

"Select all names of persons directly known by G.B. or the names of persons appearing in the files linked by `rdfs:seeAlso` links."

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

select ?N
from <http://www.mat.unical.it/~ianni/foaf.rdf>
from named???
where {<http://www.mat.unical.it/~ianni/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.

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."*

```
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/>
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 )
      }
```

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."*

```
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/>
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 )
      }
```

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

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 the Reasoning Web Series but have not co-authored with any of the authors of the present paper

- 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, ; Polleres *et al.*, 2007]
- 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. [Pérez *et al.*, 2006; Polleres and Schindlauer, 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!

Unit Outline

What does RDF data mean?

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

[6] "data" rather than "ontology", in DL terminology this distinction is often called ABox vs. TBox.

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)[6]

[6] "data" rather than "ontology", in DL terminology this distinction is often called ABox vs. TBox.

What does RDF data mean?

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  - *properties*,i.e., predicates
  - *classes*, i.e., objects of `rdf:type` triples
  - (*individuals*, i.e., concrete objects)[6]
- Ontologies describe *relations* among properties, classes and individuals (subclasses, subproperties, equivalence, domain, range, etc.)

[6] "data" rather than "ontology", in DL terminology this distinction is often called ABox vs. TBox.

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)[6]
- 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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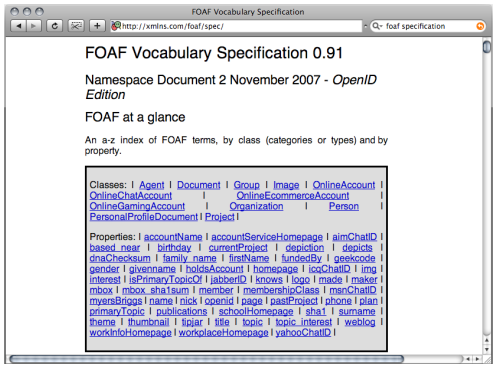
Example Vocabulary 1 – The FOAF ontology:

- **Properties:** `name`, `knows`, `homepage`, `primaryTopic` etc.
- **Classes:** `Person`, `Agent`, `Document`, `Organisation`, etc.
- **Relations:** e.g.
  - *Each* `Person` *is a* `Agent` (subclass)



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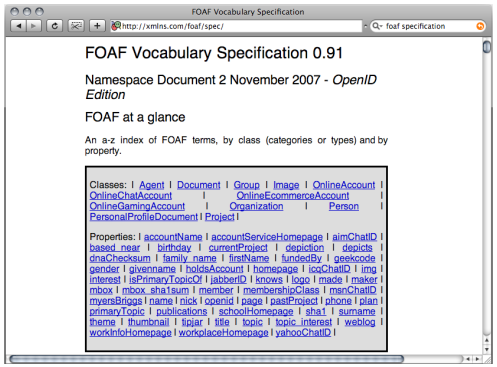

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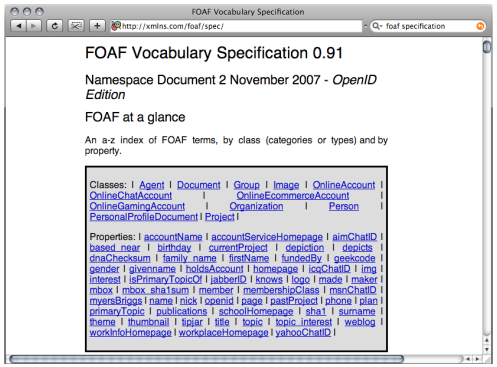

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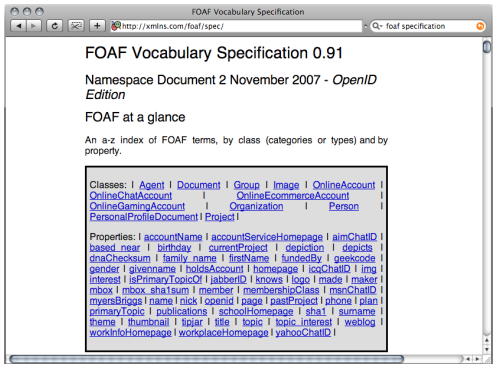

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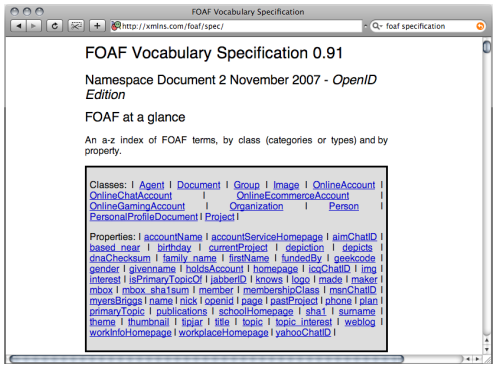

Examples 2 – A simple ontology about reviewers:

- **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)

[7] reuse of external ontologies!

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  - *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)

⋮

[7] reuse of external ontologies!

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

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

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- **Classes:** `rdf:XMLLiteral`, `rdf:Literal`, `rdfs:Resource`, `rdfs:Property`, `rdfs:Class`, `rdf:List`, etc.
- **Relations:** The semantics of the RDFs vocabulary is defined in [Hayes, 2004]; it is a "meta vocabulary" used to define the semantics of other vocabularies

The Semantics of RDF graphs:

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

The Semantics of RDF graphs:

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

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

The Semantics of RDF graphs:

Alternatively, especially in the SW community, F-Logic has gained popularity:

$$\begin{aligned}\exists me, b1, b2, b3, b4\ (&\texttt{foaf.rdf\#PersonalProfileDocument}\\ \wedge\ &\texttt{foaf.rdf}[\texttt{maker} \longrightarrow me]\\ \wedge\ &\texttt{foaf.rdf}[\texttt{primaryTopic} \longrightarrow me]\\ \wedge\ &me\#\texttt{Person} \wedge \cdots)\end{aligned}$$

- special notion for class membership (`rdf:type`): `#`
- frames $s[p \longrightarrow o]$ naturally represent triples

The Semantics of RDF graphs:

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

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

- 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 as first-order formulas again:

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

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

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

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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* `Imgages` (domain/range)
- `knows` *is a relation between two* `Persons` (domain/range)
- `homepage` *denotes* ***unique*** *homepage of an* `Agent` (uniquely identifying property)

$$\vdots$$

RDFS: Semantics

$$\vdots$$

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$$\vdots$$

Data:

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

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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:img rdfs:domain foaf:Person ; rdfs:range foaf:Person .`
- `???`

⋮

RDFS: Semantics

⋮

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

⋮

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

[8] 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 `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.`	$P^+ \sqsubseteq P$	$\forall x, y, z.P(x, y) \wedge P(y, z) \supset P(x, z)$

OWL DL in two slides: 1/2

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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` $(n))$	$\geqslant nP$	$\exists y_1 \ldots y_n \cdot \bigwedge_{k=1}^{n} P(x,y_k) \wedge \bigwedge_{i<j} y_j \neq y_j$
`owl:restriction` $(P$ `owl:maxCardinality` $(n))$	$\leqslant nP$	$\forall y_1 \ldots y_{n+1} \cdot \bigwedge_{k=1}^{n+1} P(x,y_k) \supset \bigvee_{i<j} y_i = y_j$

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

OWL DL in two slides: 2/2

Relating Class descriptions:

C_1 `rdfs:subClassOf` C_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	$o_1 = o_2$
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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
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- *homepage denotes* ***unique*** *homepage of an* `Agent` (uniquely identifying property)

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foaf:homepage rdf:type owl:InverseFunctionalProperty .
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- **Rule/LP engines**: cf. Unit3

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OWL2 WG tries to define SPARQL DL . . . stay tuned!

Unit Outline

What's next? Rules!

- Can I use my favorite rules engine/language to do Ontology Reasoning with RDFS+OWL?
- Can I use *rules* to aggregate the Web data I collected from various sites beyond the expressivity of RDFS+OWL?
- Can I combine RDFS, OWL, SPARQL and custom rules?


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