INF3580/4580 – Semantic Technologies – Spring 2017

Lecture 14: Introduction to Ontology-based Data Access (OBDA)

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Today's Plan

1. Exposing data as RDF
2. Data Access in Statoil: limitations and solutions
3. OBDA Ingredients
   - Overview
   - Ontology
   - Mappings
   - Query rewriting
   - Bootstrapping
   - Visual Query Formulation
   - Optique

Outline

RDF

- Why URIs?
  - URIs naturally have a "global" scope, unique throughout the web.
  - URLs are also addresses.
  - *"A web of data."*

RDF

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  - URIs naturally have a "global" scope, unique throughout the web.
  - URLs are also addresses.
  - *"A web of data."*
- Why triples?
  - Any information format can be transformed to triples.
  - Relationships are made explicit and are elements in their own right

RDF on the web: Where is it?

- In files:
  - In some serialisation format: XML/RDF, Turtle, ...
  - Typically small RDF graphs, i.e., max. a few 100 triples, e.g.,
    - Vocabularies: `http://xmlns.com/foaf/spec/index.rdf`.
    - Tiny datasets: `http://folk.uio.no/martingi/foaf.rdf`.

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- "Behind" *SPARQL endpoints*:
  - Data kept in a *triple store*, i.e., a database of triples.
  - RDF is served from endpoint as results of *SPARQL queries*.
  - Exposes data (in different ways)
    - with endpoint frontends, e.g., `http://dbpedia.org/resource/Norway`, or
    - by direct SPARQL query: `http://dbpedia.org/sparql`.

RDF on the web: Where is it?

- "Behind" *OBDA repositories*:
  - OBDA: Ontology-based Data Access
  - Data kept in a traditional *relational database*
  - Access is transparent via SPARQL queries
  - SPARQL queries are "internally" transformed to SQL queries
  - An RDF representation of the relational database is "virtualized" to answer the SPARQL query.

Exposing data as RDF

- **Virtual exposure of data** (OBDA)
  - ✓ End-users' friendly access to "unfriendly" relational data
  - ✓ Pay as you go data integration
  - × Requires an ontology in OWL 2 QL
  - × Data remains in old-fashioned databases

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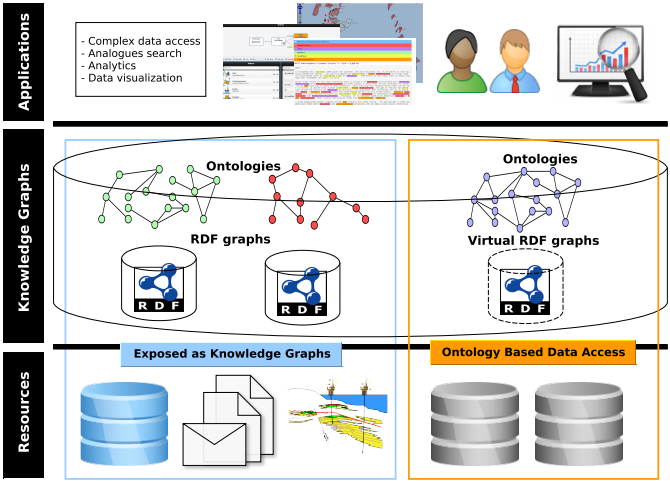
- **Data Export**
  - ✓ Easy to exchange data (over the Web)
  - ✓ Ontology not limited to OWL 2 QL
  - × Data replication
  - × Due to size or privacy it may not be possible to export the data

Exposing data as RDF



Outline

EU project Optique

- EU Project from 2012-2016
- Aimed at facilitating **scalable end-user access to big data** in the oil and gas industry.
- Advocated for an **OBDA approach**
  - ontology provides a virtual access to the data
  - mappings connect the ontology with the data source.

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- Advocated for an **OBDA approach**
  - ontology provides a virtual access to the data
  - mappings connect the ontology with the data source.
- Focused around two demanding use cases provided by the industry partners **Siemens** and **Statoil**
- Currently takes 30-70% of engineers' time (e.g., more than 250 MNOK annually).

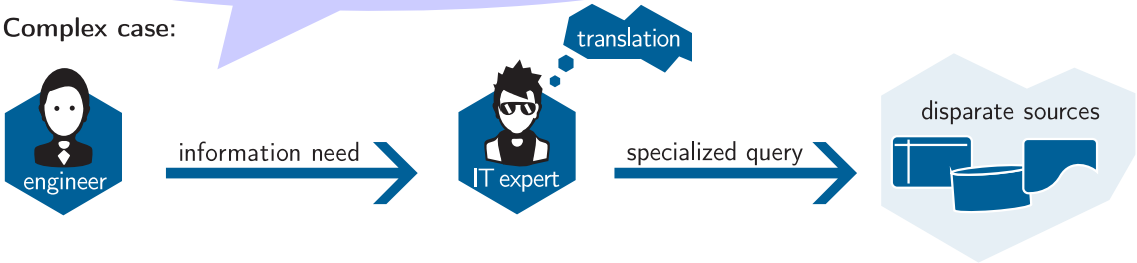
Limitations

Simple case:

Limitations

All norwegian wellbores of [type] nearby [place] having a permeability near [value]. [...] Attributes: completion date, depth, etc.

Complex case:



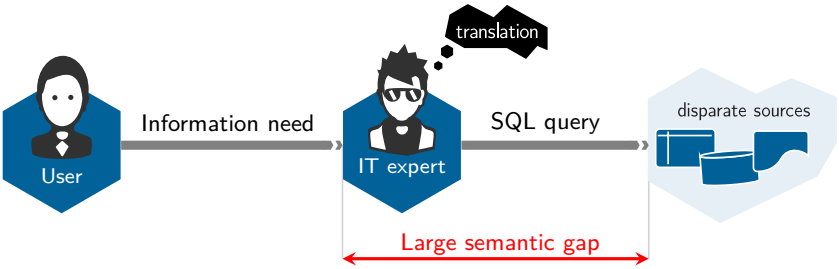
Takes 4 days in average

A typical query at Statoil

Anonymized extract

```
SELECT [...]
FROM
db_name.table1 table1,
db_name.table2 table2a,
db_name.table2 table2b,
db_name.table3 table3a,
db_name.table3 table3b,
db_name.table3 table3c,
db_name.table3 table3d,
db_name.table4 table4a,
db_name.table4 table4b,
db_name.table4 table4c,
db_name.table4 table4d,
db_name.table4 table4e,
db_name.table4 table4f,
db_name.table5 table5a,
db_name.table5 table5b,
db_name.table6 table6a,
db_name.table6 table6b,
db_name.table7 table7a,
db_name.table7 table7b,
db_name.table8 table8,
db_name.table9 table9,
db_name.table10 table10a,
db_name.table10 table10b,
db_name.table10 table10c,
db_name.table11 table11,
db_name.table12 table12,
db_name.table13 table13,
db_name.table14 table14,
db_name.table15 table15,
db_name.table16 table16
WHERE [...]
table2a.attr1='keyword' AND
table3a.attr2=table10c.attr1 AND
table3a.attr6=table6a.attr3 AND
table3a.attr9='keyword' AND
table4a.attr10 IN ('keyword') AND
table4a.attr1 IN ('keyword') AND
table5a.kinds=table4a.attr13 AND
table5b.kinds=table4c.attr74 AND
table5b.name='keyword' AND
(table6a.attr19=table10c.attr17 OR
(table6a.attr2 IS NULL AND
table10c.attr4 IS NULL)) AND
table6a.attr14=table5b.attr14 AND
table6a.attr2='keyword' AND
(table6b.attr14=table10c.attr8 OR
(table6b.attr4 IS NULL AND
table10c.attr7 IS NULL)) AND
table6b.attr19=table5a.attr55 AND
table6b.attr2='keyword' AND
table7a.attr19=table2b.attr19 AND
table7a.attr17=table15.attr19 AND
table4b.attr11='keyword' AND
table8.attr19=table7a.attr80 AND
table8.attr19=table13.attr20 AND
table8.attr4='keyword' AND
table9.attr10=table16.attr11 AND
table3b.attr19=table10c.attr18 AND
table3b.attr22=table12.attr63 AND
table3b.attr66='keyword' AND
table10a.attr54=table7a.attr8 AND
table10a.attr70=table10c.attr10 AND
table10a.attr16=table4d.attr11 AND
table4c.attr99='keyword' AND
table4c.attr1='keyword' AND
table11.attr10=table5a.attr10 AND
table11.attr40='keyword' AND
table11.attr50='keyword' AND
table2b.attr1=table1.attr8 AND
table2b.attr9 IN ('keyword') AND
table2b.attr2 LIKE 'keyword'% AND
table12.attr9 IN ('keyword') AND
table7b.attr1=table2a.attr10 AND
table3c.attr13=table10c.attr1 AND
table3c.attr10=table6b.attr20 AND
table3c.attr13='keyword' AND
table10b.attr16=table10a.attr7 AND
table10b.attr11=table7b.attr8 AND
table10b.attr13=table4b.attr89 AND
table13.attr1=table2b.attr10 AND
table13.attr20=''keyword'' AND
table13.attr15='keyword' AND
table3d.attr49=table12.attr18 AND
table3d.attr18=table10c.attr11 AND
table3d.attr14='keyword' AND
table4d.attr17 IN ('keyword') AND
table4d.attr19 IN ('keyword') AND
table16.attr28=table11.attr56 AND
table16.attr16=table10b.attr78 AND
table16.attr5=table14.attr56 AND
table4e.attr34 IN ('keyword') AND
table4e.attr48 IN ('keyword') AND
table4f.attr89=table5b.attr7 AND
table4f.attr45 IN ('keyword') AND
table4f.attr1='keyword' AND
table10c.attr2=table4e.attr19 AND
(table10c.attr78=table12.attr56 OR
(table10c.attr55 IS NULL AND
table12.attr17 IS NULL))
```

Limitations



Querying over RDB requires a lot of knowledge about:

- Magic numbers *(e.g., 1 → full professor)*
- Cardinalities and normal forms
- Relevant and closely-related information spread over many tables

High-level translation solution

General approach: two steps

1. Translate the information needs into a **high-level (formal) query**
   1. *Mediator 1* could be a user, an IT expert or a GUI
   2. Make such a translation easy *(Ideally: IT expertise not required)*
2. Answer the high-level query **automatically** using *Mediator 2*

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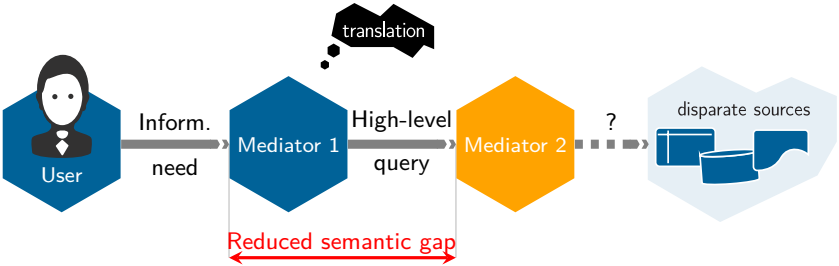
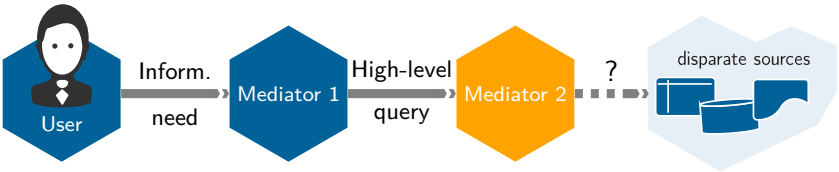


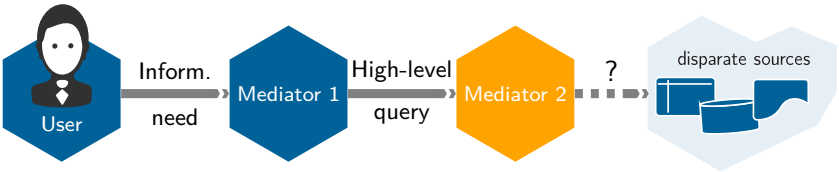
Two orthogonal choices to be made



Choice 1: Generating a new representation of the data

1. Extract Transform Load (ETL) process
2. Virtual views

Two orthogonal choices to be made



Choice 1: Generating a new representation of the data

1. Extract Transform Load (ETL) process
2. Virtual views

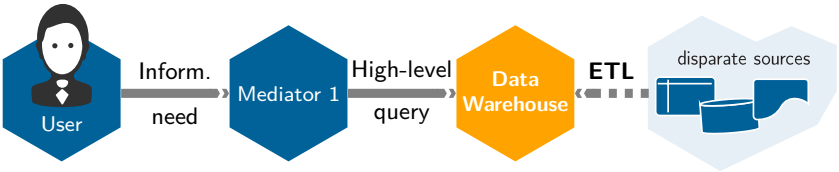
Choice 2: Which data format for the new representation

1. New relational schema
2. JSON (or XML) documents
3. Resource Description Framework (RDF)

Generating a new representation of the data

1. Extract Transform Load (ETL)

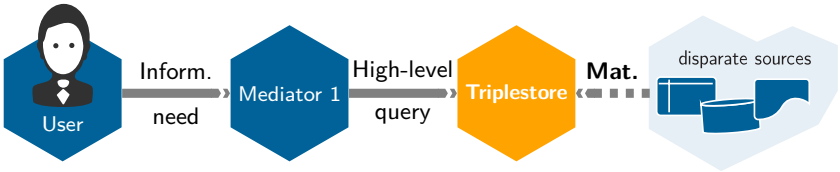
E.g., relational data warehouse



Generating a new representation of the data

1. Extract Transform Load (ETL) / Materialization

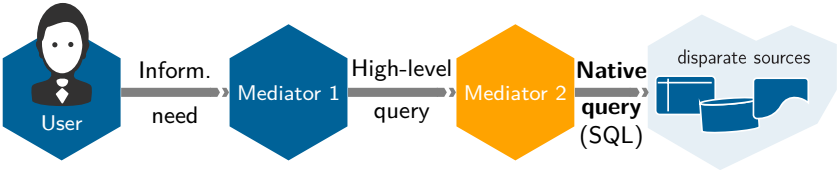
E.g., relational data warehouse, triplestore (RDF)



Generating a new representation of the data

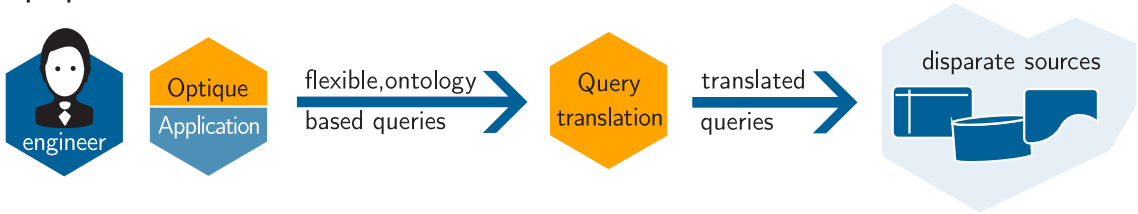
2. Virtual views

E.g., virtual databases (Teiid, Apache Drill, Exareme), **OBDA with Optique**



Optique solution: Ontology-Based Data Access (OBDA)

Optique solution



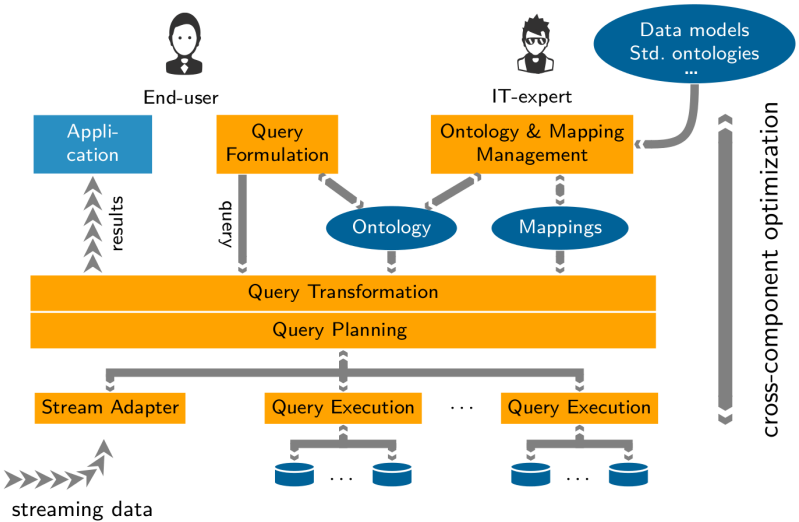
Choice 1: Generating a new representation of the data

1. Virtual views

Choice 2: Which data format for the virtual view

1. Resource Description Framework (RDF)

Optique architecture



Outline

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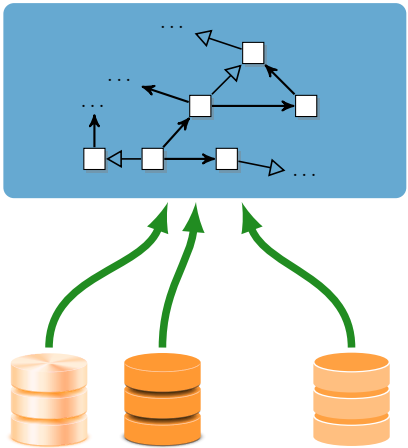
OBDA framework



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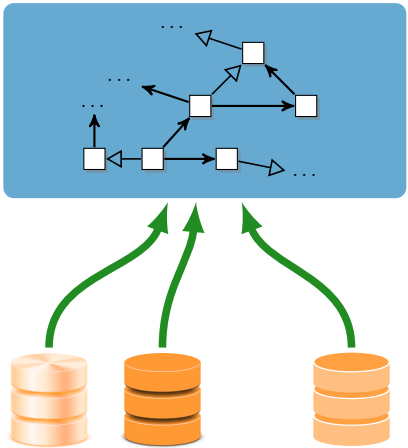
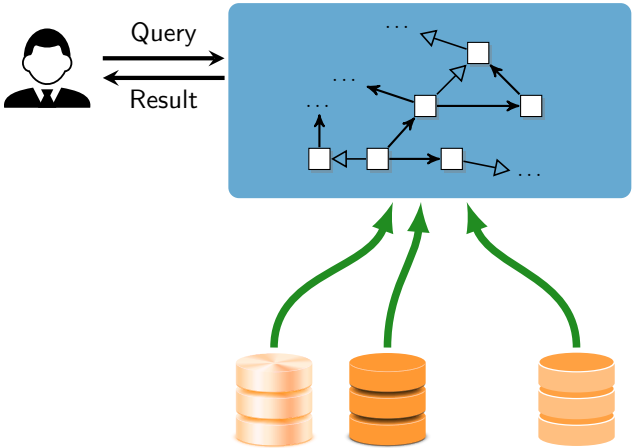


Ontology
provides
global vocabulary
and
conceptual view

Mappings
how to populate
the ontology
from the data

Data Sources
external and
heterogeneous

OBDA framework



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Data Sources
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OBDA framework

Logical transparency in accessing data:

- does not know where and how the data is stored.
- can only see a conceptual view of the data.

OBDA Ingredients

- Relies on...
  - **ontology** to provide a virtual access to the data
  - **mappings** to connect the ontology with the data

- Required infrastructure
  - **Query formulation system** to express the information needs in SPARQL (Mediator 1)
  - **Query transformation/rewriting** system to covert from SPARQL to (native) SQL (Mediator 2)
  - **Ontology and mapping bootstrapper**

Outline

The Ontology: OWL 2 QL profile

- OWL 2 QL is one of the three standard profiles of OWL 2.
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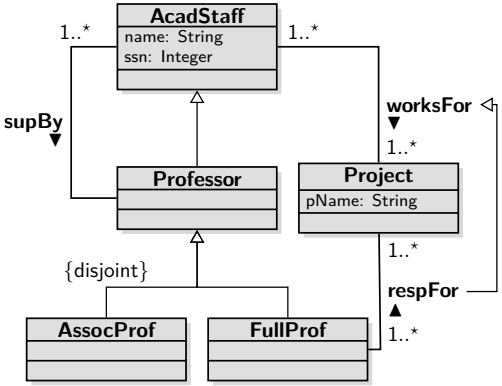
- OWL 2 QL is one of the three standard profiles of OWL 2.
- Is considered a lightweight ontology language:
  - controlled expressive power
  - efficient inference
- Optimized for accessing large amounts of data (i.e., for data complexity):
  - *First-order rewritability* of query answering: queries over the ontology can be rewritten into SQL queries over the underlying relational database.
  - Consistency checking is also first-order rewritable.
- The ontology data (ABox) in an OBDA setting is (usually) implicitly defined through the database and mappings.

Capturing UML class diagrams/ER schemas in OWL 2 QL



$$
\begin{aligned}
\mathtt{Professor} &\sqsubseteq \mathtt{AcadStaff} \\
\mathtt{AssocProf} &\sqsubseteq \mathtt{Professor} \\
\mathtt{FullProf} &\sqsubseteq \mathtt{Professor} \\
\mathtt{AssocProf} &\sqsubseteq \neg \mathtt{FullProf} \\
\mathtt{AcadStaff} &\sqsubseteq \exists \mathtt{ssn} \\
\exists \mathtt{ssn} &\sqsubseteq \mathtt{AcadStaff} \\
\exists \mathtt{ssn}^- &\sqsubseteq \mathtt{Integer} \\
\exists \mathtt{worksFor} &\sqsubseteq \mathtt{AcadStaff} \\
\exists \mathtt{worksFor}^- &\sqsubseteq \mathtt{Project} \\
\mathtt{AcadStaff} &\sqsubseteq \exists \mathtt{worksFor} \\
\mathtt{Project} &\sqsubseteq \exists \mathtt{worksFor}^- \\
\mathtt{respFor} &\sqsubseteq \mathtt{worksFor}
\end{aligned}
$$

Outline

OBDA Mappings

Global-As-View (GAV) mapping assertion $\varphi \rightsquigarrow \psi$

- φ: FO query
- ψ: atom
- Open-World Assumption (by default)

Class instance (`:Student`)

Source	$\boldsymbol{q}(s) \leftarrow \texttt{uni1-student}(s, f, l)$
	
	`SELECT s_id`
	`FROM uni1.student`

Target	$\text{Student}(\text{URI}_1(s))$ `ex:uni1/student/{s_id} a :Student .`

OBDA Mappings

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OBDA Mappings: R2RML

- R2RML is a W3C recommended RDB-to-RDF mapping language
  - `https://www.w3.org/TR/r2rml/`
- Generates RDF triples from a relational database based on specific mappings
- The mappings are specified in Turtle syntax

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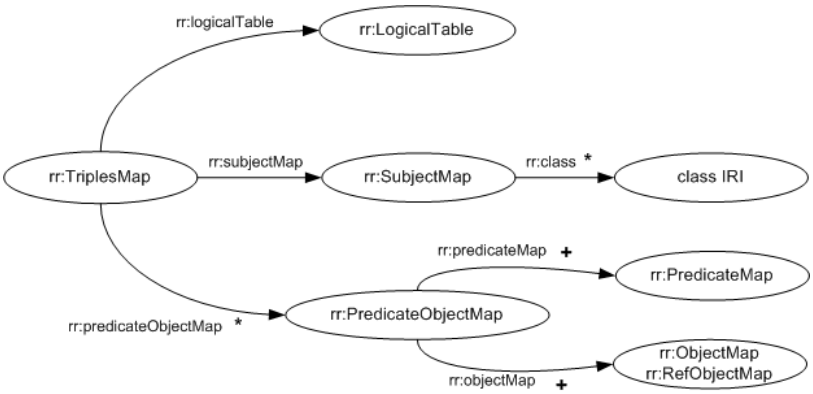
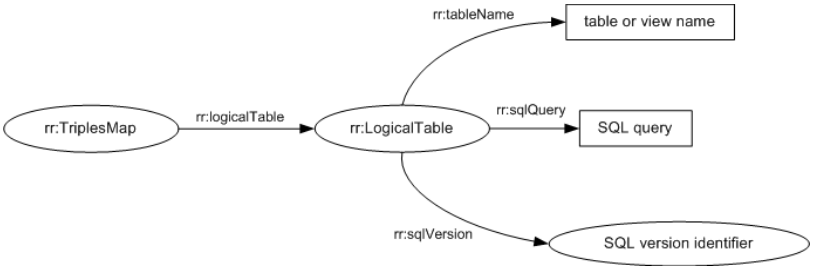
- Generates RDF triples from a relational database based on specific mappings
- The mappings are specified in Turtle syntax
- The R2RML mapping is an RDF graph consisting of several rr:TriplesMaps
  - how to map a logical table in the input relational database into RDF

OBDA Mappings: R2RML



OBDA Mappings: R2RML



OBDA Mappings: R2RML example

Triples map to populate Student class"

```
<TriplesMap1>        a rr:TriplesMapClass;
    rr:logicalTable [rr:SQLQuery "Select s_id, name, from STUDENT"];
    rr:subjectMap
    [
        rr:template "http://example.com/uni1/student/{s_id}";
        rr:class ex:Student;
    ] ;
    rr:predicateObjectMap
    [
        rr:predicate foaf:name;
        rr:objectMap [ rr:column "name" ]
    ] .
```

OBDA Mappings: R2RML example

Table STUDENT:

s_id	**name**
1	Ernesto
2	Martin
3	Leif

OBDA Mappings: R2RML example

Table STUDENT:

s_id	**name**
1	Ernesto
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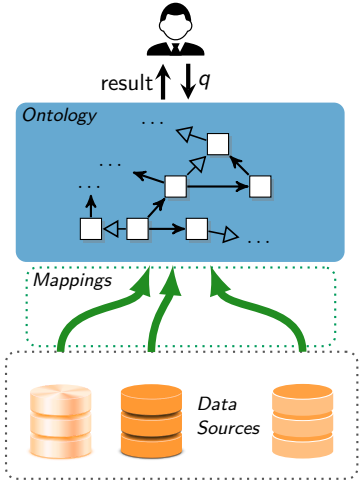
Triples:

```
http://example.com/uni1/student/1   foaf:name   Ernesto
http://example.com/uni1/student/2   foaf:name   Martin
http://example.com/uni1/student/3   foaf:name   Leif
```

Outline

Query answering by rewriting



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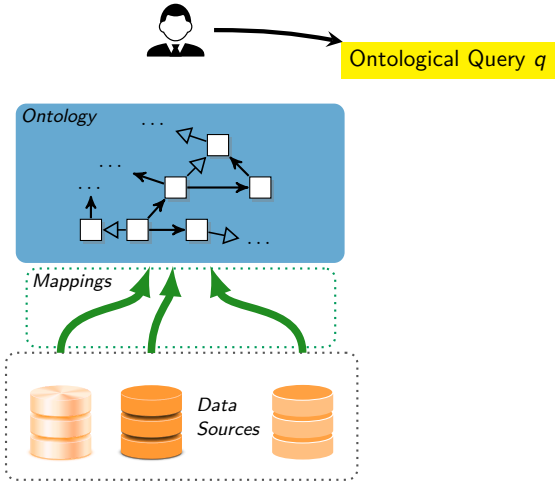

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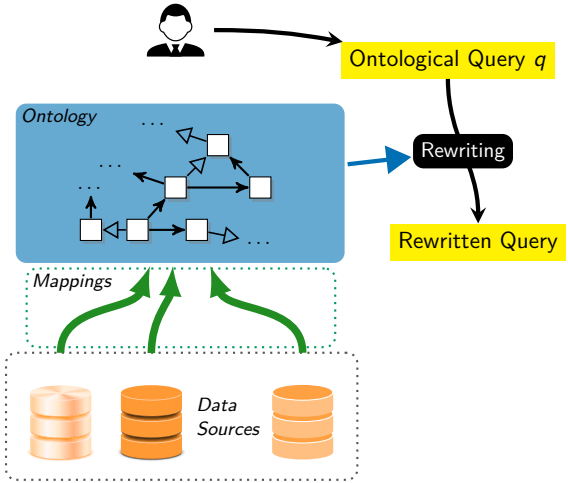

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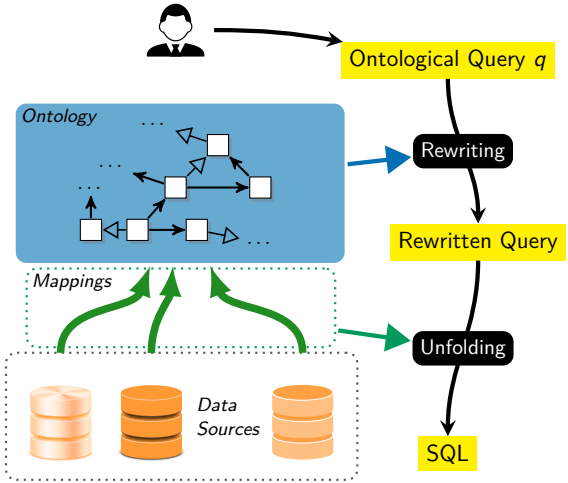

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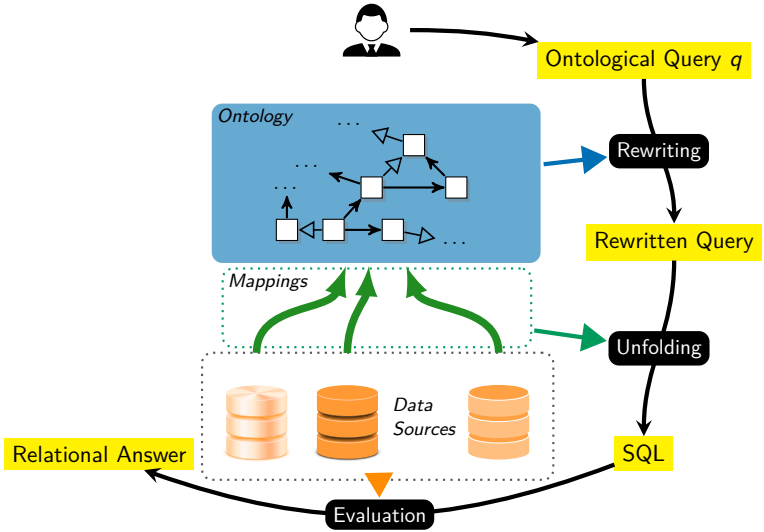

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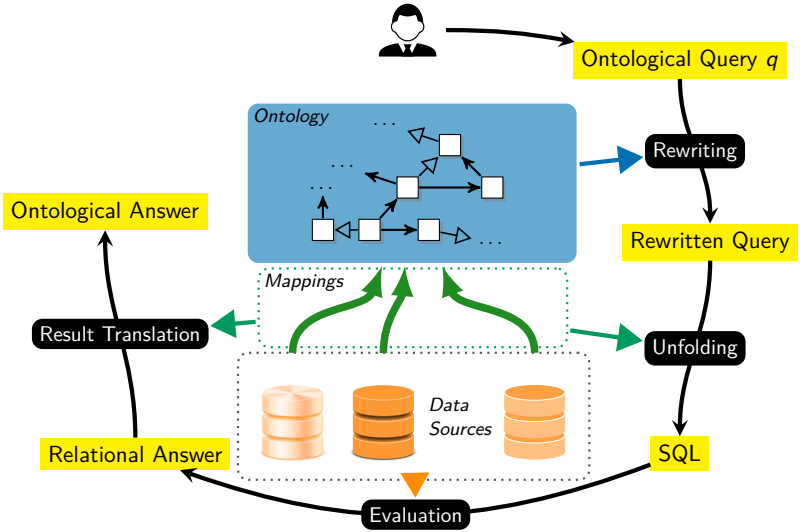

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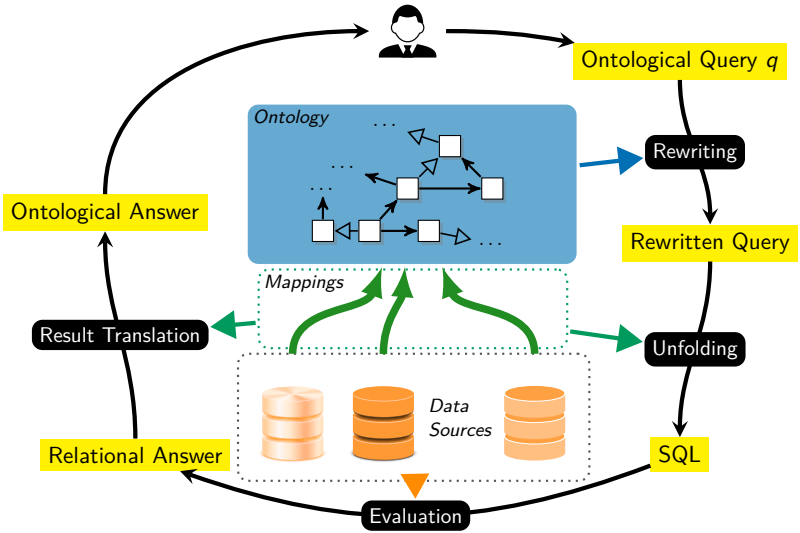


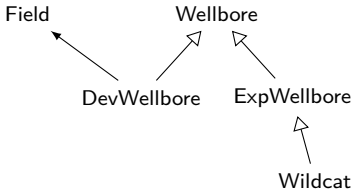
Query answering by rewriting (example)

Database:

```
wlb_dev(name, ...)
wlb_exp(name, purpose, ...)
```

Query: *List all wellbores.*

Ontology:



Mappings:

DevWellbore(name) $\mapsto$ `SELECT name FROM wlb_dev`

ExpWellbore(name) $\mapsto$ `SELECT name FROM wlb_exp`

Wildcat(name) $\mapsto$ `SELECT name FROM wlb_exp WHERE purpose = 'WILDCAT'`

Query answering by rewriting (example)

Database:

```
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Query: *List all wellbores.*

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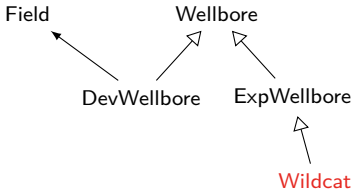

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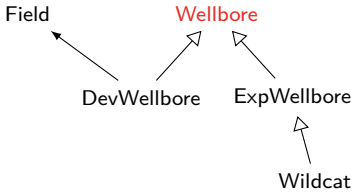

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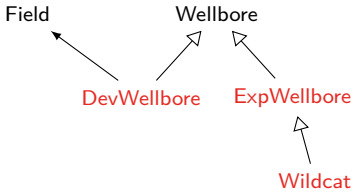

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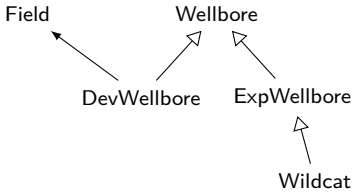

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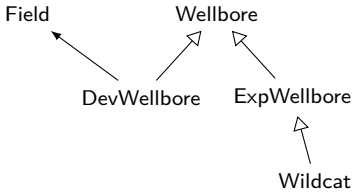

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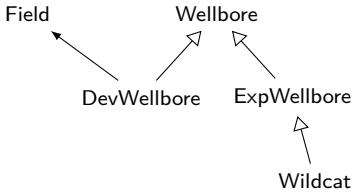

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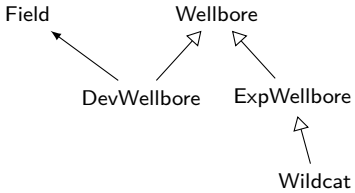

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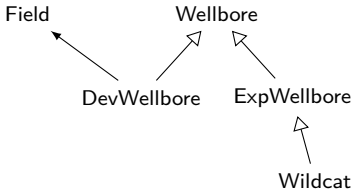

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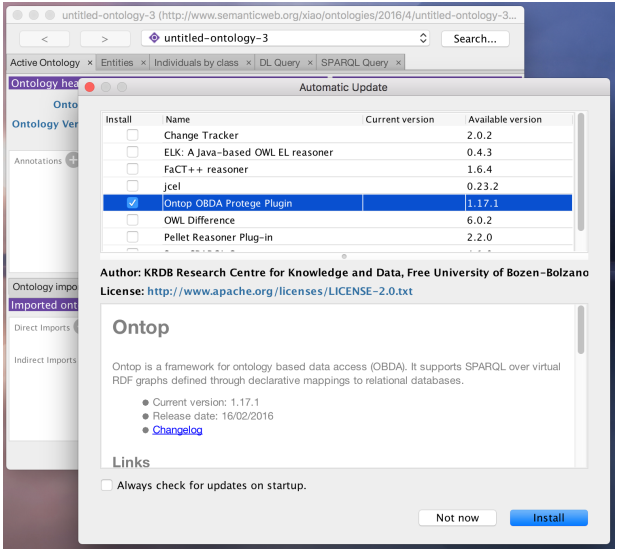
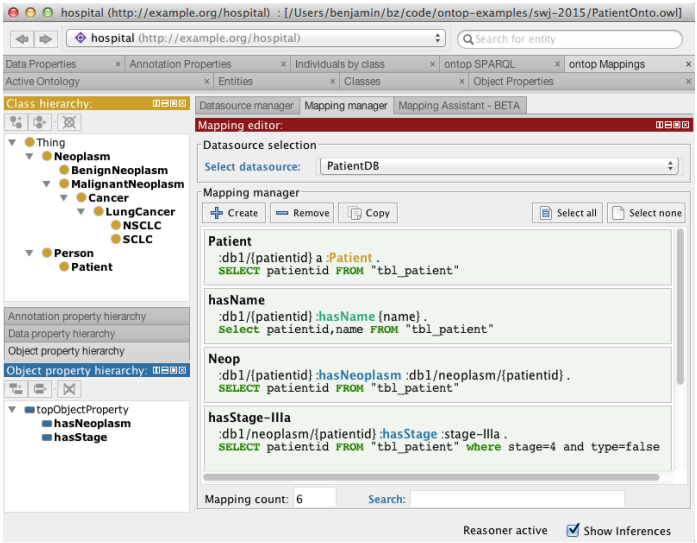
Query answering by rewriting (tool suport)

- **Ontop**: state-of-the-art OBDA system. `http://ontop.inf.unibz.it/`
- Compliant with the RDFS, OWL 2 QL, R2RML, and SPARQL standards.
- Supports all major relational DBs
  - Oracle, DB2, MS SQL Server, Postgres, MySQL, Teiid, Exareme, etc.
- Open-source and released under Apache 2 license
- Development of -ontop-:
  - Development started in 2009
  - -ontop- supports (essentially) all features of SPARQL 1.0 and the OWL 2 QL entailment regime of SPARQL 1.1.
  - Other features of SPARQL 1.1 (e.g., aggregates, property path queries, negation) are work in progress.

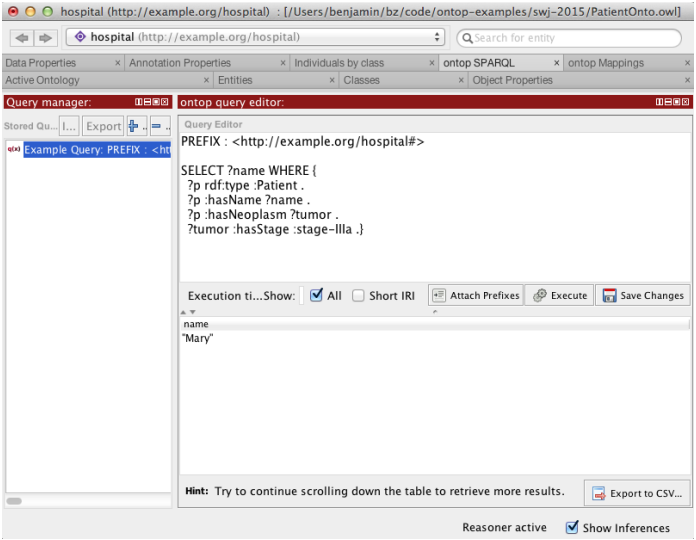
Ontop plugin available from Protégé



Ontop: Mapping editor in Protégé



Ontop: SPARQL query answering in Protégé



Outline

Bootstrapping overview

- Given a relational database (semi)automatically extracts ontological vocabulary, ontology and R2RML mappings
- Bootstrappers may also accept as input an ontology
  - R2RML mappings will link the given ontoloy to the database, or
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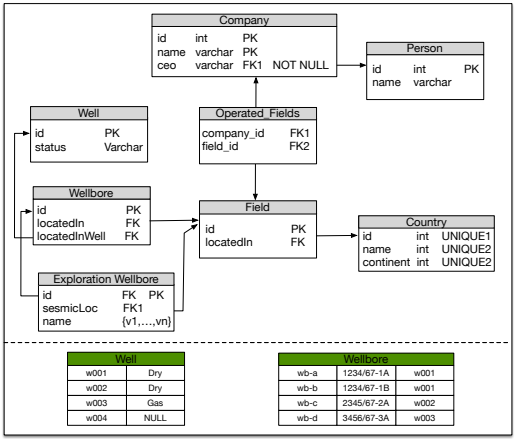
  - The given ontology will be *aligned* with the boostrapped ontology
- Type of mappings:
  - W3C direct mapping specification (*schema driven*)
    - To a given or bootstrapped ontology vocabulary
  - Mappings beyond direct ones (*data driven*)
    - Clusters of tuples
    - Joinable tuples

Bootstrapping: Vocabulary Generation

- **W3C directives**
  - Tables → classes
  - Foreign Keys → object properties
  - Data columns → data properties
  - Binary tables → fresh object properties



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  - Tables → classes
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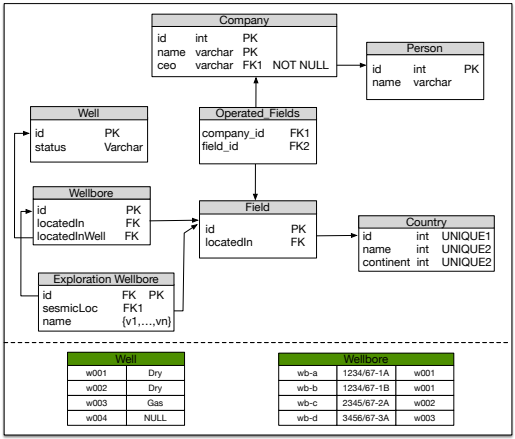
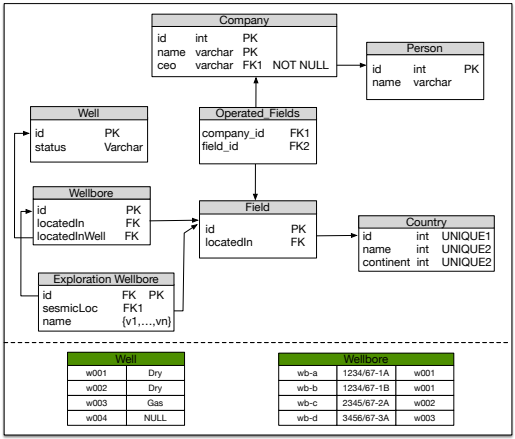
- **Attribute naming schema:**
  - Unique names (e.g. Person.name)
  - Reusable names (e.g. name)



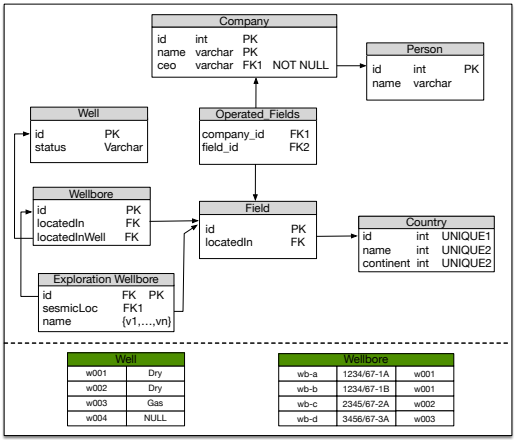
Bootstrapping: Axiom Generation

- **OWL 2 expressiveness**
  - OWL 2 QL (e.g. OBDA/Optique)
  - OWL 2 EL (e.g. EOLO)
  - OWL 2 RL (e.g. RDFox)
  - OWL 2 (e.g. PAGOdA, HermiT)



Bootstrapping: Axiom Generation

- Unique constraints
  - Person **HasKey:** id (OWL 2 RL/EL)



Bootstrapping: Axiom Generation

- Unique constraints
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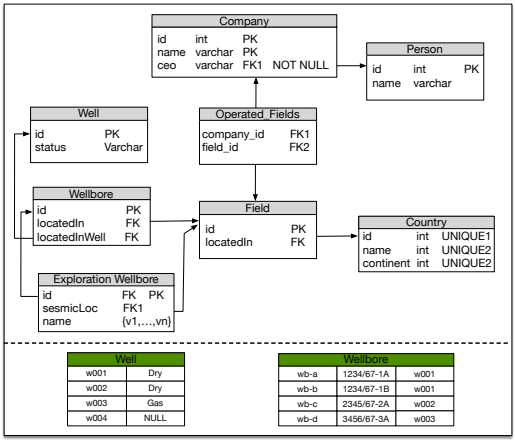
  - **Functional:** Person.name (OWL 2 RL)
  - name **Domain:** Person (all profiles)
  - Person.name **Range:** xsd:string (all profiles)



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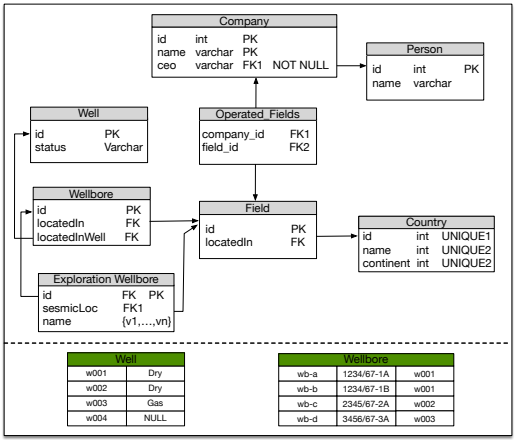
- Local onto. constraints
  - Person **subclassOf:** name **some** xsd:string (OWL 2 QL/EL)
  - Person **subclassOf:** name **only** xsd:string (OWL 2 RL)
  - Person **subclassOf:** name **exactly 1** xsd:string (OWL 2)



Bootstrapping: Datatypes

- Clear mapping between SQL and XML schema datatypes
- Not all XML Schema datatypes are included in OWL 2
  - *xsd:date* not in OWL 2
  - *xsd:boolean* and *xsd:double* not in OWL 2 QL/EL
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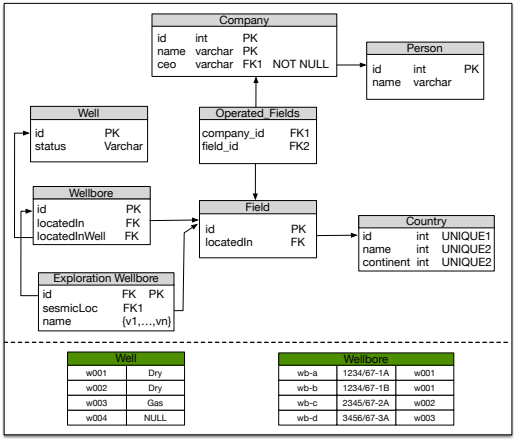
× Problems when materalizing the data or using the ontology for virtual access to data

✓ Solution: *rdfs:Literal*

Bootstrapping: Taxonomy Generation



Bootstrapping: Taxonomy Generation

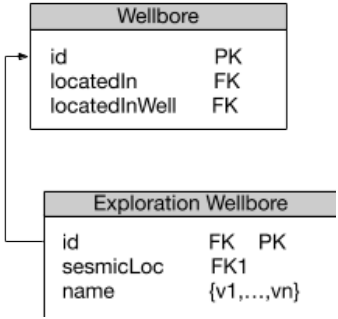
- **Data driven**
  - Clusters of tuples
  - Joinable tuples
  - e.g. Well_Dry **SubclassOf:** Well (w001, w002)
  - e.g. Well_with_Wellbore **SubclassOf:** Well (w001, w002, w003)

Well	
w001	Dry
w002	Dry
w003	Gas
w004	NULL

Wellbore		
wb-a	1234/67-1A	w001
wb-b	1234/67-1B	w001
wb-c	2345/67-2A	w002
wb-d	3456/67-3A	w003

Bootstrapping: Taxonomy Generation

- **Schema driven**
  - A single-column Foreign Key and Primary key
  - e.g. Exploration_Welllbore **SubclassOf:** Wellbore



Tool support and Lessons learnt

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- **Feedback from use cases and evaluation...**
  - ✓ Good as a first approximation of the ontology and mappings
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  - × For the largest Statoil datasources, the solution is far from perfect
  - × Ontology close to the original database
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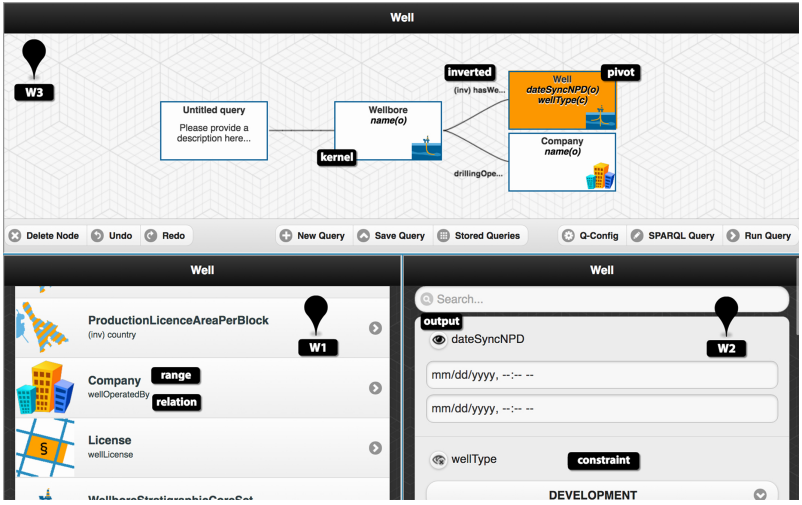
- **Future work...**
  - New ways to exploit the data and schema (e.g. views)

Outline

Visual query formulation (OptiqueVQS)



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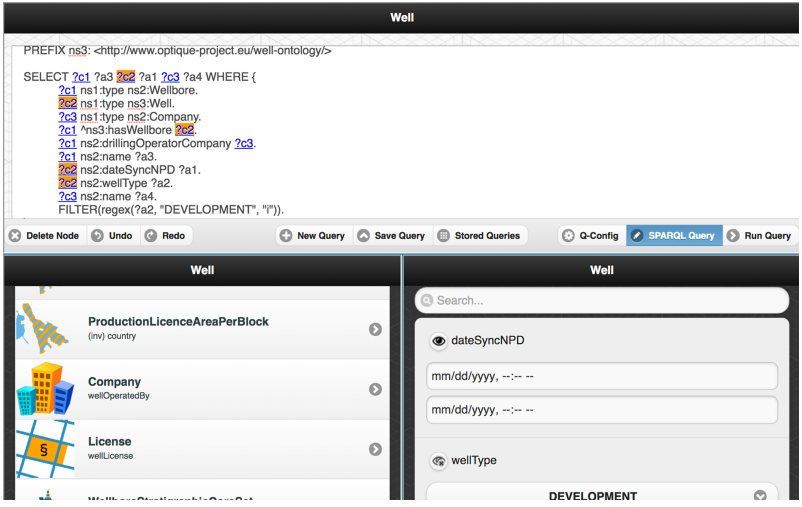

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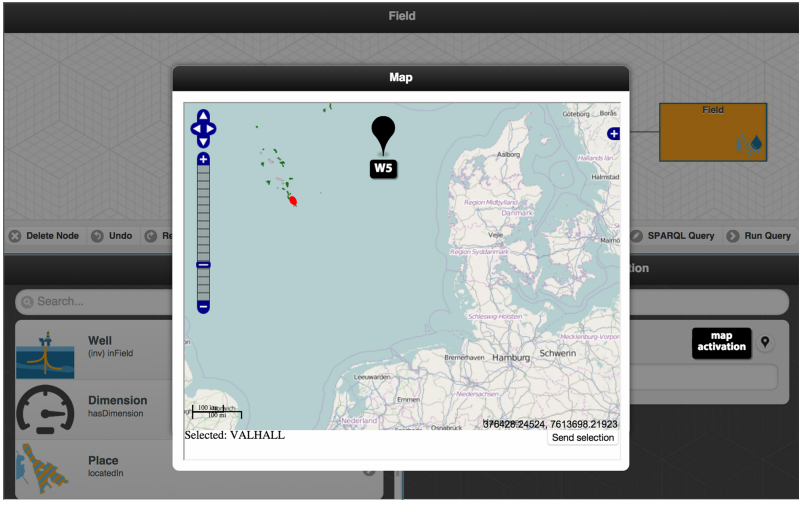

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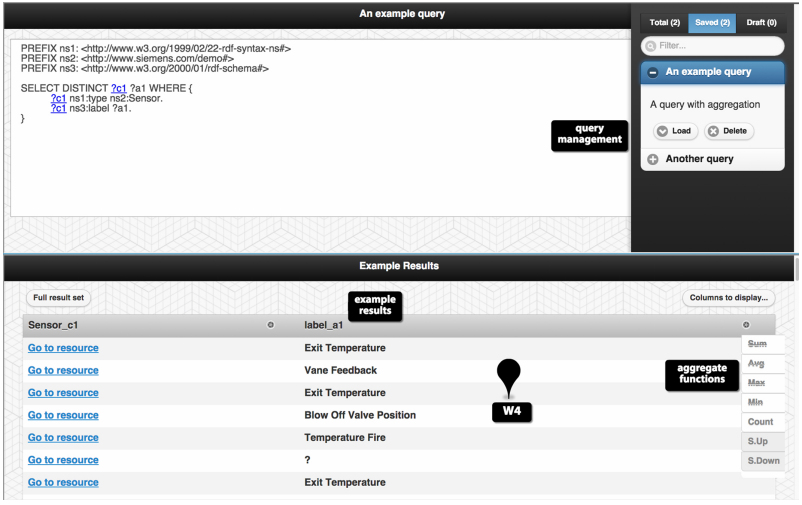

Outline

Optique infrastructure

- Training material:
  - `http://optique-northwind.fluidops.net` (demo/demo)
- OptiqueVQS can be tested online
- Local installation possible (academic license):
  - `https://appcenter.fluidops.com/resource/Search?search=optique`
- What is next?
  - *SIRIUS*: `http://sirius-labs.no/`

Questions?

Ernesto Jiménez-Ruiz (ernestoj@ifi.uio.no)
Office hours: from 9:00 to 16:00 at OJD 8165

Acknowledgements

- -ontop- team (Diego Calvanese, Benjamin Cogrel, Guohui Xiao, etc.) and Dag Hovland for sharing their wonderful slides
  - http://ontop.inf.unibz.it/ekaw-2016-tutorial/
- Ahmet Soylu: main person behind OptiqueVQS
- Optique partners