Ontology-Based Data Access with Ontop

Benjamin Cogrel
benjamin.cogrel@unibz.it

KRDB Research Centre for Knowledge and Data
Free University of Bozen-Bolzano, Italy

Freie Universität Bozen
Libera Università di Bolzano
Free University of Bozen-Bolzano

Optique

IT4BI,
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Ontology-Based Data Access (OBDA)

Outline

Outline

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Toy example: University Information System

Relational source

uni1.student

s_id	first_name	last_name
1	Mary	Smith
2	John	Doe

uni1.academic

a_id	first_name	last_name	position
1	Anna	Chambers	1
2	Edward	May	9
3	Rachel	Ward	8

uni1.course

c_id	title
1234	Linear algebra

uni1.teaching

c_id	a_id
1234	1
1234	2

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<table>
<tr><th>Information need</th><th>SQL query</th></tr>
<tr><td>1. First and last names of the students</td><td><pre><code>SELECT DISTINCT "first_name", "last_name"
FROM "uni1"."student"</code></pre></td></tr>
<tr><td>2. First and last names of the persons</td><td><pre><code>SELECT DISTINCT "first_name", "last_name"
FROM "uni1"."student"
UNION
SELECT DISTINCT "first_name", "last_name"
FROM "uni1"."academic"</code></pre></td></tr>
<tr><td>3. Course titles and teacher names</td><td><pre><code>SELECT DISTINCT co."title", ac."last_name"
FROM "uni1"."course" co,
     "uni1"."academic" ac,
     "uni1"."teaching" teach
WHERE co."c_id" = teach."c_id"
      AND ac."a_id" = teach."a_id"</code></pre></td></tr>
<tr><td>4. All the teachers</td><td><pre><code>SELECT DISTINCT "a_id"
FROM "uni1"."teaching" UNION
SELECT DISTINCT "a_id"
FROM "uni1"."academic"
WHERE "position" BETWEEN 1 AND 8</code></pre></td></tr>
</table>

Integration of a second source

Fusion of two universities

`uni2.person`

pid	fname	lname	status
1	Zak	Lane	8
2	Mattie	Moses	1
3	Céline	Mendez	2

`uni2.course`

cid	lecturer	lab_teacher	topic
1	1	3	Information security

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Translation of information needs I

Information need	SQL query

1. First and last names of the students	`SELECT DISTINCT "first_name", "last_name"`
	`FROM "uni1"."student"`
	`UNION`
	`SELECT DISTINCT "fname" AS "first_name",`
	`"lname" AS "last_name"`
	`FROM "uni2"."person"`
	`WHERE "status" BETWEEN 1 and 2`

2. First and last names of the persons	`SELECT DISTINCT "first_name", "last_name"`
	`FROM "uni1"."student"`
	`UNION`
	`SELECT DISTINCT "first_name", "last_name"`
	`FROM "uni1"."academic"`
	`UNION`
	`SELECT DISTINCT "fname" AS "first_name",`
	`"lname" AS "last_name"`
	`FROM "uni2"."person"`

Translation of information needs II

Information need	SQL query
3. Course titles and teacher names	`SELECT DISTINCT co."title", ac."last_name" FROM "uni1"."course" co, "uni1"."academic" ac, "uni1"."teaching" teach WHERE co."c_id" = teach."c_id" AND ac."a_id" = teach."a_id" UNION SELECT DISTINCT co."topic" AS "title", pe."lname" AS "last_name" FROM "uni2"."person" pe, "uni2"."course" co WHERE pe."pid" = co."lecturer" OR pe."pid" = co."lab_teacher"`

```sql
SELECT DISTINCT co."title", ac."last_name"
FROM "uni1"."course" co,
     "uni1"."academic" ac,
     "uni1"."teaching" teach
WHERE co."c_id" = teach."c_id"
      AND ac."a_id" = teach."a_id"
UNION
SELECT DISTINCT co."topic" AS "title",
                pe."lname" AS "last_name"
FROM "uni2"."person" pe,
     "uni2"."course" co
WHERE pe."pid" = co."lecturer"
      OR pe."pid" = co."lab_teacher"
```

Translation of information needs III

Information need	SQL query

4. All the teachers	`SELECT DISTINCT 'uni1/' || "a_id" AS "id"`
	`FROM "uni1"."teaching"`
	`UNION`
	`SELECT DISTINCT 'uni1/' || "a_id" AS "id"`
	`FROM "uni1"."academic"`
	`WHERE "position" BETWEEN 1 AND 8`
	`UNION`
	`SELECT DISTINCT 'uni2/' || "lecturer" AS "id"`
	`FROM "uni2"."course"`
	`UNION`
	`SELECT DISTINCT 'uni2/' || "lab_teacher" AS "id"`
	`FROM "uni2"."course"`
	`UNION`
	`SELECT DISTINCT 'uni2/' || "pid" AS "id"`
	`FROM "uni2"."person"`
	`WHERE "status" BETWEEN 6 AND 9`

Industrial case: stratigraphic model design

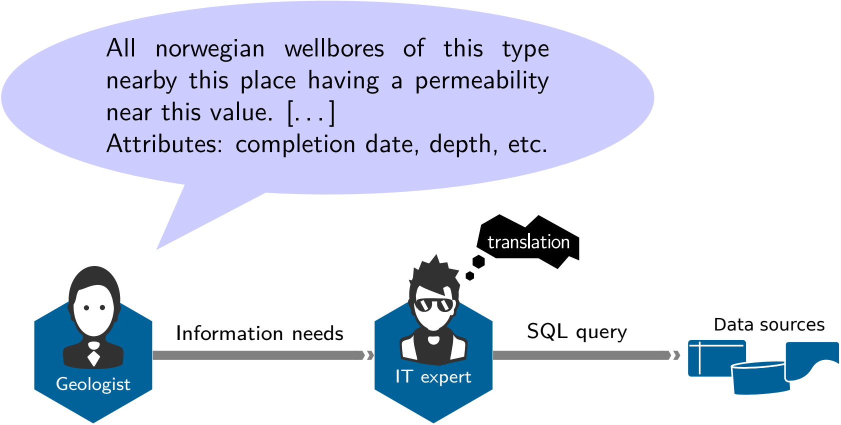
Users: domain experts

- $\sim$ 900 geologists et geophysicists
- Data collecting: 30-70% of their time

Sources

- *Exploitation and Production Data Store*: $\sim$ 1500 tables (100s GB)
- *Norwegian Petroleum Directorate FactPages*
- *OpenWorks*

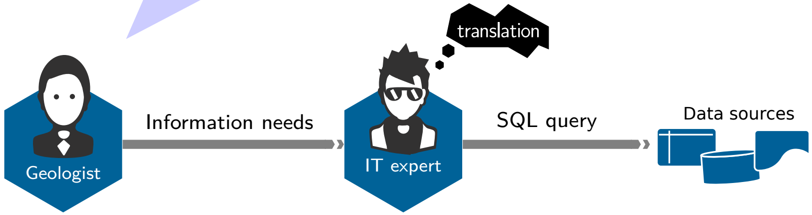
Designing a new (ad-hoc) query



NB: Simplified information needs

Designing a new (ad-hoc) query

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



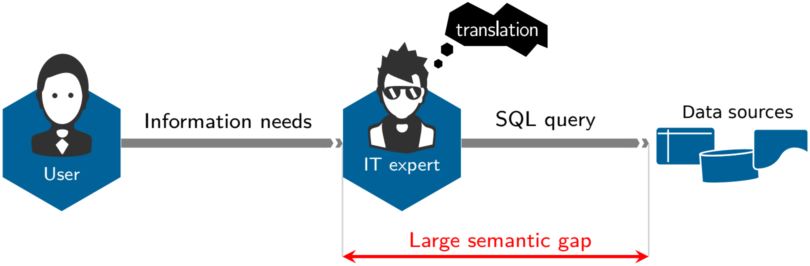
Takes 4 days in average (with EPDS only)

NB: Simplified information needs

Anonymized extract of a typical query

```
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))
```

Semantic gap



Querying over tables

Requires a lot of knowledge about:

1. Magic numbers
   (e.g. 1 → full professor)
2. Cardinalities and normal forms
3. Spreading of closely-related information across many tables

Data integration

- Make things (much) worse!
- Variety: **challenge #1** for most Big Data initiatives

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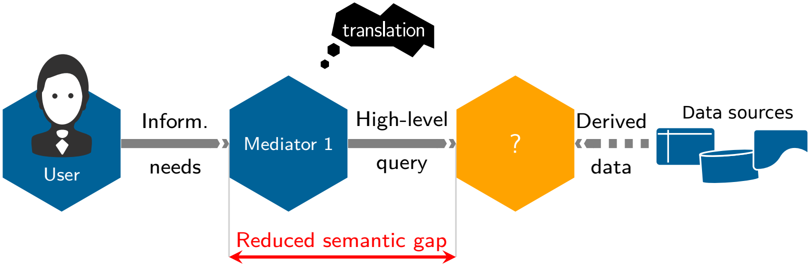
High-level translation

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

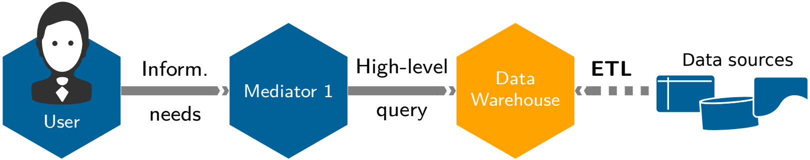
General approach: two steps

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

Choice 1: How to derive data from the data sources

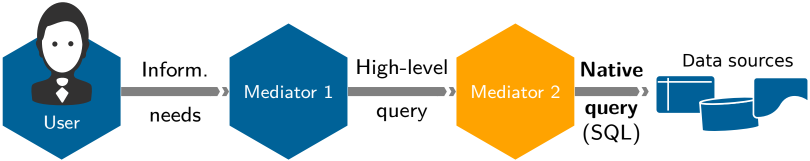
Extract Transform Load (ETL) process

E.g. relational data warehouse, triplestore



Virtual views

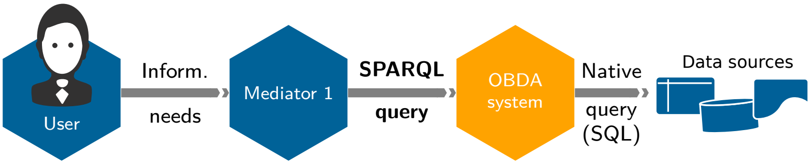
E.g. virtual databases (Teiid, Apache Drill, Exareme), **OBDA** (Ontop)



Choice 2: How to represent the derived data

New representation	Corresponding query language
Relational schema	SQL
JSON document	Mongo Aggregate, SQL (with e.g. Drill or Teiid)
XML document	XPath, XQuery, SQL (with e.g. Teiid)
RDF graph	SPARQL

Ontology-Based Data Access (OBDA)



Choice 1: How to derive data from the DBs

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

Choice 2: How to represent the derived data

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

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Outline

1. SQL queries over tables can be hard to write manually
2. RDF and other Semantic Web standards
   - RDF
   - SPARQL
   - Ontologies
   - Mappings
3. Ontology-Based Data Access
4. Optique platform
5. Recent work
6. Conclusion

Resource Description Framework (RDF)

W3C standard

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

Predicate/Property → `<http://xmlns.com/foaf/0.1/firstName>`

Object → "Céline"`^^xsd:string`

Resource Description Framework (RDF)

W3C standard

Subject

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

Predicate/Property

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

Object

"Céline"^^xsd:string

With the base IRI http://example.org/ and some prefixes:

<uni2/person/3>	foaf:lastName	"Mendez"^^xsd:string
<uni2/person/1>	rdf:type	:AssociateProfessor
<uni2/person/1>	:givesLecture	<uni2/course/1>

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Resource Description Framework (RDF)

W3C standard

Subject	Predicate/Property	Object
<http://example.org/uni2/person/3>	<http://xmlns.com/foaf/0.1/firstName>	"Céline"^^xsd:string

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<uni2/person/1>	:givesLecture	<uni2/course/1>

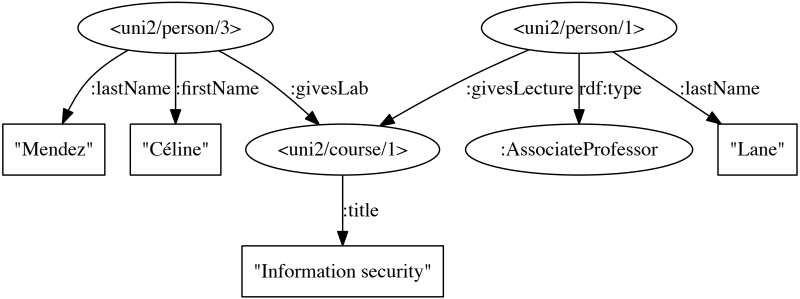
Some characteristics

- Use global identifiers (IRI)
- Fixed arity (ternary)
- Self-descriptive
- *Advanced: blank nodes*

RDF graph

- Labelled directed graph
- Set of triples
- Trivial to merge
- *Advanced: named graph*

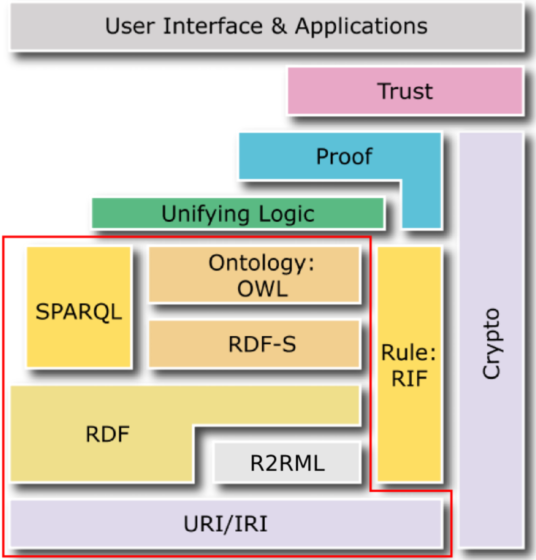
RDF graph



<uni2/person/3>
<uni2/person/1>
:lastName
:firstName
:givesLab
:givesLecture
rdf:type
:lastName
"Mendez"
"Céline"
<uni2/course/1>
:AssociateProfessor
"Lane"
:title
"Information security"

Semantic Web technologies

Layer cake



SPARQL

SPARQL Protocol and RDF Query Language

Title of courses taught by a professor and professor names

```
PREFIX : <http://example.org/voc#>
# Other prefixes omitted

SELECT ?title ?fName ?lName {

  ?teacher rdf:type :Professor .
  ?teacher :teaches ?course .
  ?teacher foaf:lastName ?lName .

  ?course :title ?title .

  OPTIONAL {
    ?teacher foaf:firstName ?fName .
  }
}
```

Algebra

- Basic Graph Patterns
- `OPTIONAL`
- `UNION`
- `GROUP BY`
- `MINUS`
- `FILTER NOT EXISTS`

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RDF Schema (RDFS)

Lightweight ontology

rdfs:subClassOf

	:AssociateProfessor rdfs:subClassOf :Professor . <uni1/academic/1> rdf:type :AssociateProfessor .
$\Longrightarrow$	<uni1/academic/1> rdf:type :Professor .

rdfs:subPropertyOf

	:givesLecture rdfs:subPropertyOf :teaches . <uni2/academic/2> :givesLecture <uni2/course/1> .
$\Longrightarrow$	<uni2/academic/2> :teaches <uni2/course/1> .

rdfs:domain

	:teaches rdfs:domain :Teacher . <uni2/academic/2> :teaches <uni2/course/1> .
$\Longrightarrow$	<uni2/academic/2> rdf:type :Teacher .

rdfs:range

	:teaches rdfs:range :Course . <uni2/academic/2> :teaches <uni2/course/1> .
$\Longrightarrow$	<uni2/course/1> rdf:type :Course .

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Web Ontology Language (OWL)

Some constructs

owl:inverseOf

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

owl:disjointWith

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

$\Longrightarrow$	Inconsistent RDF graph

owl:sameAs

	`<uni2/person/2> :sameAs <uni1/academic/21> .` `<uni2/person/2> :teaches <uni2/course/1> .`
$\Longrightarrow$	`<uni1/academic/21> :teaches <uni2/course/1> .`

Full OWL 2 is very expressive

- Many more constructs
- Computation costs become easily prohibitive

Profile OWL 2 QL

Based on the Description Logic *DL-Lite*$_{\mathcal{R}}$

Supported constructs

- Class and property hierarchies (`rdfs:subClassOf` and (`rdfs:subPropertyOf`)
- Property domain and range (`rdfs:domain`, `rdfs:range`)
- Inverse properties (`owl:inverseOf`)
- Class disjunction (`owl:disjointWith`)
- Mandatory participation (advanced)

Not supported

- Individual identities (`owl:sameAs`)
- Cardinality constraints (functional property, etc.)
- Many other constructs

Summary

- Lightweight ontologies
- A bit more than RDFS
- First-order rewritability (rewritable into a SQL query)

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Mappings RDB-RDF

Ontop native format (similar to the R2RML standard)

Source (SQL)

```
SELECT s_id, firstName, lastName
FROM uni1.student
```

Target (RDF, Turtle-like)

```
ex:uni1/student/{s_id} a :Student ;
          foaf:firstName "{firstName}"^^xsd:string ;
          foaf:lastName "{lastName}"^^xsd:string .
```

Result

- DBs unified into one RDF graph
- This graph can be queried with SPARQL

Mappings RDB-RDF

Other mappings

Object property (`:teaches`)

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

Mappings RDB-RDF

Other mappings

Object property (:teaches)

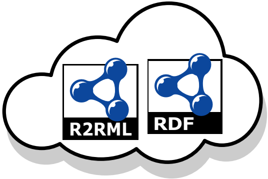
Target (RDF)	`ex:uni1/academic/{a_id} :teaches ex:uni1/course/{c_id} .`
Source	`SELECT * FROM "uni1"."teaching"`

Magic number

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

Outline

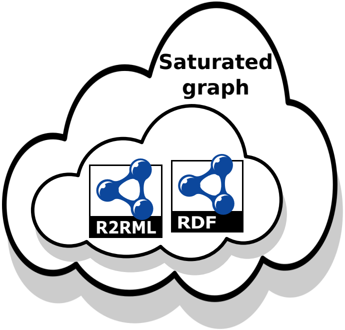
Querying the saturated RDF graph
With SPARQL



Querying the saturated RDF graph
With SPARQL

Saturated RDF graph

- Saturation of the RDF graph derived from the mappings
- According to the ontology constraints
- Usually much bigger graph!



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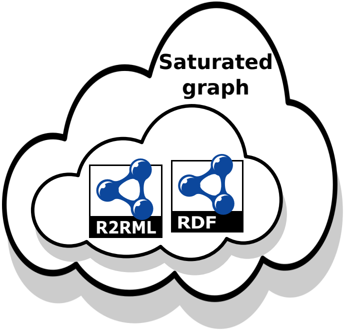


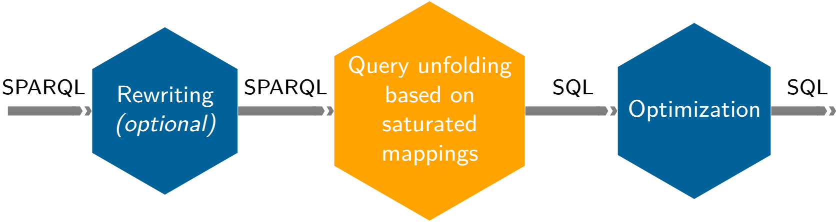
Materialized RDF graph

- ETL + saturation
- − Maintenance
- + Expressive ontology profiles (like OWL 2 RL)
- + More SPARQL 1.1 constructs

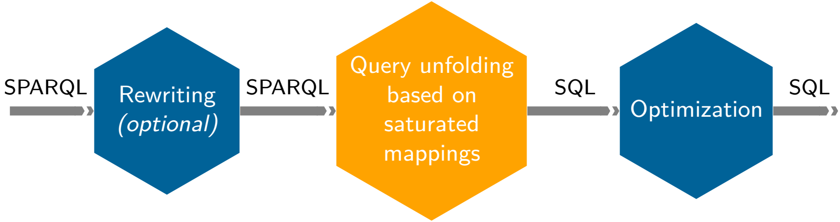
Virtual RDF graph

- Query reformulation
- + No materialization
- − Limited profiles like OWL 2 QL*

Query reformulation



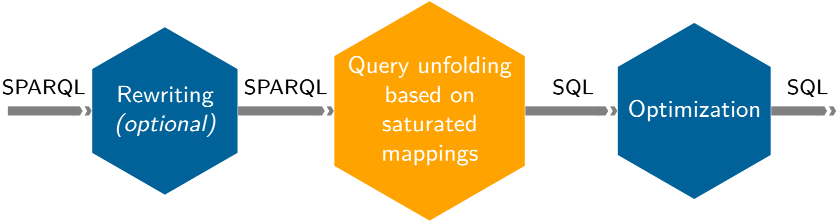
Query reformulation



Role of the OWL 2 QL ontology

- Minor: SPARQL query rewriting *(very specific cases)*
- Main: mapping saturation *(offline)*

Query reformulation



Role of the OWL 2 QL ontology

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Mapping saturation

- Query containment optimization
- Not only OWL 2 QL:
  - Horn fragment of OWL 2 [Botoeva *et al.*, 2016c]
  - SWRL with linear recursion [Xiao *et al.*, 2014]

SQL query optimization

Objective : produce a SQL query...

- Similar to manually written ones
- Adapted to existing query planners

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Structural optimization

- From Join-of-unions to union-of-joins
- IRI decomposition to improve joining performance

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Semantic optimization

- Redundant join elimination
- Redundant union elimination
- Using functional constraints

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Semantic optimization

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- Redundant union elimination
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Functional constraints

- Primary and foreign keys, unique constraints
- Implicit in the business processes *(Statoil)*
- Vital for query reformulation!

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Ontop

http://ontop.inf.unibz.it

Ontop framework

- Started in 2010
- Open-source *(Apache 2)*
- W3C standard compliant *(SPARQL, OWL 2 QL, R2RML)*
- Supports all major relational DBs *(Oracle, DB2, Postgres, MySQL, etc.)* and some virtual DBs *(Teiid, Exareme)*

Components

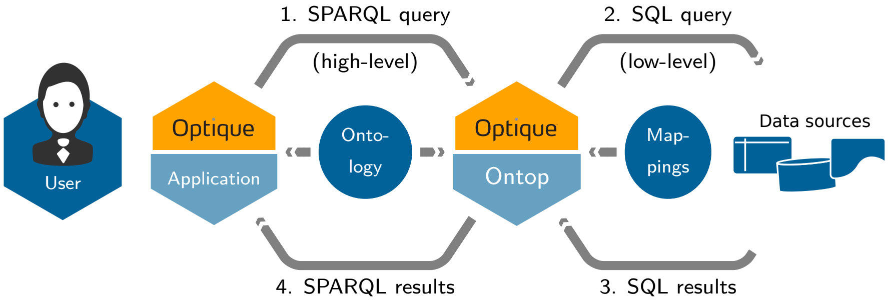
- Java APIs
- Protégé extension (GUI)
- Sesame endpoint

Integration

- Optique platform
- Stardog 4.0 (virtual graphs)

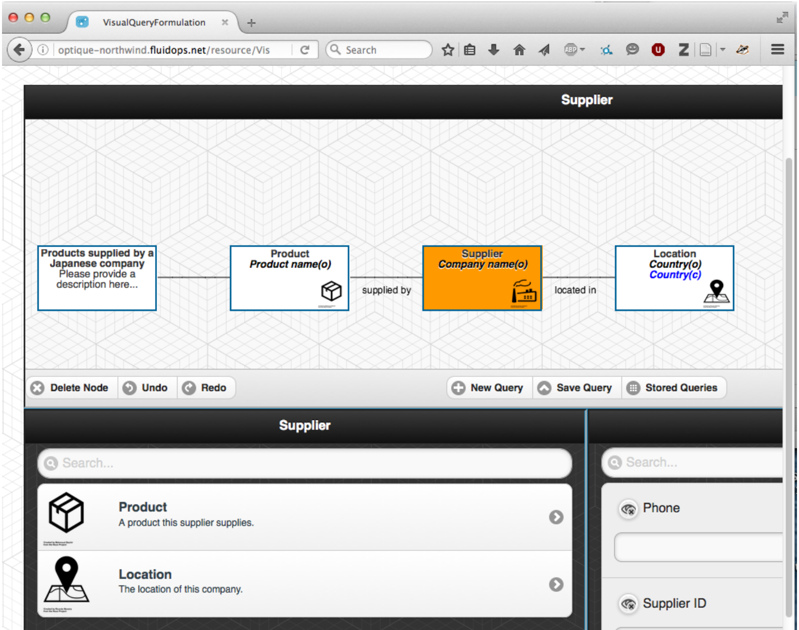
Outline

Optique platform



Visual query formulation (Optique VQS)

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



Outline

1. SQL queries over tables can be hard to write manually
2. RDF and other Semantic Web standards
3. Ontology-Based Data Access
4. Optique platform
5. Recent work
   - Cross-linked datasets
   - Beyond OWL 2 QL
   - MongoDB support
6. Conclusion

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Cross-linked datasets

[Calvanese *et al.*, 2015]

Linking tables

- Different identifiers used across datasets
- Tables keeping track of the equivalence

D_1 and D_2

id1	id2
a1	b2
a2	b1

D_2 and D_3

id2	id3
b1	c4
b2	c3

D_1 and D_3

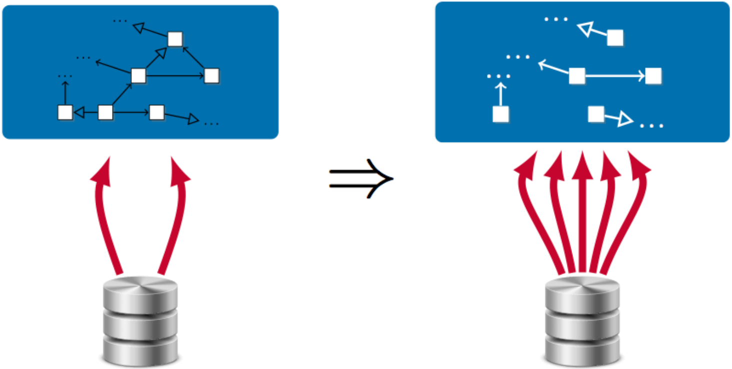
id1	id3
a3	c5

Support for linking tables

- SPARQL query rewriting
- `owl:sameAs` properties specified in the mappings
- Pruning based on incompatible URI templates

Beyond OWL 2 QL (I)

Framework for rewriting and approximation of OBDA specifications [Botoeva *et al.*, 2016c]



$\langle \mathcal{T}, \mathcal{M}, \mathcal{S} \rangle$ $\Rightarrow$ $\langle \mathcal{T}', \mathcal{M}', \mathcal{S} \rangle$

Rewriting The new specification is equivalent to the original one w.r.t. query answering (**query-inseparable**).

Approximation The new specification is a sound approximation of the original one w.r.t. query answering.

Beyond OWL 2 QL (II)

$$\mathcal{T} = \{ A \sqcap B \sqsubseteq C \} \quad \mathcal{M} = \{ \mathsf{SQL}_A(x) \rightsquigarrow A(x), \; \mathsf{SQL}_B(x) \rightsquigarrow B(x) \}$$

$$\Rightarrow$$

$$\mathcal{T}' = \{ \; \} \quad \mathcal{M}' = \{ \mathsf{SQL}_A(x) \rightsquigarrow A(x), \; \mathsf{SQL}_B(x) \rightsquigarrow B(x), \; \mathsf{SQL}_A(x) \land \mathsf{SQL}_B(x) \rightsquigarrow C(x) \}$$

$$\mathcal{T} = \{ \exists R.A \sqsubseteq C \} \quad \mathcal{M} = \{ \mathsf{SQL}_A(x) \rightsquigarrow A(x), \; \mathsf{SQL}_R(x,y) \rightsquigarrow R(x,y) \}$$

$$\Rightarrow$$

$$\mathcal{T}' = \{ \; \} \quad \mathcal{M}' = \{ \mathsf{SQL}_A(x) \rightsquigarrow A(x), \; \mathsf{SQL}_R(x,y) \rightsquigarrow R(x,y), \; \mathsf{SQL}_R(x,y) \land \mathsf{SQL}_A(y) \rightsquigarrow C(x) \}$$

$$\mathcal{T} = \{ \exists R.A \sqsubseteq A \} \quad \mathcal{M} = \{ \mathsf{SQL}_A(x) \rightsquigarrow A(x), \; \mathsf{SQL}_R(x,y) \rightsquigarrow R(x,y) \}$$

$$\Rightarrow$$

$$\begin{aligned} \mathcal{T}' = \{ \; \} \\ \mathcal{M}' = \{ & \mathsf{SQL}_A(x) \rightsquigarrow A(x), \\ & \mathsf{SQL}_R(x,y) \rightsquigarrow R(x,y), \\ & \mathsf{SQL}_R(x,y) \land \mathsf{SQL}_A(y) \rightsquigarrow A(x) \\ & \mathsf{SQL}_R(x,y) \land \mathsf{SQL}_R(y,z) \land \mathsf{SQL}_A(z) \rightsquigarrow A(x) \\ & \mathsf{SQL}_R(x,y) \land \mathsf{SQL}_R(y,z) \land \mathsf{SQL}_R(z,w) \land \mathsf{SQL}_A(w) \rightsquigarrow A(x) \} \end{aligned}$$

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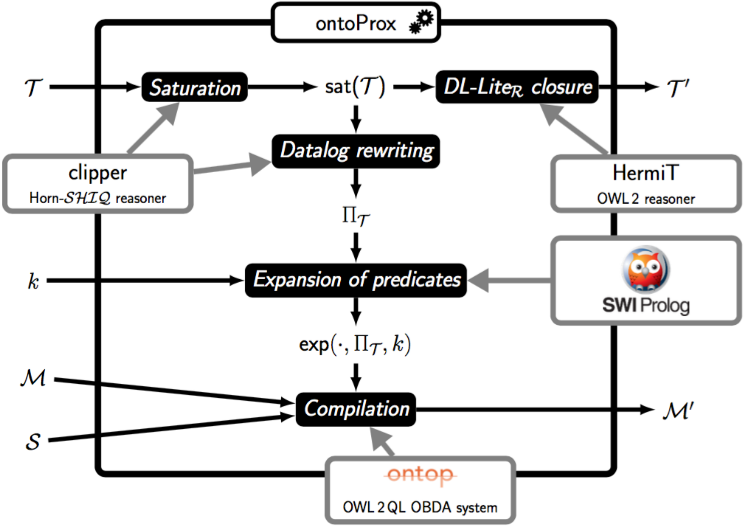
Beyond OWL 2 QL (III)

New tool: ontoprox



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MongoDB

A popular document database

JSON document described an awarded scientist

```
{ "_id": 4,
  "awards": [ {"award": "Rosing Prize", "year": 1999, "by": "Norwegian Data Association"},
              {"award": "Turing Award", "year": 2001, "by": "ACM" },
              {"award": "IEEE John von Neumann Medal", "year": 2001, "by": "IEEE"} ],
  "birth": "1926-08-27",
  "contribs": ["OOP", "Simula"],
  "death": "2002-08-10",
  "name": {"first": "Kristen", "last": "Nygaard"}
}
```

Persons who received two awards in the same year

```
db.bios.aggregate([
  {$project : {"name": true, "award1": "$awards", "award2": "$awards" }},
  {$unwind: "$award1"}, {$unwind: "$award2"},
  {$project: {"name": true, "award1": true, "award2": true,
              "twoInOneYear": { $and: [ {$eq: ["$award1.year", "$award2.year"]},
                                        {$ne: ["$award1.award", "$award2.award"]} ]}}},
  {$match: {"twoInOneYear": true} },
  {$project : {"firstName": "$name.first",    "lastName": "$name.last" ,
               "awardName1": "$award1.award", "awardName2": "$award2.award",
               "year": "$award1.year" }}
])
```

MongoDB support

[Botoeva *et al.*, 2016a] [Botoeva *et al.*, 2016b]

MongoDB

- Document database
- JSON-like documents
- Does not respect first normal form (arrays)

Mongo Aggregation Framework

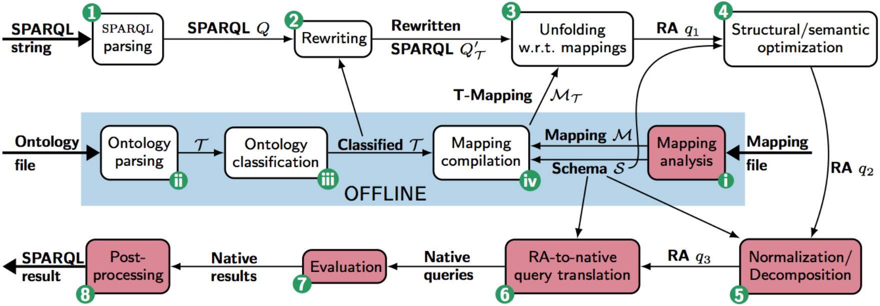
- Query language
- Use absolute paths
- At least as expressive as relational algebra (MUPGL fragment)

Integration in the OBDA setting

- JSON-RDF mapping language
- (First normal form) relational views over MongoDB
- Translation from relational algebra

Evolution of the Ontop architecture

For supporting non-relational databases



In red: components that are DB-specific.

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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

Work in progress

- SPARQL aggregation
- MongoDB
- Better SPARQL `OPTIONAL`
- SPARQL `MINUS`

Links

- Github : ontop/ontop
- ontop4obda@googlegroups.com
- Twitter : @ontop4obda
- `http://ontop.inf.unibz.it`
- `http://optique-project.eu`

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Ontop team

- Diego Calvanese
- Guohui Xiao
- Elena Botoeva
- Roman Kontchakov (Birbeck, London)
- Sarah Komla-Ebri
- Elem Güzel Kalayci
- Ugur Dönmez
- Davide Lanti
- Dag Hovland (Oslo)
- Mariano Rodriguez-Muro (now in IBM Research, NY)
- Martin Rezk (now in Rakuten, Tokyo)
- Me

Introductory resources

Journal paper [Calvanese *et al.*, 2016]

Ontop: Answering SPARQL Queries over Relational Databases.
Diego Calvanese, Benjamin Cogrel, Sarah Komla-Ebri, Roman Kontchakov, Davide Lanti, Martin Rezk, Mariano Rodriguez-Muro, and Guohui Xiao.
Semantic Web Journal. 2016 `http://www.semantic-web-journal.net/content/ontop-answering-sparql-queries-over-relational-databases-1`

Tutorial

`https://github.com/ontop/ontop-examples/tree/master/swj-2015`

University example

`https://github.com/ontop/ontop-examples/tree/master/university`

EPNET SPARQL endpoint

`http://136.243.8.213/epnet-pleiades-edh/`

References I

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CoRR Technical Report abs/1603.09291, arXiv.org e-Print archive, 2016.
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In *International workshop on Description Logic*, 2016.

[Botoeva *et al.*, 2016c] Elena Botoeva, Diego Calvanese, Valerio Santarelli, Domenico F. Savo, Alessandro Solimando, and Guohui Xiao.
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[Xiao *et al.*, 2014] Guohui Xiao, Martin Rezk, Mariano Rodriguez-Muro, and Diego Calvanese.
Rules and ontology based data access.
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