Unit 1 – a “Bird’s Eye” View on RDF(S), OWL & SPARQL

Axel Polleres

Siemens AG Österreich

VU 184.729 Semantic Web Technologies

Unit Outline

1. Motivation – Aggregating Web Data

2. How can I publish data? RDF

3. How can I query that data? SPARQL

4. What does that data mean? Ontologies described in RDFS + OWL

5. What's next?

Prerequisites

- Some basic knowledge about first-order logics.
- Some basic knowledge about databases (mainly: SQL).
- Some basic knowledge about HTML and HTTP.
- Some basic knowledge about XML would be nice.

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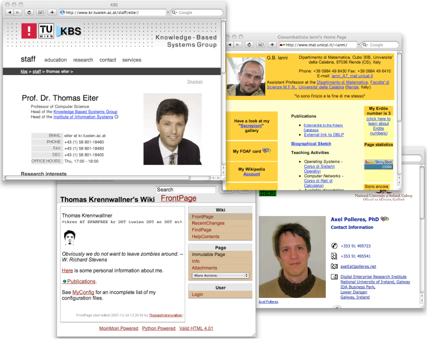
- How can I assess their expertise?
- Which reviewers are in conflict?
- Observation: Much of the necessary data is available on the Web!

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?

Where is the data? 1/4



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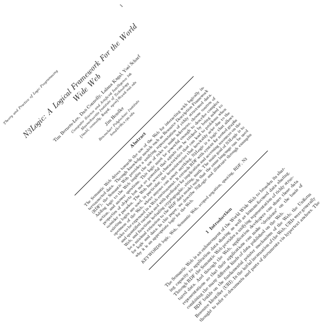

Theory and Practice of Logic Programming

1

N3Logic: A Logical Framework For the World Wide Web

Tim Berners-Lee, Dan Connolly, Lalana Kagal, Yosi Scharf
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Massachusetts Institute of Technology
{timbl, connolly, lkagal, syosi}@csail.mit.edu

Jim Hendler
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KEYWORDS: logic, Web, Semantic Web, scoped negation, quoting, RDF, N3

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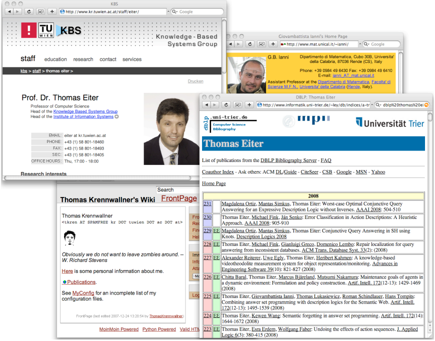

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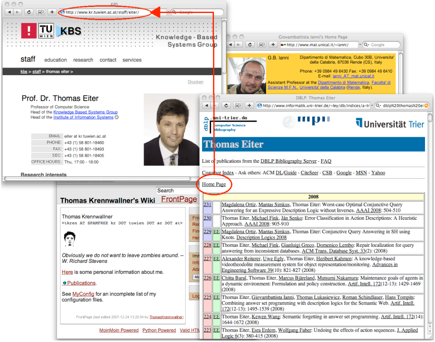
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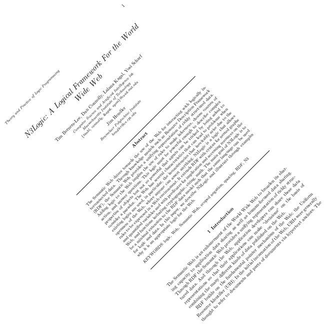
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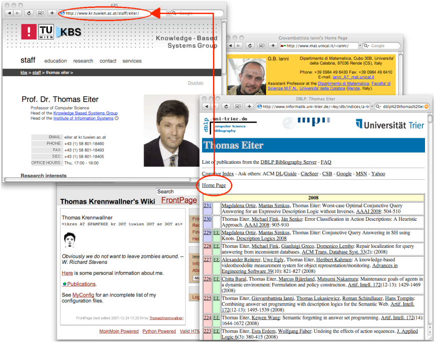

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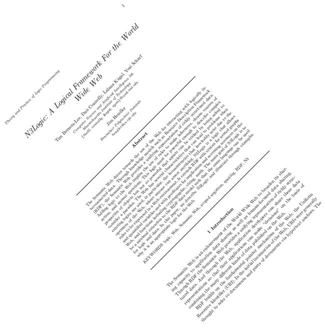

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- A lot of Web data already available "out there"
- it's linked
- More and more of it available in in a machine-readable format (RDF) following the *Linked Data* principles (cf. introductory slides from last week)

Where is the data? 2/4

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

Where is the data? 2/4

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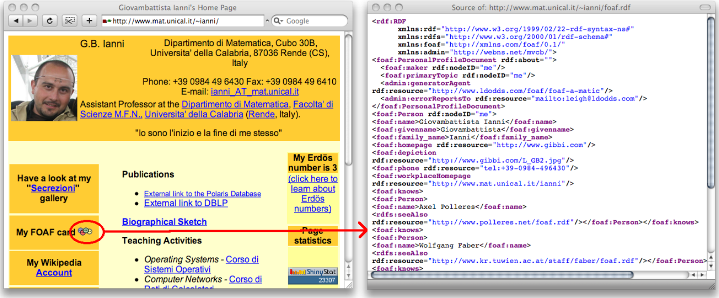
"FOAF-files" in RDF linked from a home page: personal data (`foaf:name`, `foaf:phone`, etc.), relationships `foaf:knows`, `rdfs:seeAlso`)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<foaf:PersonalProfileDocument rdf:about="">
  <foaf:maker rdf:nodeID="me"/>
  <foaf:primaryTopic rdf:nodeID="me"/>
  <admin:generatorAgent
rdf:resource="http://www.ldodds.com/foaf/foaf-a-matic"/>
  <admin:errorReportsTo rdf:resource="mailto:leigh@ldodds.com"/>
</foaf:PersonalProfileDocument>
<foaf:Person rdf:nodeID="me">
<foaf:name>Giovambattista Ianni</foaf:name>
<foaf:givenname>Giovambattista</foaf:givenname>
<foaf:family_name>Ianni</foaf:family_name>
<foaf:homepage rdf:resource="http://www.gibbi.com"/>
<foaf:depiction
rdf:resource="http://www.gibbi.com/L_GB2.jpg"/>
<foaf:phone rdf:resource="tel:+39-0984-496430"/>
<foaf:workplaceHomepage
rdf:resource="http://www.mat.unical.it/ianni"/>
<foaf:knows>
<foaf:Person>
<foaf:name>Axel Polleres</foaf:name>
<rdfs:seeAlso
rdf:resource="http://www.polleres.net/foaf.rdf"/></foaf:Person></foaf:knows>
<foaf:knows>
<foaf:Person>
<foaf:name>Wolfgang Faber</foaf:name>
<rdfs:seeAlso
rdf:resource="http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf"/></foaf:Person>
<foaf:knows>
```

Different Options:

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

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

`http://www.cs.rpi.edu/~hendler/`

Where is the data? 3/4

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

Some sites provide RDF in terms of microformats, or RDFa (=RDF embedded in HTML), e.g. on `http://bestbuy.com`, more and more using `http://schema.org` metadata

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

Where is the data? 4/4

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

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

Where is the data? 4/4

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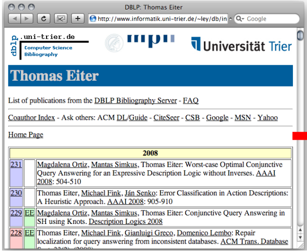


DBLP: Thomas Eiter

http://www.informatik.uni-trier.de/~ley/db/in

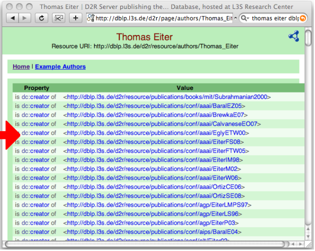
Thomas Eiter

List of publications from the DBLP Bibliography Server - FAQ

Coauthor Index - Ask others: ACM DL/Guide - CiteSeer - CSB - Google - MSN - Yahoo

Home Page

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



Thomas Eiter | D2R Server publishing the... Database, hosted at L3S Research Center

http://dblp.l3s.de/d2r/page/authors/Thomas_Eit

Thomas Eiter
Resource URI: http://dblp.l3s.de/d2r/resource/authors/Thomas_Eiter

Home | Example Authors

Property	Value
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/books/mit/Subrahmanian2000>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/BaralEZ05>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/BrewkaE07>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/CalvaneseEO07>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EglyETW00>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterFS08>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterFTW05>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterIM98>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterM02>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/EiterW06>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/OrtizCE06>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aaai/OrtizSE08>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/agp/EiterLMPS97>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/agp/EiterLS96>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/agp/EiterP03>
is dc:creator of	<http://dblp.l3s.de/d2r/resource/publications/conf/aips/BaralE04>

- 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/

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*"

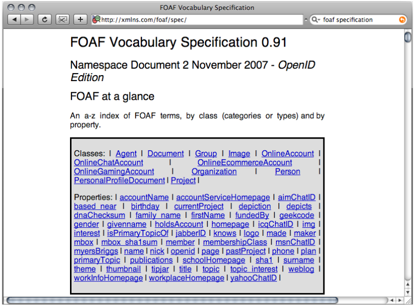
Example (**query1.sparql**):

```
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?

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

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



FOAF Vocabulary Specification 0.91

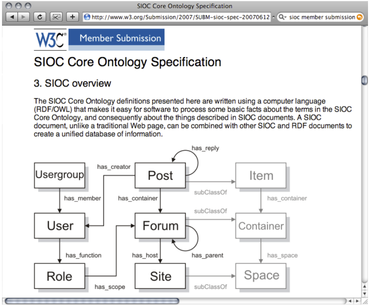
Namespace Document 2 November 2007 - *OpenID Edition*

FOAF at a glance

An a-z index of FOAF terms, by class (categories or types) and by property.

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

Properties: | accountName | accountServiceHomepage | aimChatID | based_near | birthday | currentProject | depiction | depicts | dnaChecksum | family_name | firstName | fundedBy | geekcode | gender | givenname | holdsAccount | homepage | icqChatID | img | interest | isPrimaryTopicOf | jabberID | knows | logo | made | maker | mbox | mbox_sha1sum | member | membershipClass | msnChatID | myersBriggs | name | nick | openid | page | pastProject | phone | plan | primaryTopic | publications | schoolHomepage | sha1 | surname | theme | thumbnail | tipjar | title | topic | topic_interest | weblog | workInfoHomepage | workplaceHomepage | yahooChatID |


SIOC Core Ontology Specification
http://www.w3.org/Submission/2007/SUBM-sioc-spec-20070612
sioc member submission
W3C
Member Submission

SIOC Core Ontology Specification

3. SIOC overview

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

Unit Outline

1. Motivation – Aggregating Web Data

2. How can I publish data? RDF

3. How can I query that data? SPARQL

4. What does that data mean? Ontologies described in RDFS + OWL

5. What's next?

Semantic Web Data: The Resource Description Framework (RDF)

- RDF is describing *resources* per triples/statements
  Subject **P**redicate **O**bject.

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  axel isA Person .
  axel hasName "Axel Polleres".
  axel knows gb .
  axel knows thomas.
  thomas hasCreated an Article
  titled "Rules and Ontologies for the Semantic Web".

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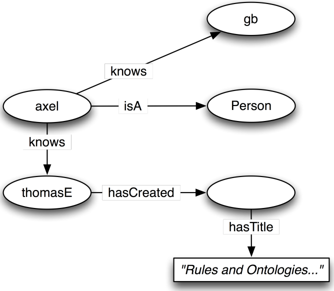
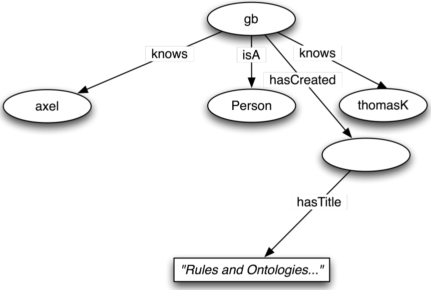
- abstracts away from tables (RDBMS) or tree-like (XML) schemas
- triples can be viewed as edges of a labeled,directed graph.
- main advantage: Graphs are easy to merge! (Trees,Tables aren't)

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

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.

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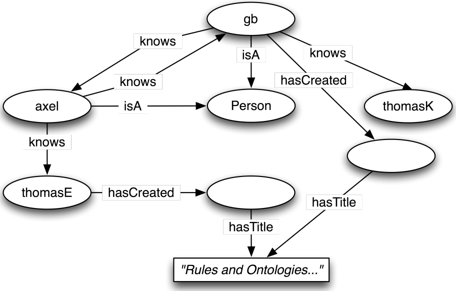

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gb knows thomasK.
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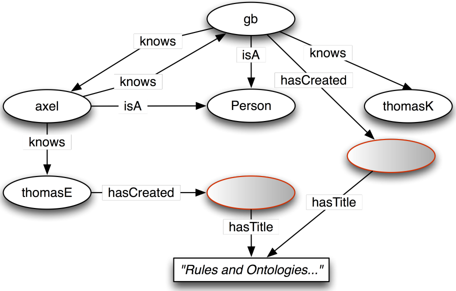

Observe: the "existential variables" became "blank" nodes in the Graph. Note that we have no reason to assume that the two blank nodes are the same.

A Syntax for RDF: Turtle

There are different syntaxes for RDF

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

We'll use Turtle syntax in this lecture:

- it is a subset of Notation 3 [Berners-Lee and Connolly, 2008]
- sufficient to write all RDF
- almost human-readable
- also the basis for SPARQL
- upcoming W3C standard!
- tools and APIs to convert from one syntax into the other

Resources in RDF, Turtle Syntax

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

axel isA Person .
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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’’.
```

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<http://polleres.net/foaf.rdf#me> <http://xmlns.com/foaf/0.1/name>
                    ‘‘Axel Polleres’’^^<http://www.w3.org/2001/XMLSchema#string>.
```

Resources in RDF, Turtle Syntax

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                    ‘‘Axel Polleres’’^^<http://www.w3.org/2001/XMLSchema#string>.
```

Ugly to read. . . more compact syntaxes like Turtle [Beckett *et al.*, 2008] 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#>
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@prefix foaf:  <http://xmlns.com/foaf/0.1/> .
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: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 .
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```

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

More on RDF – Shortcuts in Turtle Syntax

```
@prefix :  <http://polleres.net/foaf.rdf#>
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@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 .
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- Blank nodes in Turtle are written as _:*Varname*
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@prefix dc:  <http://purl.org/dc/elements/1.1/> .
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             <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
             rdf:type foaf:Document ;
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:me a foaf:Person;
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```

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  - `rdf:type` is often abbreviated with a.

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:me  foaf:Person;
    foaf:name ‘‘Axel Polleres’’^^xs:string;
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
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<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
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```

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

More on RDF – Shortcuts in Turtle Syntax

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

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

More on RDF – Shortcuts in Turtle Syntax

```
@prefix :  <http://polleres.net/foaf.rdf#>
@prefix rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix foaf:  <http://xmlns.com/foaf/0.1/> .
@prefix dc:  <http://purl.org/dc/elements/1.1/> .
:me  foaf:Person;
    foaf:name ‘‘Axel Polleres’’^^xs:string;
    foaf:knows <http://dblp.l3s.de/d2r/data/authors/Giovambattista_Ianni> ,
             <http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> .
<http://dblp.l3s.de/d2r/page/authors/Thomas_Eiter> dc:creator [
             a foaf:Document ;
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- Blank nodes in Turtle are written as _:*Varname*
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  - `rdf:type` is often abbreviated with a.
  - typed literals l of type dt are written as $l^{\wedge\wedge}dt$.
  - untyped literals can have a language tag [BCP-47, 2006].
  - (untyped literals with or without language tag are also called “plain” literals.)

Collecting RDF from the Web

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

[1] http://librdf.org/

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

Collecting RDF from the Web

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

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

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

[1] http://librdf.org/

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Collecting RDF from the Web

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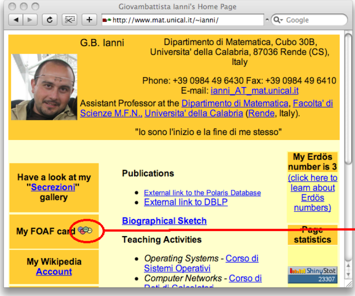
- For published RDF data there exists a machine-readable XML syntax. Lots of tools and APIs to read/process/convert this data (Redland (C++),[1] Jena (Java),[2] etc.)

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



Giovambattista Ianni's Home Page
http://www.mat.unical.it/~ianni/
Google

G.B. Ianni

Dipartimento di Matematica, Cubo 30B, Universita' della Calabria, 87036 Rende (CS), Italy

Phone: +39 0984 49 6430 Fax: +39 0984 49 6410
E-mail: ianni_AT_mat.unical.it

Assistant Professor at the Dipartimento di Matematica, Facolta' di Scienze M.F.N., Universita' della Calabria (Rende, Italy).

"Io sono l'inizio e la fine di me stesso"

Have a look at my "Secrezioni" gallery

My FOAF card

My Wikipedia Account

Publications

- External link to the Polaris Database
- External link to DBLP

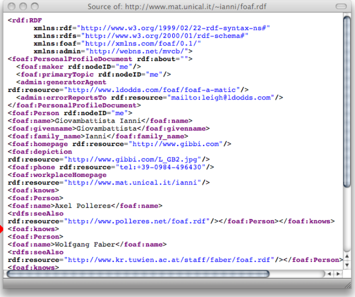
Biographical Sketch

Teaching Activities

- *Operating Systems* - Corso di Sistemi Operativi
- *Computer Networks* - Corso di Reti di Calcolatori

My Erdös number is 3 (click here to learn about Erdös numbers)

Page statistics



```
<rdf:RDF
      xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
      xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
      xmlns:foaf="http://xmlns.com/foaf/0.1/"
      xmlns:admin="http://webns.net/mvcb/">
<foaf:PersonalProfileDocument rdf:about="">
  <foaf:maker rdf:nodeID="me"/>
  <foaf:primaryTopic rdf:nodeID="me"/>
  <admin:generatorAgent
rdf:resource="http://www.ldodds.com/foaf/foaf-a-matic"/>
  <admin:errorReportsTo rdf:resource="mailto:leigh@ldodds.com"/>
</foaf:PersonalProfileDocument>
<foaf:Person rdf:nodeID="me">
<foaf:name>Giovambattista Ianni</foaf:name>
<foaf:givenname>Giovambattista</foaf:givenname>
<foaf:family_name>Ianni</foaf:family_name>
<foaf:homepage rdf:resource="http://www.gibbi.com"/>
<foaf:depiction
rdf:resource="http://www.gibbi.com/L_GB2.jpg"/>
<foaf:phone rdf:resource="tel:+39-0984-496430"/>
<foaf:workplaceHomepage
rdf:resource="http://www.mat.unical.it/ianni"/>
<foaf:knows>
<foaf:Person>
<foaf:name>Axel Polleres</foaf:name>
<rdfs:seeAlso
rdf:resource="http://www.polleres.net/foaf.rdf"/></foaf:Person></foaf:knows>
<foaf:knows>
<foaf:Person>
<foaf:name>Wolfgang Faber</foaf:name>
<rdfs:seeAlso
rdf:resource="http://www.kr.tuwien.ac.at/staff/faber/foaf.rdf"/></foaf:Person>
<foaf:knows>
```

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

[1] http://librdf.org/

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

Using *rapper*

Example tool for converting RDF between different syntaxesL: `rapper` (part of the Redland API, cf. `http://librdf.org/`), e.g.

```
rapper http://polleres.net/foaf.rdf -i rdfxml -o turtle
```

or

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

cf. Part 1 of assignment 1:

- Create your own FOAF file. You can use a generator tool such as FOAF-a-Matic (returns RDF/XML) to generate a skeleton.
- Convert the FOAF file to Turtle syntax [...]

Unit Outline

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

How can I query/aggregate RDF data? SPARQL

- First “ingredient”: a standardized query language – SPARQL [Prud’hommeaux and Seaborne, 2008;
  Harris and Seaborne, 2013] – 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	

How can I query/aggregate RDF data? SPARQL

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Head:	**C** or	`CONSTRUCT` { *template* }	. . . construct a new RDF graph
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	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:
  - basic graph patterns (Conjunctive queries)
  - `FILTER`s
  - `UNION`s of patterns
  - `OPTIONAL` Patterns
  - `GRAPH` Patterns

Basic Graph Patterns (Conjunctive queries)

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

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

- graph patterns (WHERE part) allow Turtle syntax

Basic Graph Patterns (Conjunctive queries)

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

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

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed[3]

[3] 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[3]
- merge of several graphs can be queried at once

Basic Graph Patterns (Conjunctive queries)

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

```
PREFIX foaf:  <http://xmlns.com/foaf/0.1/>
SELECT ?N
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[3]
- 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_2012/testdata/query2.sparql
  ```

FILTERs in Basic Graph Patterns

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

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

- graph patterns (`WHERE` part) allow Turtle syntax
- all Turtle shortcuts allowed
- Dataset can also be implicit, depending on the implementation

FILTERs in Basic Graph Patterns

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

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

- graph patterns (WHERE part) allow Turtle syntax
- all Turtle shortcuts allowed
- Dataset can also be implicit, depending on the implementation
- Now, let us try to filter out the authors' names from the result.

UNIONs (Disjunction)

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

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

UNIONs (Disjunction)

"Names of persons who know Axel Polleres or who are known by Axel Polleres"

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

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

OPTIONALs 1/2 – Partial Matching

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

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

SELECT ?N ?L
FROM <http://www.polleres.net/foaf.rdf>
WHERE {<http://www.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 **both** a name **and** a `rdfs:seeAlso` link.

?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

“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 .  OPTIONAL  { ?X rdfs:seeAlso ?L }
      }
```

- “Normal” basic graph pattern doesn’t work here, returns only those `?X` with **both** a name **and** 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>
...	
"Thomas Eiter"	
...	

CONSTRUCT

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

> *"Create a graph which establishes 'foaf:knows relations for all persons who I have co-authored with according to DBLP."* (query7.sparql)

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

CONSTRUCT

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CONSTRUCT  { <http://polleres.net/foaf.rdf#me> foaf:knows ?Y }
WHERE { ?D dc:creator :Axel_Polleres;
        dc:creator ?Y . FILTER( ?Y != :Axel_Polleres )
      }
```

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

ASK

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

> *"Does Axel know one of the co-authors of <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>?"*

```
PREFIX rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf:  <http://xmlns.com/foaf/0.1/>
PREFIX dc:  <http://purl.org/dc/elements/1.1/>
ASK
FROM <http://polleres.net/foaf.rdf>
FROM <http://dblp.l3s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
        <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>
                                         dc:creator ?A }
```

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

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PREFIX foaf:  <http://xmlns.com/foaf/0.1/>
PREFIX dc:  <http://purl.org/dc/elements/1.1/>
ASK
FROM <http://polleres.net/foaf.rdf>
FROM <http://dblp.l3s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
        <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>
                                           dc:creator ?A }
```

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

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

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`ASK` queries are "yes/no" queries without explicit output, e.g.

> *"Does Axel know one of the co-authors of <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>?"*

```
PREFIX rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf:  <http://xmlns.com/foaf/0.1/>
PREFIX dc:  <http://purl.org/dc/elements/1.1/>
ASK
FROM <http://polleres.net/foaf.rdf>
FROM <http://dblp.l3s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
        <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>
                                                           dc:creator ?A }
```

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

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

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

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

ASK

`ASK` queries are "yes/no" queries without explicit output, e.g.

> *"Does Axel know one of the co-authors of* `<http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>`*?"*

```
PREFIX rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf:  <http://xmlns.com/foaf/0.1/>
PREFIX dc:  <http://purl.org/dc/elements/1.1/>
ASK
FROM <http://polleres.net/foaf.rdf>
FROM <http://dblp.l3s.de/d2r/data/publications/journals/tplp/Berners-LeeCKSH08>
WHERE { <http://polleres.net/foaf.rdf#me> foaf:knows ?A .
        <http://dblp.l3s.de/d2r/resource/publications/journals/tplp/Berners-LeeCKSH08>
                                                  dc:creator ?A }
```

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

More on that later...

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

Unit Outline

1. Motivation – Aggregating Web Data

2. How can I publish data? RDF

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4. What does that data mean? Ontologies described in RDFS + OWL

5. What's next?

What does RDF data mean?

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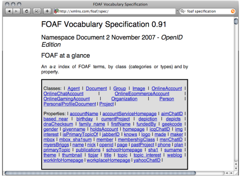
- Ontologies describe ***relations*** among properties, classes and individuals (subclasses, subproperties, equivalence, domain, range, etc.)
- The W3C has published two standards to describe ontologies, namely *RDF Schema (RDFS)* [Brickley and Guha (eds.), 2004] and the *Web Ontology language (OWL)* [W3C OWL 2 Working Group, 2012]
  - 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"

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)



FOAF Vocabulary Specification 0.91

Namespace Document 2 November 2007 - *OpenID Edition*

FOAF at a glance

An a-z index of FOAF terms, by class (categories or types) and by property.

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

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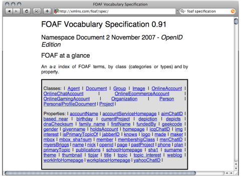

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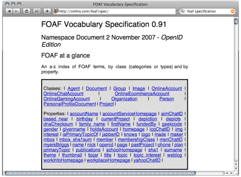

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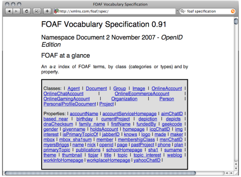

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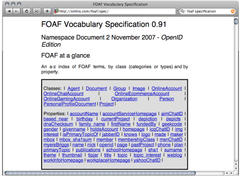
  - *knows is a relation between two Persons* (domain/range)
  - *homepage denotes **unique** homepage of an Agent* (uniquely identifying property)

⋮



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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)

[4] 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)

⋮

[4] reuse of external ontologies!

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

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

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

The Semantics of RDF graphs:

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

The Semantics of RDF graphs:

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

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

The Semantics of RDF graphs:

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

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

- 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:

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

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

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

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

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

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

$$\begin{aligned}\forall C_1, C_2, C_3\ (&\mathit{triple}(C_1, \mathtt{rdfs{:}subClassOf}, C_2) \wedge \\ &\mathit{triple}(C_2, \mathtt{rdfs{:}subClassOf}, C_3) \supset \mathit{triple}(C_1, \mathtt{rdfs{:}subClassOf}, C_3))\end{aligned}$$

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

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

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

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⋮

RDFS: Semantics

⋮

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⋮

Data:

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

RDFS Semantics Example: The FOAF ontology

FOAF Ontology in RDF:

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

$\vdots$

RDFS: Semantics

$\vdots$

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$\vdots$

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

$\vdots$

RDFS: Semantics

$\vdots$

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

$\vdots$

Data:

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

The OWL vocabulary:

- *foaf: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
  - in terms of its RDF reading (RDF-based-semantics), and

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  - in terms of its RDF reading (RDF-based-semantics), and
  - in terms of its Description Logics reading (direct semantics)[5]

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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 one slide

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.	$P^{+} \sqsubseteq P$	$\forall x, y, z.P(x, y) \wedge P(y, z) \supset P(x, z)$

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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 $(C_1 \dots C_n)$	$C_1 \sqcap \dots \sqcap C_n$	$C_1(x) \wedge \dots \wedge C_n(x)$
owl:unionOf $(C_1 \dots C_n)$	$C_1 \sqcup \dots \sqcup C_n$	$C_1(x) \vee \dots \vee C_n(x)$
owl:complementOf (C)	$\neg C$	$\neg C(x)$
owl:oneOf $(o_1 \dots o_n)$	$\{o_1, \dots, o_n\}$	$x = o_1 \vee \dots \vee x = o_n$
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 $(n))$	$\geqslant nP$	$\exists y_1 \dots y_n . \bigwedge_{k=1}^{n} P(x, y_k) \wedge \bigwedge_{i<j} y_j \neq y_j$
owl:restriction $(P$ owl:maxCardinality $(n))$	$\leqslant nP$	$\forall y_1 \dots y_{n+1} . \bigwedge_{k=1}^{n+1} P(x, y_k) \supset \bigvee_{i<j} y_i = y_j$

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

OWL DL in two slides: 2/2

Relating Class descriptions:

C_1 `rdfs:subClassOf` C_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	$o_1 \neq o_2$

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

OWL DL in two slides: 2/2

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

OWL Example: The FOAF ontology

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

. . . in OWL/RDF syntax:

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foaf:homepage rdf:type owl:InverseFunctionalProperty .
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        <http://www.polleres.net/> .
```

$$\models$$

```
<http://www.polleres.net/foaf.rdf#me> owl:sameAs
        <http://dblp.l3s.de/d2r/resource/authors/Axel_Polleres> .
```

Reasoning with Ontologies

Tools:

- Special purpose DL reasoners:
  Pellet [Sirin *et al.*, 2005], Racer [Haarslev and Möller, 2001], Fact++ [Tsarkov and Horrocks, 2006], Hermit [Motik *et al.*, 2007]
- General purpose FOL theorem provers:
  SNARK [Stickel *et al.*, online], SPASS [SPASS, online], Vampire [Riazanov and Voronkov, 2002]
- For special fragments of OWL [Motik *et al.*, 2012]:
  - **Rule/LP engines** (OWL RL)
  - **Relational databases** (OWL QL)

SPARQL & Ontologies

SPARQL on top of ontologies not trivial:

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- Challenge 2: blank nodes as existentials
- Challenge 3: SPARQL is SQL inspired (CWA), OWL/RDFS are (OWA):
  e.g., OPTIONAL patterns are non-monotonic, RDFS+OWL inference are both monotonic

SPARQL & Ontologies

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  e.g., OPTIONAL patterns are non-monotonic, RDFS+OWL inference are both monotonic

→ W3C's SPARQL1.1 WG has defined Entailment regimes for RDFS and OWL [Glimm *et al.*, 2013], stay tuned for later lectures.

Unit Outline

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

Summary

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

Details to come!

What's next?

- Details on the semantics of RDF+RDFS
- Details on the semantics of SPARQL+SPARQL1.1
- OWL2 and efficient reasoning for some fragments (particularly, OWL RL & OWL QL
- Linked Data
- Using SPARQL1.1 + RDFS + OWL on Linked Data
- Time allowed: applications.

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