Mapping Management and Expressive Ontologies in Ontology-Based Data Access

1. Introduction to OBDA

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Outline

1. Motivation
2. Semantic Web standards
3. OBDA framework
4. Ontop system and its ecosystem
5. Use Cases
6. Conclusion

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1. Motivation
   - Semantic gap
   - Solutions

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Typical view of Big Data

But: data has a lot of structure

Challenge: how to use the data – Statoil Exploration

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900 geologists and geophysicists in Statoil Exploration develop stratigraphic models of unexplored areas on the basis of data acquired from previous operations at nearby locations.

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Statoil

Data stores:

- Exploration and Production Data Store (EPDS): ∼1500 tables (100s GBs)
- OpenWorks
- Norwegian Petroleum Directorate FactPages

Optique

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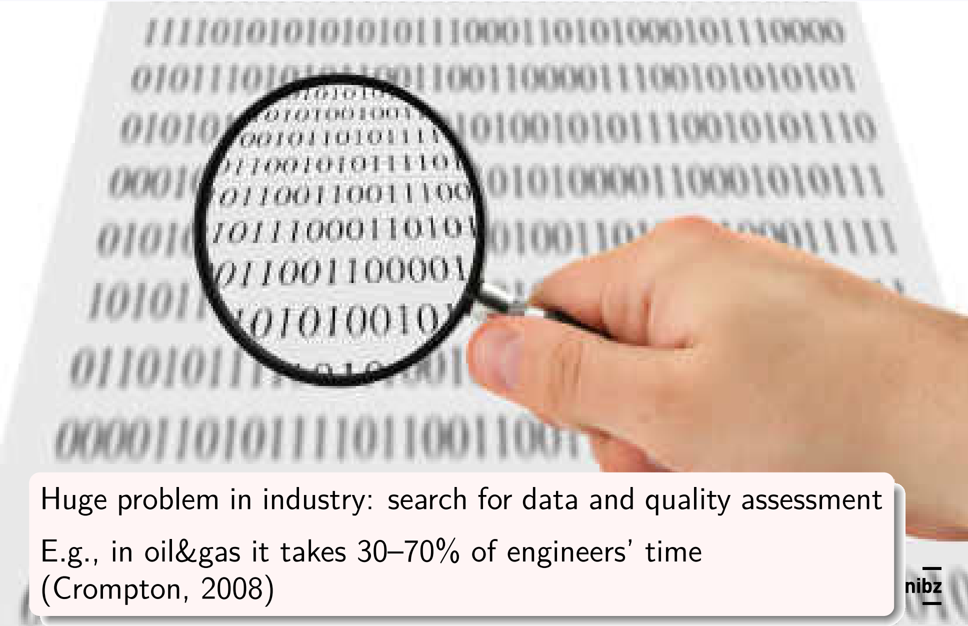
How much time is spent searching for data?

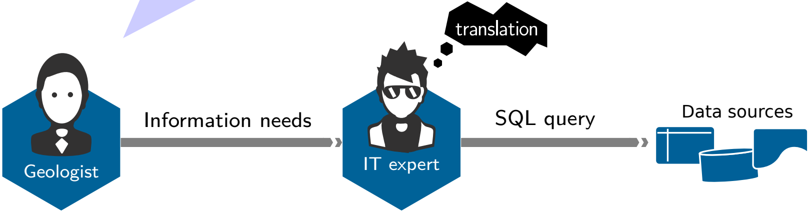


Huge problem in industry: search for data and quality assessment

E.g., in oil&gas it takes 30–70% of engineers' time (Crompton, 2008)

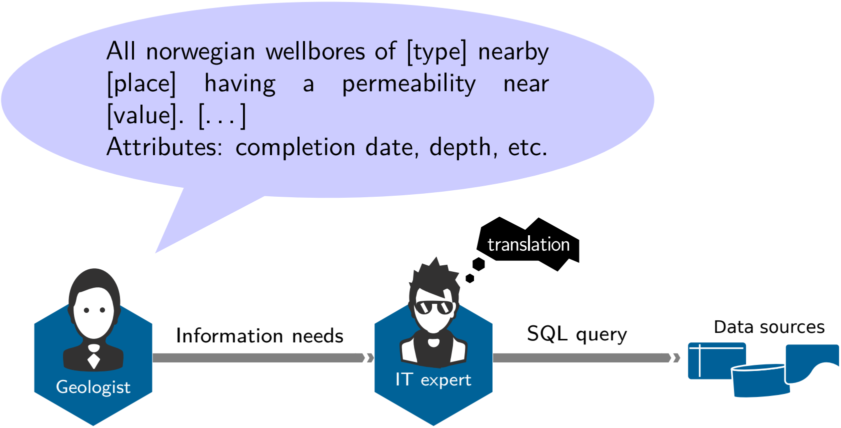
Designing a new (ad-hoc) query

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



NB: Simplified information needs

Designing a new (ad-hoc) query



Takes 4 days in average (with EPDS only)

NB: Simplified information needs

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))
```

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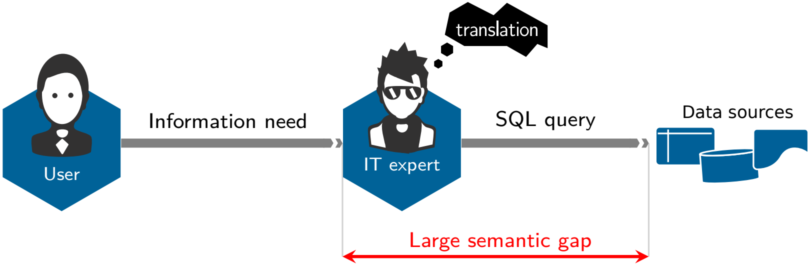
Semantic gap



Querying over tables

Requires a lot of knowledge about:

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

Data integration

- Exacerbates these issues
- Variety: **challenge #1** for most Big Data initiatives

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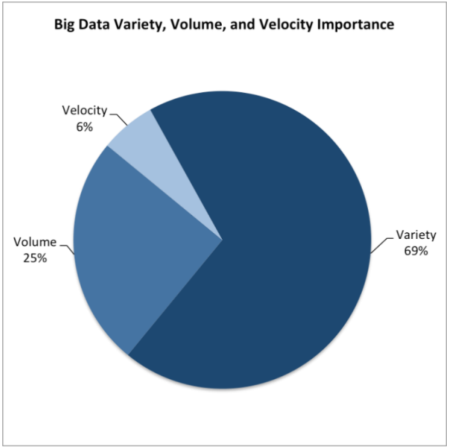
Challenges in “Big Data” era



“Variety, Not Volume, Is Driving Big Data Initiatives”
MIT Sloan Management Review (28 March 2016)

http://sloanreview.mit.edu/article/variety-not-volume-is-driving-big-data-initiatives/

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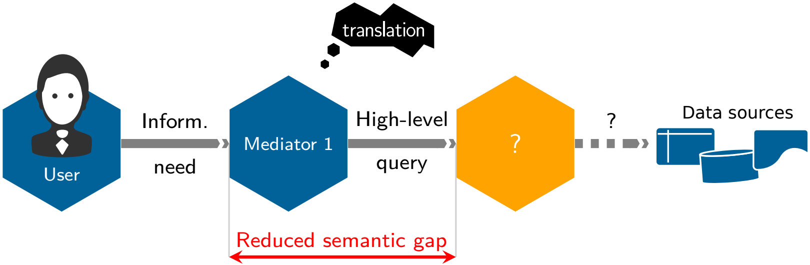
High-level translation

Main bottleneck: translation

- of the information needs
- ... into a **formal query**

Goal

Make such a translation easy
(Ideally: IT expertise not required)

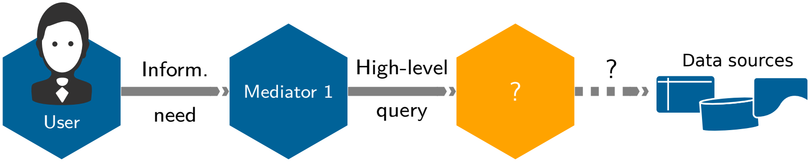


Mediator 1 could be a user, an IT expert or a GUI

General approach: two steps

1. Translate the information needs into a **high-level query**
2. Answer the high-level query **automatically**

Two orthogonal choices to be made



Choice 1: Generating a new representation of the data

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

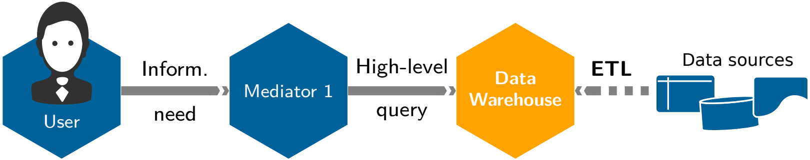
Choice 2: Which data format for the new representation

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



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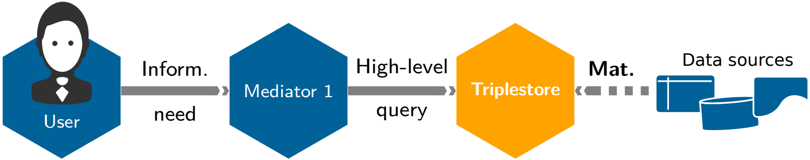
Generating a new representation of the data

1. Extract Transform Load (ETL) / Materialization

E.g., relational data warehouse, triplestore



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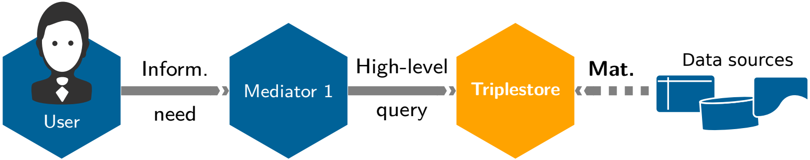
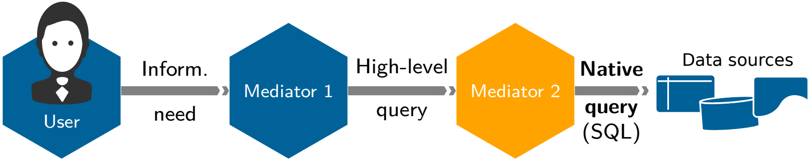


2. Virtual views

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



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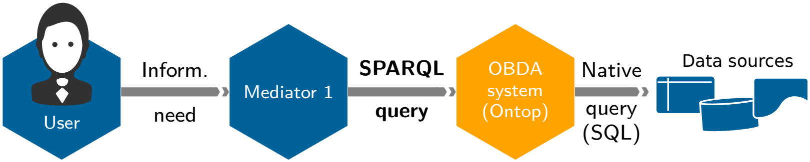
Ontology-Based Data Access (OBDA)



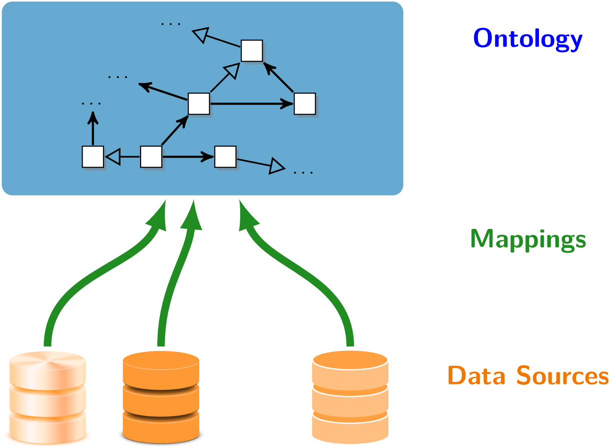
Choice 1: Generating a new representation of the data

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

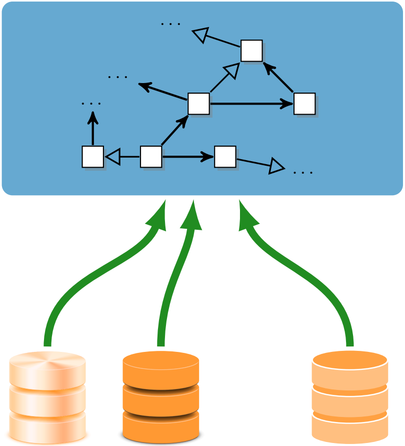
Choice 2: Which data format for the virtual view

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

OBDA framework



OBDA framework



Ontology
provides global vocabulary and conceptual view

Mappings
how to populate the ontology from the data

Data Sources
external and heterogeneous

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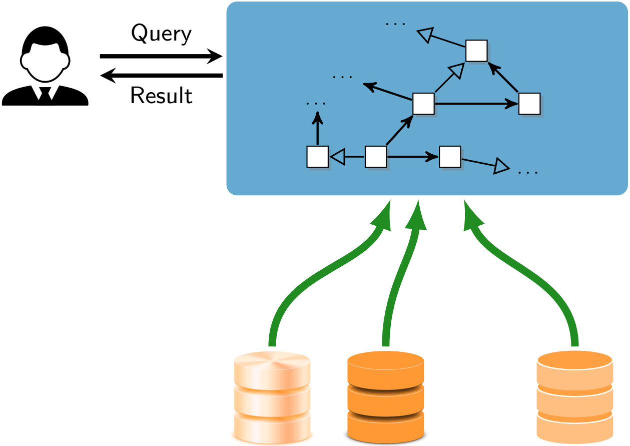
OBDA framework



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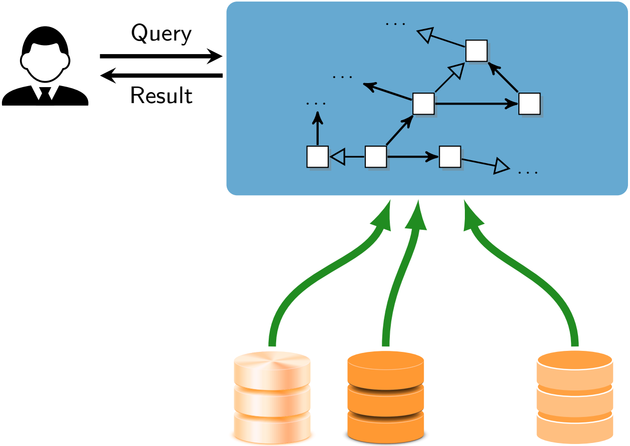

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Data Sources
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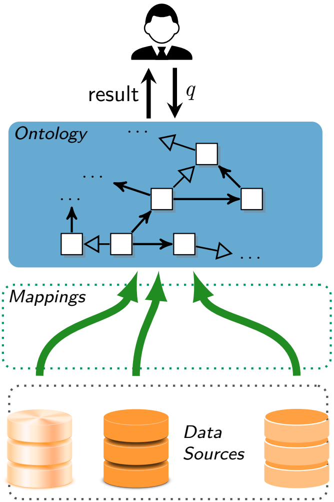
Logical transparency in accessing data:

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

Query answering by rewriting (conceptual framework)



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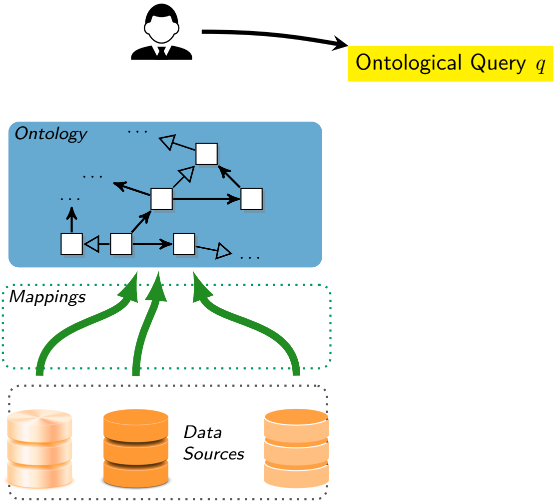

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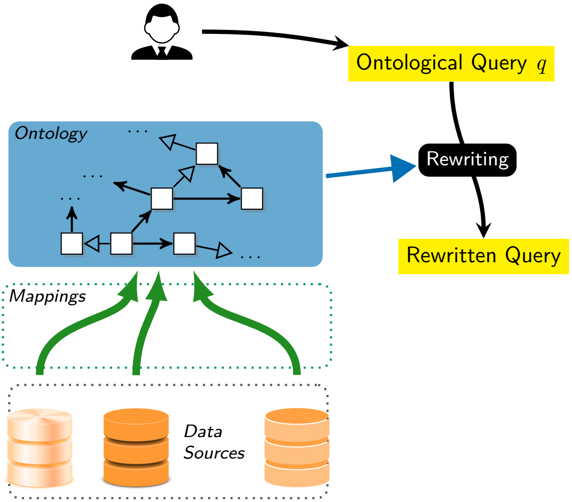

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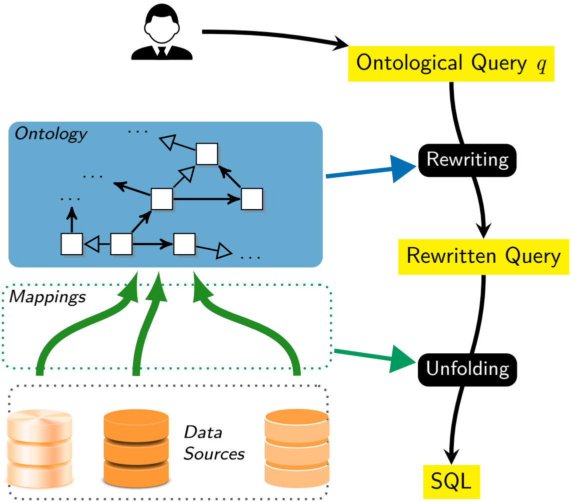

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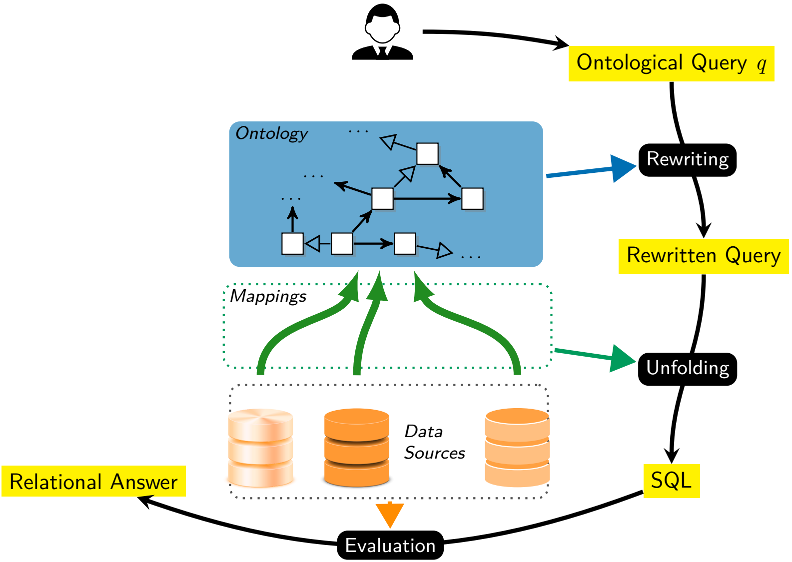

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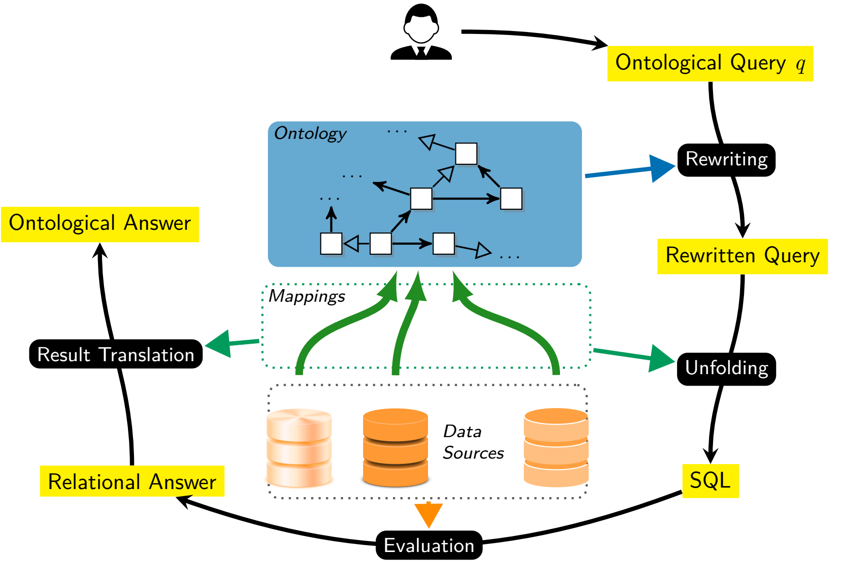

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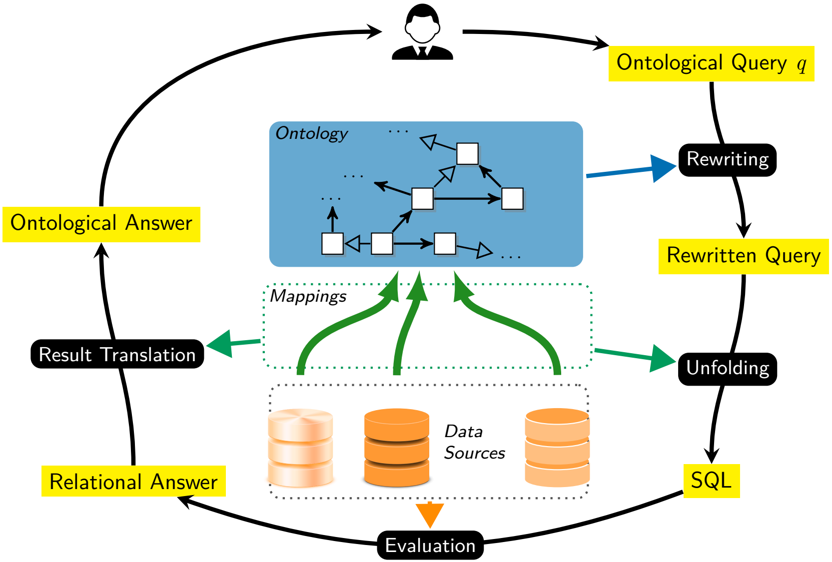

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Outline

Semantic Web standards

1. RDF (Resource Description Framework): format for Semantic Web data
2. SPARQL: query language for RDF data
3. RDFS and OWL 2 QL: ontology languages
4. Mapping languages

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Outline

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Resource Description Framework (RDF)

RDF provides a description of the domain in terms of **triples**:

Subject

<http://example.org/uni2/person/3>

Predicate

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

Object

"Céline"^^xsd:string

Triple elements: resources denoted by global identifiers (IRIs)

1. Subject: IRI of the described resource
2. Predicate: IRI of the property
3. Object: attribute value or IRI of another resource

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```
@prefix foaf: <http://xmlns.com/foaf/0.1/>
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Resource Description Framework (RDF)

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Subject → `<http://example.org/uni2/person/3>`

Predicate → `foaf:firstName`

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```

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@base <http://example.org/>
```

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RDF provides a description of the domain in terms of **triples**:

Subject	Predicate	Object
<uni2/person/3>	foaf:firstName	"Céline"^^xsd:string

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RDF – Examples

Class membership:

Fact	Prof(*uni2/person/1*)
RDF triple	`<uni2/person/1> a :Prof`

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Note: This is an abbreviation for

RDF triple	`<uni2/person/1> rdf:type :Prof`

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Attribute of an individual:

Fact	lastName(*uni2/person/3*, 'Mendez')
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Fact	lastName(*uni2/person/3*, 'Mendez')
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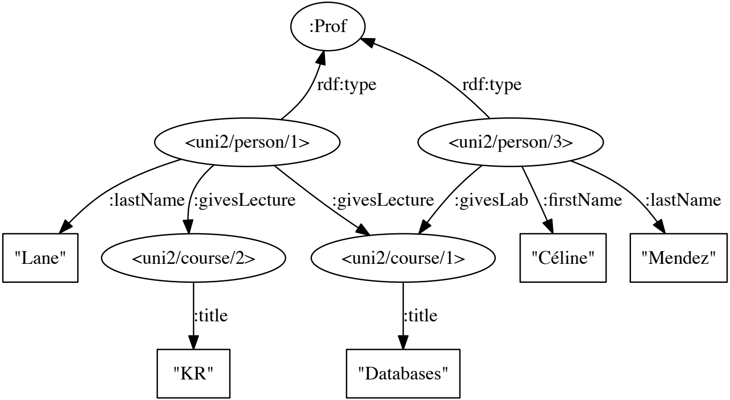
Property of an individual:

Fact	givesLab(*uni2/person/3*, *uni2/course/1*)
RDF triple	`<uni2/person/3> :givesLab <uni2/course/1>`

RDF graph – Example

```
<uni2/person/1> rdf:type :Prof
<uni2/person/1> foaf:lastName "Lane"
<uni2/person/1> :givesLecture <uni2/course/1>
...
```

We can represent such a set of facts graphically:



Additional RDF features

RDF has additional features not covered here:

- blank nodes
- named graphs

Outline

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SPARQL Basic Graph Patterns

- SPARQL is the standard query language for RDF.
- **Basic Graph Pattern (BGP)**: simplest form of SPARQL query, asking for a pattern in the RDF graph

Ex.: BGP

```
SELECT ?p ?ln ?c ?t
WHERE {
  ?p :lastName ?ln .
  ?p :givesLecture ?c .
  ?c :title ?t .
}
```

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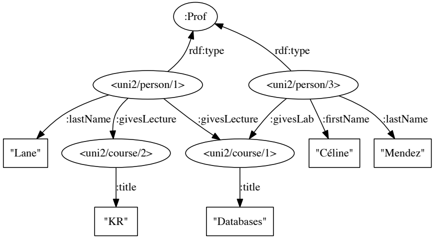
When evaluated over the RDF graph



... the query returns:

p	ln	c	t
<uni2/person/1>	"Lane"	<uni2/course/1>	"Databases"
<uni2/person/1>	"Lane"	<uni2/course/2>	"KR"

Projecting out variables in a SPARQL query

A query may also return only a subset of the variables used in the BGP.

Ex.: BGP with projection

```
SELECT ?ln ?t
WHERE {
  ?p :lastName ?ln .
  ?p :givesLecture ?c .
  ?c :title ?t .
}
```

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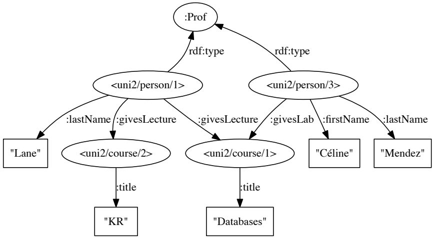

... the query returns:

ln	t
"Lane"	"Databases"
"Lane"	"KR"

Union of Basic Graph Patterns

Ex.: BGPs with UNION

```
SELECT ?p ?ln ?c
WHERE {
  { ?p :lastName ?ln .    ?p :givesLecture ?c . }
  UNION
  { ?p :lastName ?ln .    ?p :givesLab ?c . }
}
```

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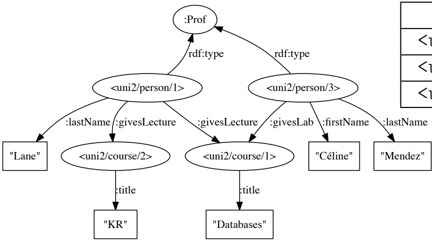
When evaluated over



. . . the query returns:

p	ln	c
<uni2/person/1>	"Lane"	<uni2/course/1>
<uni2/person/1>	"Lane"	<uni2/course/2>
<uni2/person/3>	"Mendez"	<uni2/course/1>

BGPs vs. conjunctive queries

We can write queries using a more compact and abstract syntax, borrowed from database theory.

Ex.: BGP

```
SELECT ?p ?ln ?c ?t
WHERE {
  ?p :lastName ?ln .
  ?p :givesLecture ?c .
  ?c :title ?t .
}
```

vs. conjunctive query

$$\boldsymbol{q}(p, ln, c, t) \leftarrow \begin{array}{l} \mathsf{lastName}(p, ln), \\ \mathsf{givesLecture}(p, c), \\ \mathsf{title}(c, t) \end{array}$$

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```

vs. conjunctive query

$$\boldsymbol{q}(p, ln, c, t) \leftarrow \text{lastName}(p, ln), \text{givesLecture}(p, c), \text{title}(c, t)$$

A **conjunctive query** $\boldsymbol{q}$ has the form $\boldsymbol{q}(\vec{x}) \leftarrow p_1(\vec{y}_1), \ldots, p(\vec{y}_k)$ where

- $\boldsymbol{q}(\vec{x})$ is called the head of $\boldsymbol{q}$,
- $p_1(\vec{y}_1), \ldots, p(\vec{y}_k)$ is a conjunction of atoms called the body of $\boldsymbol{q}$,
- all variables $\vec{x}$ in the head are among $\vec{y}_1, \ldots, \vec{y}_k$, and
- the variables in $\vec{y}_1, \ldots, \vec{y}_k$ not among $\vec{x}$ are existentially quantified.

BGPs vs. conjunctive queries (cont.)

Ex.: BGP with projection

```
SELECT ?ln ?t
WHERE {
  ?p :lastName ?ln .
  ?p :givesLecture ?c .
  ?c :title ?t .
}
```

vs. conjunctive query

$$\boldsymbol{q}(ln, t) \leftarrow \mathsf{lastName}(p, ln), \mathsf{givesLecture}(p, c), \mathsf{title}(c, t)$$

BGPs vs. conjunctive queries (cont.)

Ex.: BGP with projection

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SELECT ?ln ?t
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  ?c :title ?t .
}
```

vs. conjunctive query

$$\boldsymbol{q}(ln, t) \leftarrow \mathsf{lastName}(p, ln), \mathsf{givesLecture}(p, c), \mathsf{title}(c, t)$$

But there is a difference in semantics when we have an ontology.

SPARQL UNION vs. unions of CQs

Ex.: BGP with UNION

```
SELECT ?p ?ln ?c
WHERE {
  { ?p :lastName ?ln .
    ?p :givesLecture ?c .
  }
  UNION
  { ?p :lastName ?ln .
    ?p :givesLab ?c .
  }
}
```

vs. union of CQs (UCQ)

$$\begin{aligned}\boldsymbol{q}(p, ln, c) &\leftarrow \mathsf{lastName}(p, ln), \\ &\quad\ \mathsf{givesLecture}(p, c) \\ \boldsymbol{q}(p, ln, c) &\leftarrow \mathsf{lastName}(p, ln), \\ &\quad\ \mathsf{givesLab}(p, c)\end{aligned}$$

A UCQ is written as a set of CQs, all with the same head.

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Extending BGPs with OPTIONAL

We might want to add information when available, but **not reject** a solution **when some part of the query does not match**.

Ex.: BGP with OPTIONAL

```
SELECT ?p ?fn ?ln
WHERE {
  ?p :lastName ?ln .
  OPTIONAL {
    ?p :firstName ?fn .
  }
}
```

Extending BGPs with OPTIONAL

We might want to add information when available, but **not reject** a solution **when some part of the query does not match**.

Ex.: BGP with OPTIONAL

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WHERE {
  ?p :lastName ?ln .
  OPTIONAL {
    ?p :firstName ?fn .
  }
}
```
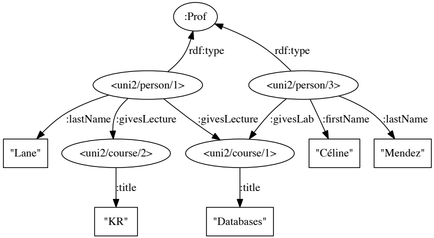

When evaluated over the RDF graph



... the query returns:

p	fn	ln
<uml2/person/1>		"Lane"
<uml2/person/3>	"Céline"	"Mendez"

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SPARQL algebra

We have seen the following features of the SPARQL algebra:

- Basic Graph Patterns
- `UNION`
- `OPTIONAL`

SPARQL algebra

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- Basic Graph Patterns
- `UNION`
- `OPTIONAL`

The overall algebra has additional features:

- more complex `FILTER` conditions
- `GROUP BY`, to express aggregations and support aggregation operators
- `MINUS`, to remove possible solutions
- `FILTER NOT EXISTS`, to test for the absence of a pattern

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Outline

The OWL 2 QL profile

- OWL 2 QL is one of the three standard profiles of OWL 2.
- Derived from the ***DL-Lite*** $_{\mathcal{R}}$ description logic of the *DL-Lite*-family:
  - Groups the domain into classes of objects with common properties.
  - Binary relations between objects (object properties).
  - Binary relations from objects to values (data properties).

The OWL 2 QL profile

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- Derived from the ***DL-Lite***$_{\mathcal{R}}$ description logic of the *DL-Lite*-family:
  - Groups the domain into classes of objects with common properties.
  - Binary relations between objects (object properties).
  - Binary relations from objects to values (data properties).
- 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.

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Constructs of OWL 2 QL/ $DL\text{-}Lite_{\mathcal{R}}$

- Class hierarchies: `rdfs:subClassOf`
- Property hierarchies: `rdfs:subPropertyOf`
- Property domain: `rdfs:domain`
- Property range: `rdfs:range`
- Inverse properties: `owl:inverseOf`
- Class disjointness: `owl:disjointWith`
- Mandatory participation: `owl:someValuesFrom` in superclass expression

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RDF Schema (RDFS)

rdfs:subClassOf $(A \sqsubseteq B)$

```
:FullProf rdfs:subClassOf :Professor .
<uni1/academic/1> a :FullProf .
⟹ <uni1/academic/1> a :Professor .
```

rdfs:subPropertyOf $(P \sqsubseteq R)$

```
:givesLecture rdfs:subPropertyOf :teaches .
<uni2/academic/2> :givesLecture <uni2/course/1> .
⟹ <uni2/academic/2> :teaches <uni2/course/1> .
```

rdfs:domain $(\exists P \sqsubseteq A)$

```
:teaches rdfs:domain :Teacher .
<uni2/academic/2> :teaches <uni2/course/1> .
⟹ <uni2/academic/2> a :Teacher .
```

rdfs:range $(\exists P^{-} \sqsubseteq A)$

```
:teaches rdfs:range :Course .
<uni2/academic/2> :teaches <uni2/course/1> .
⟹ <uni2/course/1> a :Course .
```

Other constructs of OWL 2 QL I

owl:inverseOf $(P^- \sqsubseteq R,\ R^- \sqsubseteq P)$

```
:isTaughtBy owl:inverseOf :teaches .
<uni2/academic/2> :teaches <uni2/course/1> .
```

```
⟹   <uni2/course/1> :isTaughtBy <uni2/academic/2> .
```

owl:someValuesFrom in the superclass expression $(A \sqsubseteq \exists R.B)$

```
:GraduateStudent rdfs:subClassOf
   [ a owl:Restriction ;
     owl:onProperty :isSupervisedBy ;
     owl:someValuesFrom :Professor ] .
<uni2/person/10> a :GraduateStudent .
```

```
        <uni2/person/10> a
          [ a owl:Restriction ;
⟹           owl:onProperty :isSupervisedBy ;
             owl:someValuesFrom :Professor ] .
```

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Other constructs of OWL 2 QL II

owl:disjointWith $(A \sqsubseteq \neg B,\ B \sqsubseteq \neg A)$

```
:Student owl:disjointWith :Professor .
<uni1/academic/19> a :Professor .
<uni1/academic/19> a :Student .
```

$\Longrightarrow$ Inconsistent RDF graph

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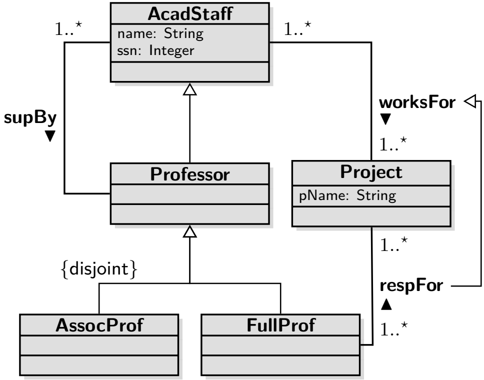
Capturing UML class diagrams/ER schemas in *DL-Lite*$_\mathcal{R}$



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

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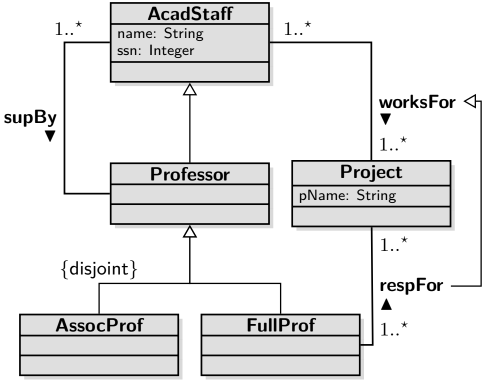
Capturing UML class diagrams/ER schemas in *DL-Lite*$_\mathcal{R}$



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\mathsf{AcadStaff} & \sqsubseteq & \exists\mathsf{worksFor}\\
\mathsf{Project} & \sqsubseteq & \exists\mathsf{worksFor}^-\\
\mathsf{respFor} & \sqsubseteq & \mathsf{worksFor}\\
 & \vdots &
\end{array}
$$

DL-Lite$_\mathcal{R}$ / OWL 2 QL **cannot capture**:

- covering constraints – This would require **disjunction**
- identity between individuals – This would `owl:sameAs` – see later
- functionality of roles – This would require number restrictions

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DL-Lite$_\mathcal{R}$ captures conceptual modeling formalisms

Modeling construct	*DL-Lite*	FOL formalization
ISA on classes	$A_1 \sqsubseteq A_2$	$\forall x(A_1(x) \rightarrow A_2(x))$
. . . and on relations	$R_1 \sqsubseteq R_2$	$\forall x, y(R_1(x, y) \rightarrow R_2(x, y))$
Disjointness of classes	$A_1 \sqsubseteq \neg A_2$	$\forall x(A_1(x) \rightarrow \neg A_2(x))$
. . . and of relations	$R_1 \sqsubseteq \neg R_2$	$\forall x, y(R_1(x, y) \rightarrow \neg R_2(x, y))$
Domain of relations	$\exists P \sqsubseteq A_1$	$\forall x(\exists y(P(x, y)) \rightarrow A_1(x))$
Range of relations	$\exists P^- \sqsubseteq A_2$	$\forall x(\exists y(P(y, x)) \rightarrow A_2(x))$
Mandatory participation *(min card = 1)*	$A_1 \sqsubseteq \exists P$ $A_2 \sqsubseteq \exists P^-$	$\forall x(A_1(x) \rightarrow \exists y(P(x, y)))$ $\forall x(A_2(x) \rightarrow \exists y(P(y, x)))$
. . .	. . .	. . .

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Outline

1. Motivation
2. Semantic Web standards
   - Resource Description Framework
   - SPARQL
   - OWL 2 QL
   - Mapping assertions
3. OBDA framework
4. Ontop system and its ecosystem
5. Use Cases
6. Conclusion

Mapping assertions – RDB-RDF

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

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

Mapping assertions – RDB-RDF

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Mapping assertions – RDB-RDF

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

- φ: FO query (over DB predicates)
- ψ: atom (over an RDF predicate)
- 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 .`

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Mapping assertions RDB-RDF

Ontop native format (similar to the R2RML standard)

Data property (`foaf:firstName`)

Source (SQL)	`SELECT s_id, firstName, lastName FROM uni1.student`
Target (RDF)	`ex:uni1/student/{s_id} foaf:firstName "{firstName}"^^xsd:string ; foaf:lastName "{lastName}"^^xsd:string .`

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Mapping assertions RDB-RDF

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Target (RDF)	`ex:uni1/student/{s_id} foaf:firstName "{firstName}"^^xsd:string ; foaf:lastName "{lastName}"^^xsd:string .`

Object property (`:teaches`)

Source	`SELECT * FROM "uni1"."teaching"`
Target (RDF)	`ex:uni1/academic/{a_id} :teaches ex:uni1/course/{c_id} .`

Mapping assertions RDB-RDF

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Data property (`foaf:firstName`)

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Object property (`:teaches`)

Source	`SELECT * FROM "uni1"."teaching"`
Target (RDF)	`ex:uni1/academic/{a_id} :teaches ex:uni1/course/{c_id} .`

Magic number

Source	`SELECT * FROM "uni1"."academic" WHERE "position" = 1`
Target (RDF)	`ex:uni1/academic/{a_id} a :FullProf .`

Outline

1. Motivation
2. Semantic Web standards
3. OBDA framework
   - OBDA architecture
4. Ontop system and its ecosystem
5. Use Cases
6. Conclusion

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Ontology-based data access: Formalization

To formalize OBDA, we distinguish between the intensional and the extensional level information.

An **OBDA specification** is a triple $\mathcal{P} = \langle \mathcal{T}, \mathcal{S}, \mathcal{M} \rangle$, where:

- $\mathcal{T}$ is the intensional level of an ontology.
  We consider ontologies formalized in description logics (DLs), hence the intensional level is a DL TBox.
- $\mathcal{S}$ is a (possibly federated) relational database schema for the data source(s), possibly with constraints;
- $\mathcal{M}$ is a set of mapping assertions between $\mathcal{T}$ and $\mathcal{S}$.

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- $\mathcal{S}$ is a (possibly federated) relational database schema for the data source(s), possibly with constraints;
- $\mathcal{M}$ is a set of mapping assertions between $\mathcal{T}$ and $\mathcal{S}$.

An **OBDA instance** is a pair $\mathcal{O} = \langle \mathcal{P}, \mathcal{D} \rangle$, where

- $\mathcal{P} = \langle \mathcal{T}, \mathcal{S}, \mathcal{M} \rangle$ is an OBDA specification, and
- $\mathcal{D}$ is a relational database compliant with $\mathcal{S}$.

Semantics of OBDA: Intuition

In an OBDA instance $\mathcal{O} = \langle\langle\mathcal{T}, \mathcal{M}, \mathcal{S}\rangle, \mathcal{D}\rangle$, the **mapping** $\mathcal{M}$ encodes how the data $\mathcal{D}$ in the source(s) $\mathcal{S}$ should be used to populate the elements of $\mathcal{T}$.

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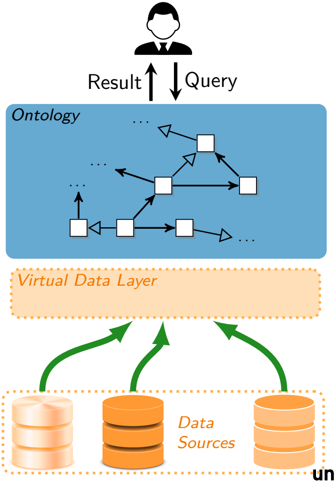
Virtual data layer

The data $\mathcal{D}$ and the mapping $\mathcal{M}$ define a virtual data layer $\mathcal{V} = \mathcal{M}(\mathcal{D})$

- Queries are answered w.r.t. $\mathcal{T}$ and $\mathcal{V}$.
- We do not really materialize the data of $\mathcal{V}$ (it is virtual!).
- Instead, the intensional information in $\mathcal{T}$ and $\mathcal{M}$ is used to translate queries over $\mathcal{T}$ into queries formulated over $\mathcal{S}$.



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Semantics of mappings

To formally define the semantics of an OBDA instance $\mathcal{O} = \langle \mathcal{P}, \mathcal{D} \rangle$, where $\mathcal{P} = \langle \mathcal{T}, \mathcal{S}, \mathcal{M} \rangle$, we first need to define the semantics of mappings.

Satisfaction of a mapping assertion with respect to a database

An interpretation $\mathcal{I}$ **satisfies** a mapping assertion $\Phi(\vec{x}) \rightsquigarrow \Psi(\vec{x})$ in $\mathcal{M}$ **with respect to a database** $\mathcal{D}$ **for** $\mathcal{S}$, if the following FOL sentence is true in $\mathcal{I} \cup \mathcal{D}$:

$$\forall \vec{x}.\, \Phi(\vec{x}) \rightarrow \Psi(\vec{x})$$

Intuitively, $\mathcal{I}$ **satisfies** $\Phi \rightsquigarrow \Psi$ w.r.t. $\mathcal{D}$ if all facts obtained by evaluating Φ over $\mathcal{D}$ and then propagating the answers to Ψ, hold in $\mathcal{I}$.

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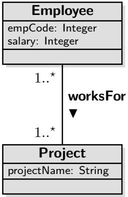
Semantics of mappings – Example



D_1:

SSN	*PrName*
23AB	optique
...	...

D_2:

Code	*Salary*
e23	1500
...	...

D_3:

Code	*SSN*
e23	23AB
...	...

m_1:
```
SELECT SSN, PrName
FROM D1
```
$\rightsquigarrow$ Employee(**pers**(*SSN*)),
Project(**proj**(*PrName*)),
projectName(**proj**(*PrName*), *PrName*),
worksFor(**pers**(*SSN*), **proj**(*PrName*))

m_2:
```
SELECT SSN, Salary
FROM D2, D3
WHERE D2.Code = D3.Code
```
$\rightsquigarrow$ Employee(**pers**(*SSN*)),
salary(**pers**(*SSN*), *Salary*)

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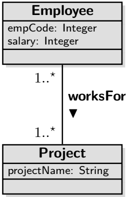
Semantics of mappings – Example



D_1:

SSN	*PrName*
23AB	optique
...	...

D_2:

Code	*Salary*
e23	1500
...	...

D_3:

Code	*SSN*
e23	23AB
...	...

The following interpretation $\mathcal{I}$ satisfies the mapping assertions m_1 and m_2 with respect to the above database:

$$\mathcal{I} : \Delta_O^{\mathcal{I}} = \{\textbf{pers}(\texttt{23AB}), \textbf{proj}(\texttt{optique}), \ldots\}, \quad \Delta_V^{\mathcal{I}} = \{\texttt{optique}, \texttt{1500}, \ldots\}$$

$$\text{Employee}^{\mathcal{I}} = \{\textbf{pers}(\texttt{23AB}), \ldots\}, \quad \text{Project}^{\mathcal{I}} = \{\textbf{proj}(\texttt{optique}), \ldots\},$$

$$\text{projectName}^{\mathcal{I}} = \{(\textbf{proj}(\texttt{optique}), \texttt{optique}), \ldots\},$$

$$\text{worksFor}^{\mathcal{I}} = \{(\textbf{pers}(\texttt{23AB}), \textbf{proj}(\texttt{optique})), \ldots\},$$

$$\text{salary}^{\mathcal{I}} = \{(\textbf{pers}(\texttt{23AB}), \texttt{1500}), \ldots\}$$

m_1:

```
SELECT SSN, PrName
FROM D1
```

$\rightsquigarrow$ Employee(**pers**(*SSN*)), Project(**proj**(*PrName*)), projectName(**proj**(*PrName*), *PrName*), worksFor(**pers**(*SSN*), **proj**(*PrName*))

m_2:

```
SELECT SSN, Salary
FROM D2, D3
WHERE D2.Code = D3.Code
```

$\rightsquigarrow$ Employee(**pers**(*SSN*)), salary(**pers**(*SSN*), *Salary*)

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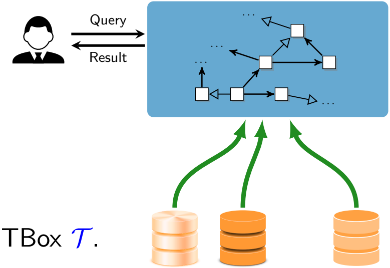
Semantics of an OBDA instance



Let $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ be an interpretation of the TBox $\mathcal{T}$.

Model of an OBDA instance

$\mathcal{I}$ is a **model** of $\mathcal{O} = \langle \mathcal{P}, \mathcal{D} \rangle$, with $\mathcal{P} = \langle \mathcal{T}, \mathcal{S}, \mathcal{M} \rangle$ if:

- $\mathcal{I}$ is a model of $\mathcal{T}$, and
- $\mathcal{I}$ satisfies $\mathcal{M}$ w.r.t. $\mathcal{D}$, i.e., it satisfies every assertion in $\mathcal{M}$ w.r.t. $\mathcal{D}$.

An OBDA instance $\mathcal{O}$ is **satisfiable** if it admits at least one model.

Outline

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Ontop

ontop

- State-of-the-art OBDA system
- Compliant with the RDFS, OWL 2 QL, R2RML, and SPARQL standards.
- Supports all major relational DBs
- Open-source and released under Apache 2 license
- Development of *Ontop*:
  - development started 6 years ago
  - already well established:
    - +200 members in the mailing list
    - +7000 downloads in last 18 months
  - main development carried out in the context of the EU project Optique

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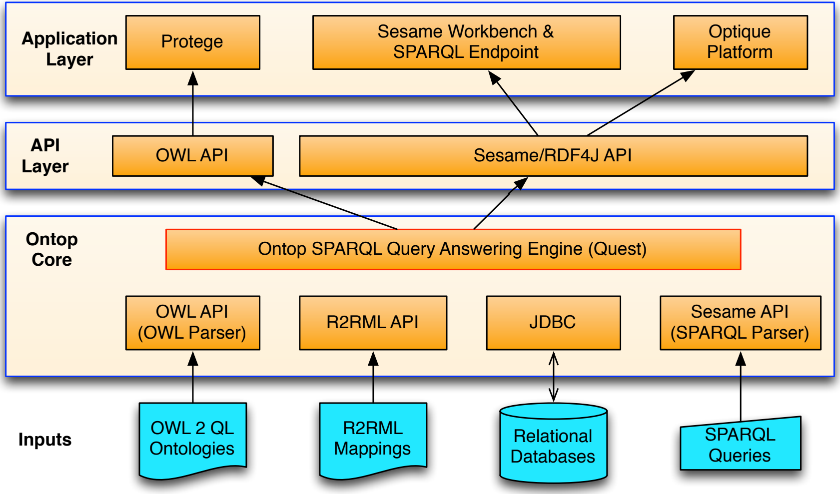
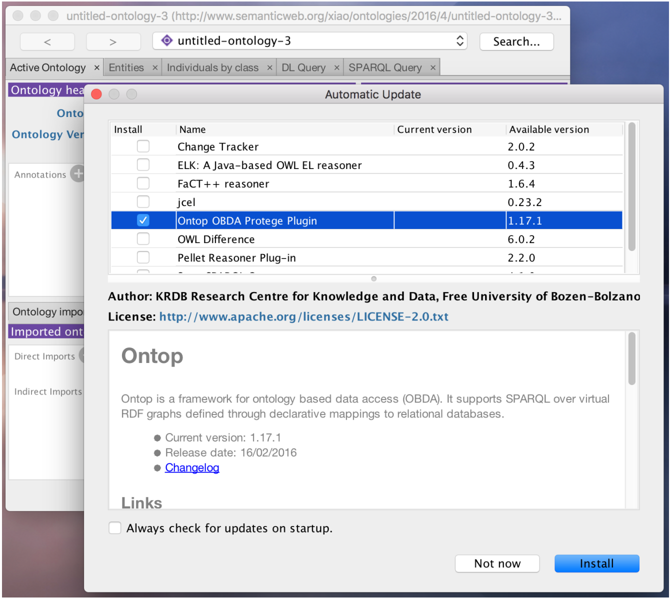
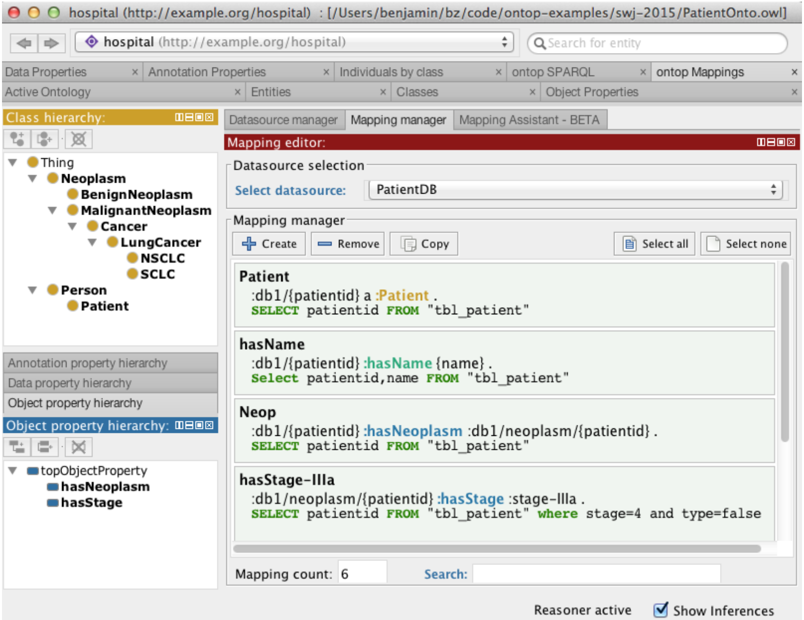
Architecture of *Ontop*



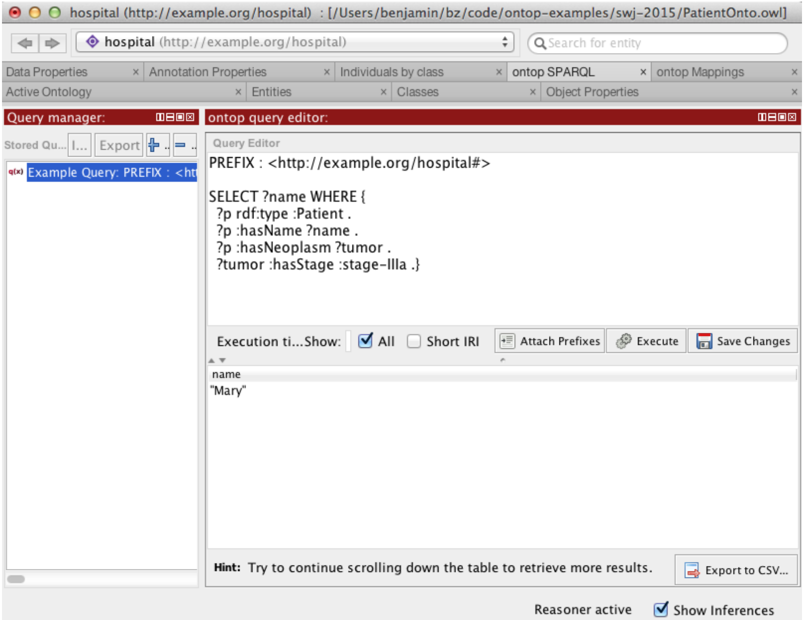
Ontop plugin available from Protégé plugin repository



Mapping editor in Protégé

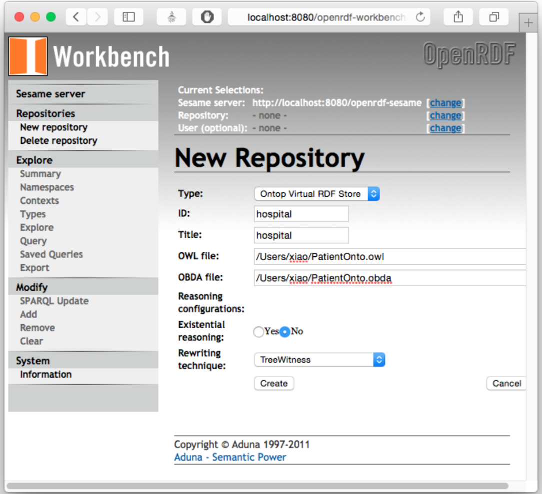


SPARQL query answering in Protégé



Sesame/RDF4J Workbench and SPARQL endpoint

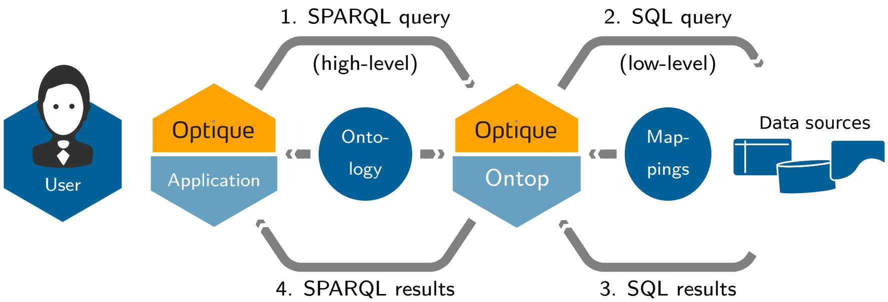
- Sesame Workbench extension to create and manage *Ontop* repositories
- Standard HTTP SPARQL endpoints.



Optique system

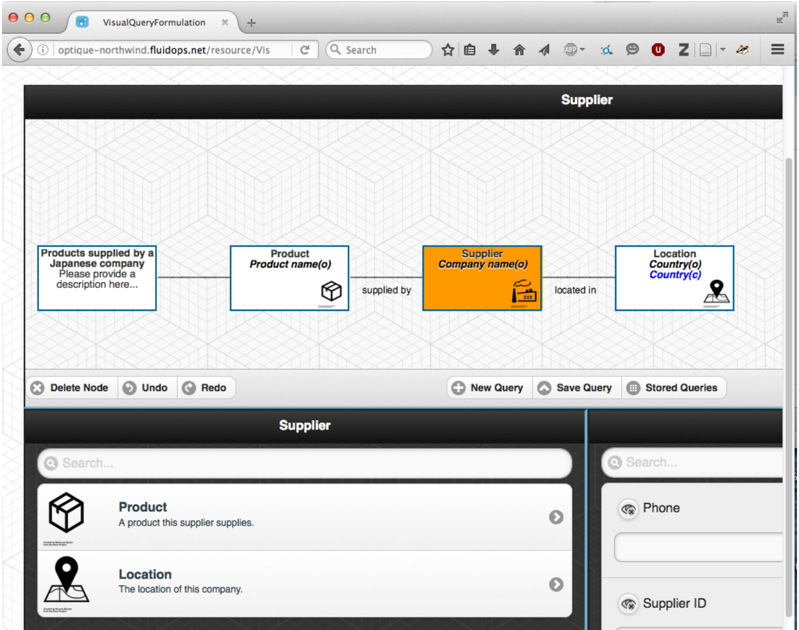
EU FP7 Project Optique: *Scalable End-user Access to Big Data*

- November 2012 – October 2016
- 10 Partners, including industrial partners Statoil, Siemens, DNV
- *Ontop* is core component of the Optique platform



Visual query formulation (Optique VQS)

`http://optique-northwind.fluidops.net` demo/demo



Commercial adoption

Ontop is adopted by several commercial tools.

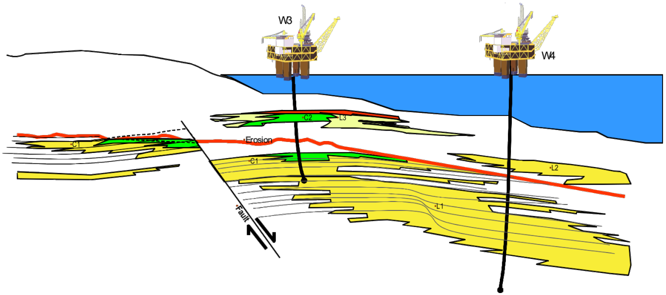
- Stardog by Complexible Inc.
- Fluidops Information Workbench
- Metaphacts semantic data management platform

Outline

1. Motivation
2. Semantic Web standards
3. OBDA framework
4. Ontop system and its ecosystem
5. Use Cases
6. Conclusion

Statoil use case [DBLP:conf/semweb/KharlamovHJLLPR15]

- Optique use case partner
- Exploration domain: analyse existing relevant data in order to find exploitable accumulations of oil or gas
- Improve the efficiency of the information gathering routine for geologists
- Efficient, creative data collection from multiple large volume data sources



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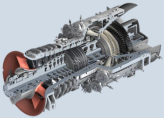
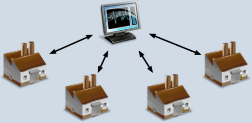
Siemens use case [KharlamovSOZHLRSW-iswc14]

- Optique use case partner
- Siemens energy department
- streaming and temporal data

- Siemens
  - produces huge appliances, e.g., turbines
  - installs them in plants

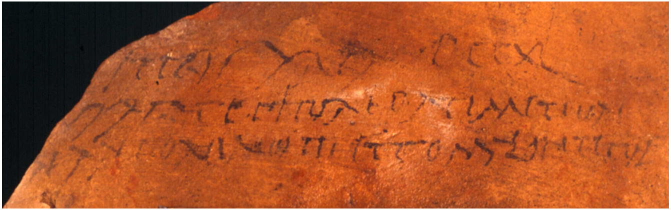


- Siemens service centers
  - offers constant monitoring and diagnostics service
  - over 50 service centers world wide
  - each SC is responsible for several thousands appliances
  - their job: monitoring and diagnostic of turbine
- Monitoring and diagnostic tasks
  - reactive and preventive diagnostics
    - offline, after an issue is detected
  - predictive analyses
    - real-time, to avoid issues



EPNet project [EAAI-2016]

- Ontology-based data integration for humanities and archaeologists
- ERC advanced grant EPNet "Production and distribution of food during the Roman Empire: Economics and Political Dynamics".
- Linking three datasets:
    1. the EPNet relational repository
    2. the Epigraphic Database Heidelberg
    3. the Pleiades dataset



Melodies project

- EU FP7 Melodies project: working with Open Data, 16 partners.
- Geospatial extension *Ontop*-spatial used for accessing geospatial data
- Use cases: urban development, land management, disaster management

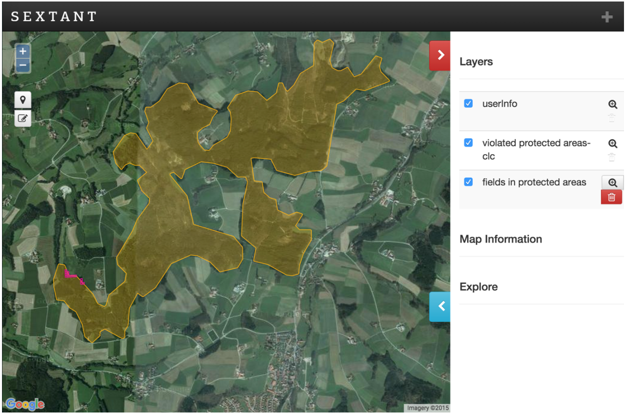


Figure: Visualization of violated protected areas in land management

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EMSec project [2016-eswc-maritime]

- German BMBF project EMSec: real-time services for maritime security
- SPARQL federation to access different kinds of data sources:
  - SPARQL endpoints of *Ontop* over *in situ* data
  - open SPARQL endpoints: Geonames, DBPedia

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Outline

Conclusion

Main message: we need high-level access to data

1. SQL queries over tables can be difficult to write manually (low-level)
2. OBDA is a powerful solution for high-level data access
3. Ontop is an open-source OBDA framework

Ontop Team

In Bolzano

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- Guohui Xiao (Leader of the development team)
- Benjamin Cogrel
- Elena Botoeva
- Vladislav Ryzhikov
- Davide Lanti (PhD student)
- Elem Güzel (PhD student)
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- Martin Rezk (Rakuten, Japan)
- Mariano Rodríguez-Muro (IBM Watson Research Center, USA)
- Michael Zakharyaschev (Birkbeck College London, UK)

Semantic web journal paper

- **Ontop: Answering SPARQL Queries over Relational Databases.** D. Calvanese, B. Cogrel, S. Komla-Ebri, R. Kontchakov, D. Lanti, M. Rezk, M. Rodriguez-Muro, and G. Xiao. Semantic Web Journal. 2016

Figure: The Semantic Web journal 2016 Outstanding Paper Award

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- *Ontop* website: `http://ontop.inf.unibz.it/`
- Github: `http://github.com/ontop/ontop/`
- Facebook: `https://www.facebook.com/obdaontop/`
- Twitter: @ontop4obda
- *Optique* website: `http://optique-project.eu/`
- Tutorial: `https://github.com/ontop/ontop-examples/tree/master/ekaw-tutorial-2016`

References I