Using Semantic Technology to Tackle Industry's Data Variety Challenge

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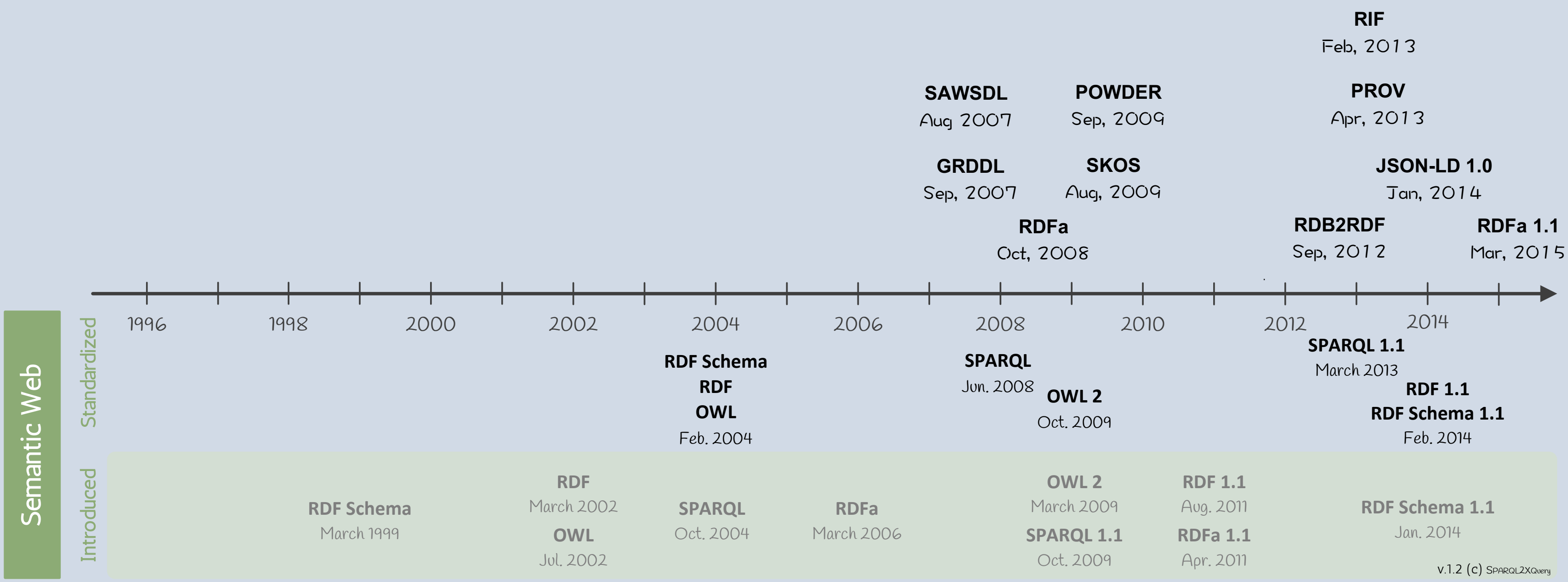
大家好!

Genesis of Semantic Web

"A new form of Web content that is meaningful to computers will **unleash a revolution of new possibilities**"

Semantic Web Standards



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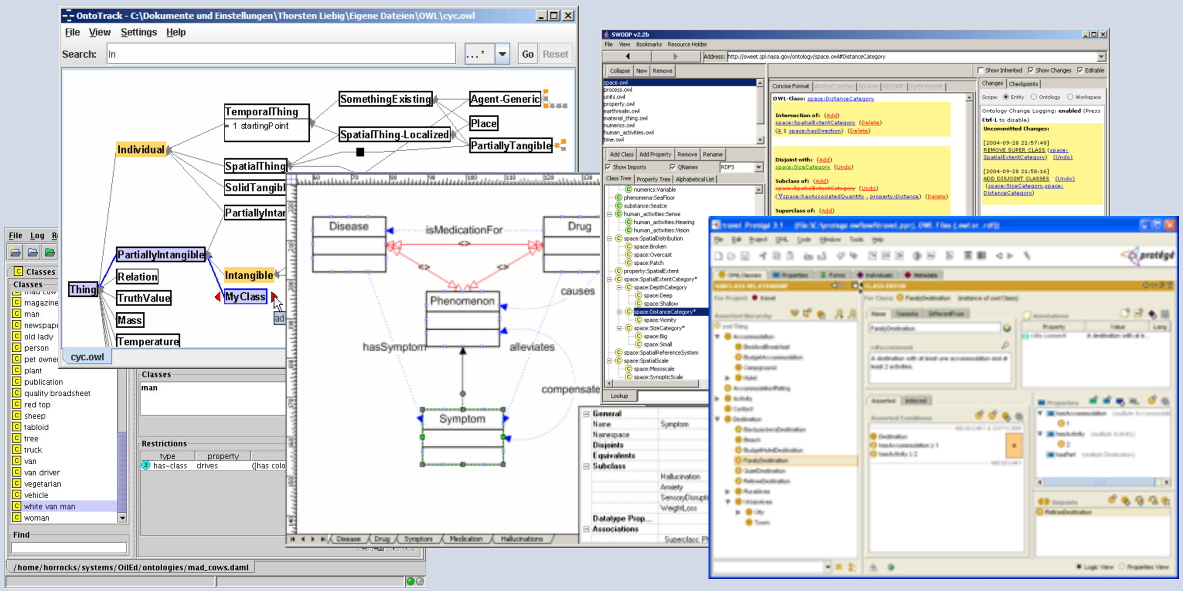
Semantic Technology Infrastructure



FaCT++

pellet

Racer

Hermit

protégé

ORACLE

OWLIM

TrOWL
www.trowl.eu

semantic web framework
Jena

QuOnto
QUerying ONTOlogies

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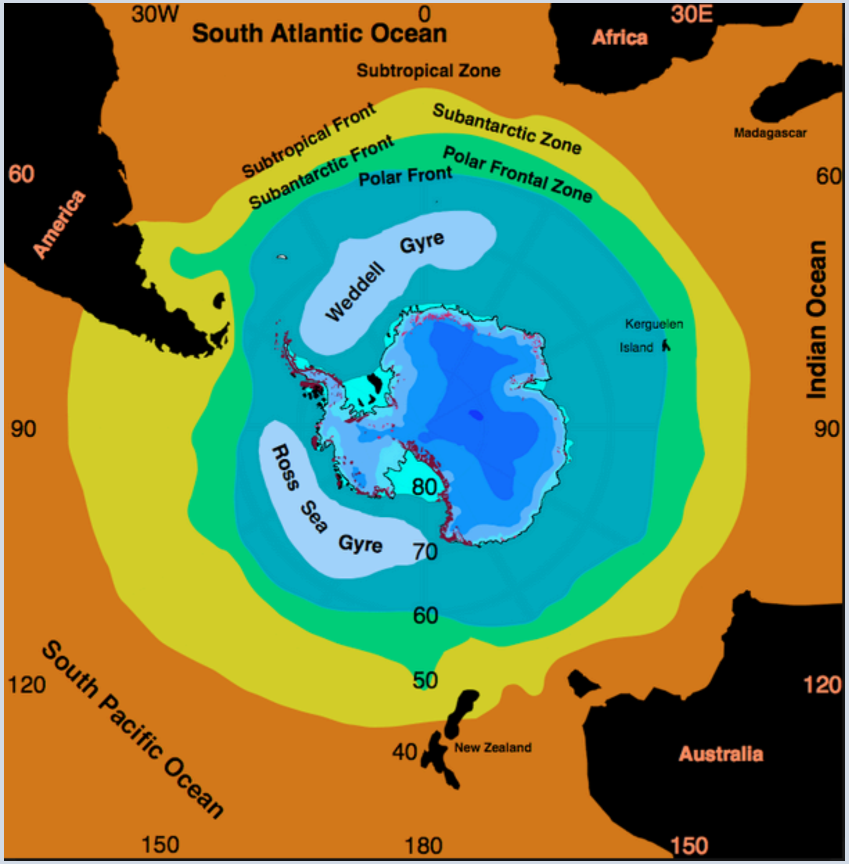
Ontology-Centric Applications

- Agriculture
- Astronomy
- Oceanography
- Defence
- Education
- Energy management
- Geography
- Gioscience
- Life sciences
- …



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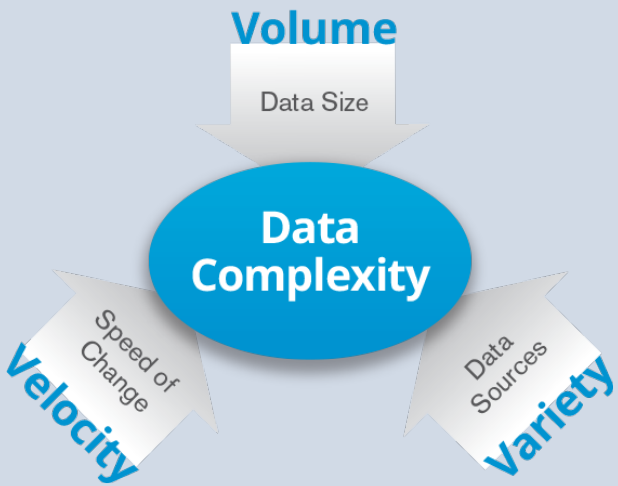
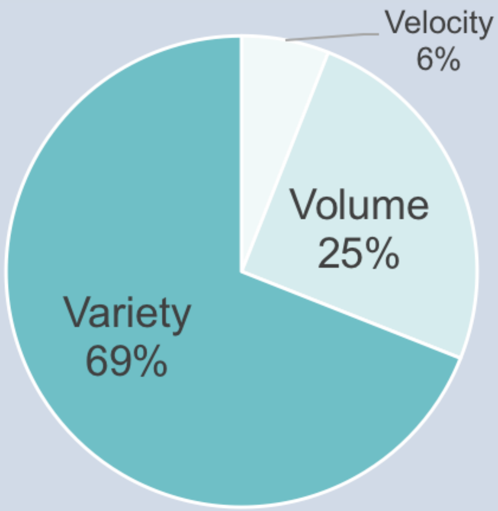
Ontology-Centric Applications

- **OBO foundry** includes more than 100 biological and biomedical ontologies
- **Siemens** "actively building OWL based clinical solutions"
- **SNOMED-CT** (Clinical Terms) ontology
  - used in healthcare systems of more than 15 countries, including Australia, Canada, Denmark, Spain, Sweden and the UK
  - also used by major US providers, e.g., Kaiser Permanente
  - ontology provides common vocabulary for recording clinical data

(Big) Data-Centric Applications

- *a collection of data sets so large and complex that it becomes difficult to process using on-hand database management tools or traditional data processing applications* (WIKIPEDIA)
- Complexity due to range of factors including Volume, Velocity & Variety
- ***Variety***, *Not Volume, Is Driving Big Data Initiatives* (MITSloan Management Review)





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Data Access: Statoil Exploration

- Geologists & geophysicists use data from previous operations in nearby locations to develop stratigraphic models of unexplored areas
  - TBs of relational data
  - using diverse schemata
  - spread over 1,000s of tables
  - and multiple data bases

Data Access

- 900 geologists & geophysicists
- 30-70% of time on data gathering
- 4 day turnaround for new queries

Data Exploitation

- Better use of experts time
- Data analysis “most important factor” for drilling success

Data Access: SIEMENS Energy Services

- Service centres responsible for remote monitoring and diagnostics of 1,000s of gas/steam turbines
- Engineers use a variety of data for visualization, diagnostics and trend detection:
  - several TB of time-stamped sensor data
  - several GB of event data
  - data grows at 30GB per day

Service Requests

- 1,000 requests per center per year
- 80% of time used on data gathering

Diagnostic Functionality

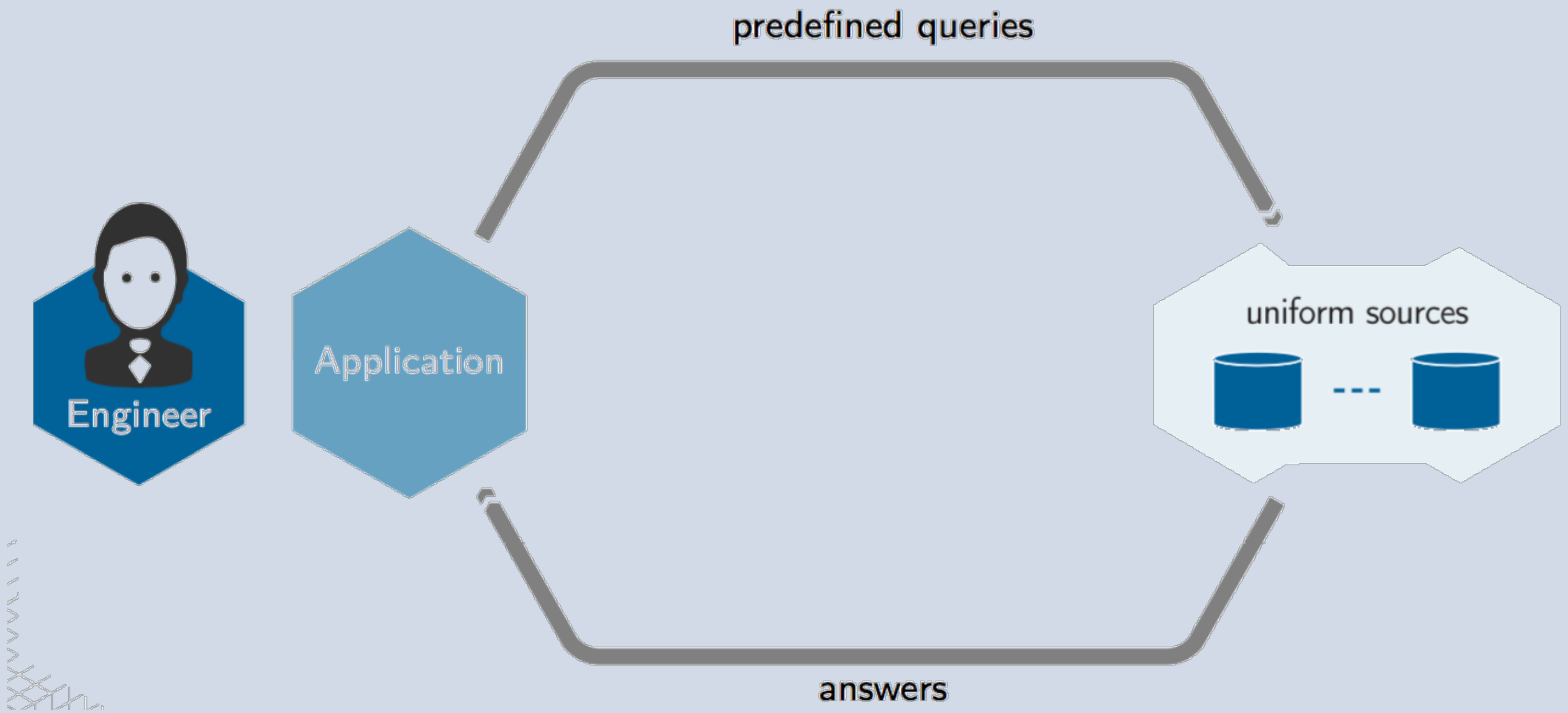
- 2–6 p/m to add new function
- New diagnostics → better exploitation of data

Data Access: Pervasive Problem

- **Oil and Gas** (e.g., Statoil, Schlumberger, …)
- **Power generation** (e.g., Siemens, …)
- **Power distribution** (e.g., EDF, …)
- **Engineering** (e.g., DNV, Aibel, …)
- **Finance** (e.g., Goldman Sachs, …)
- **Healthcare** (e.g., Kaiser Permanente, …)
- **Security** (e.g., “government agencies”)

⋮

Data Access: Statoil Exploration



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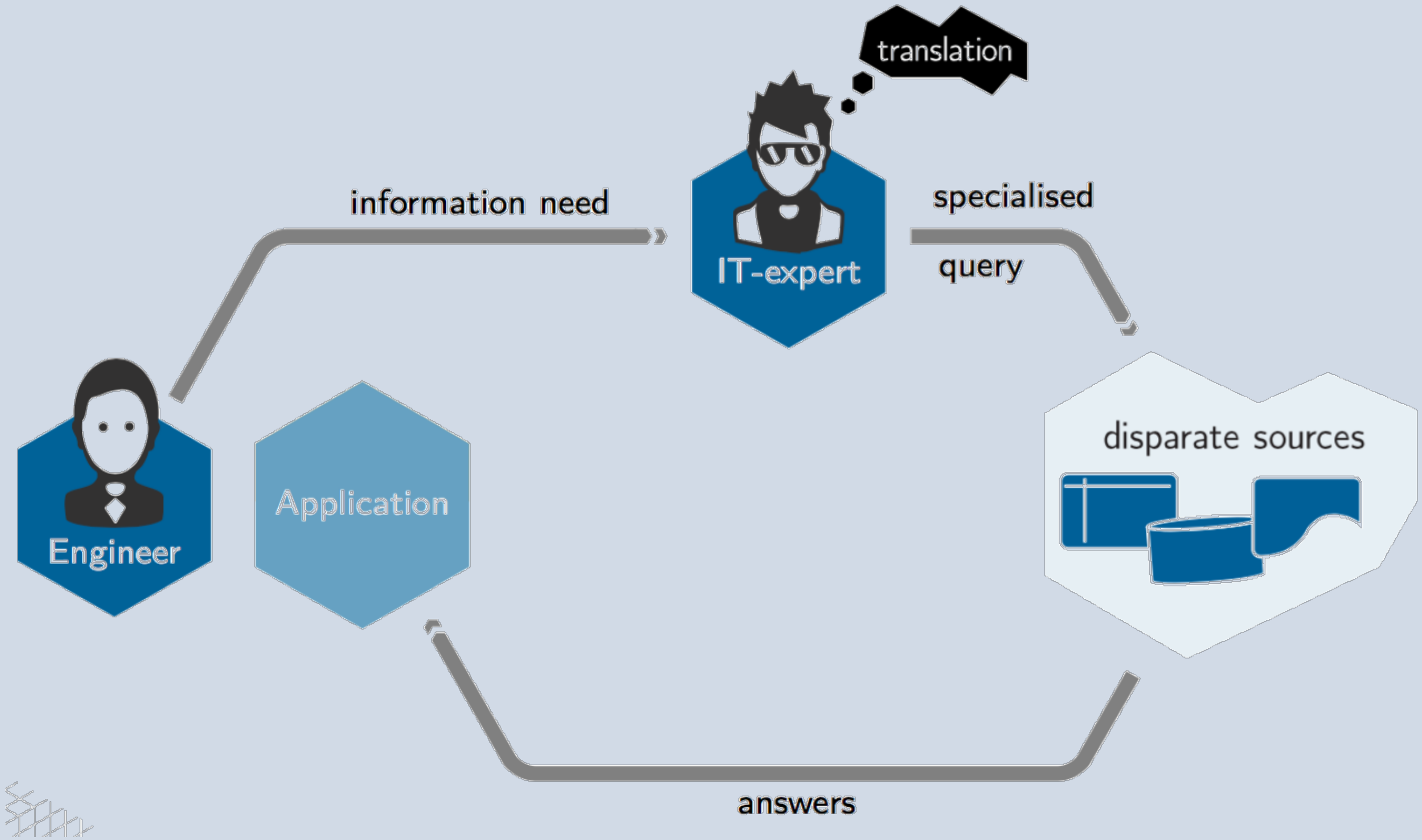
Data Access: Statoil Exploration



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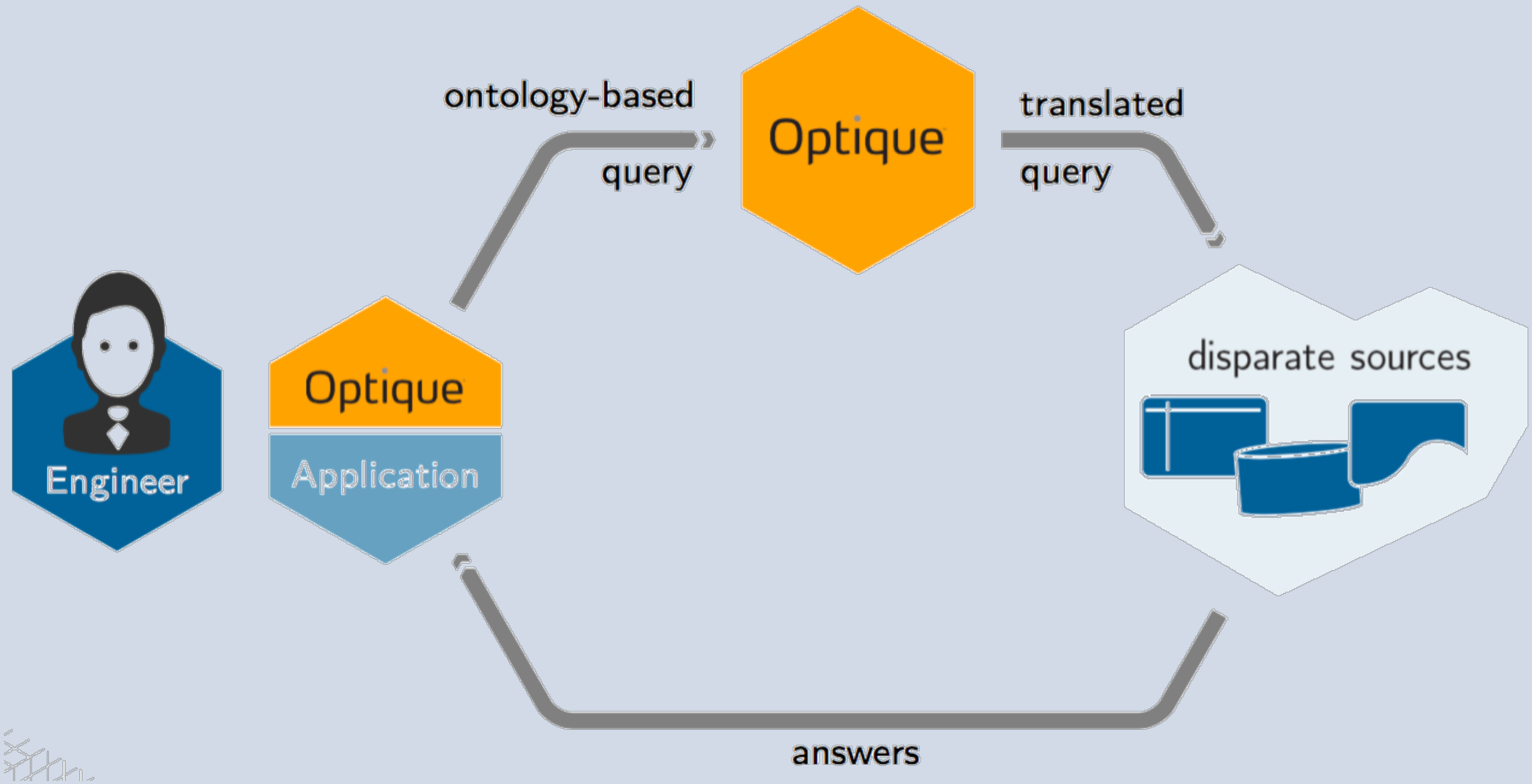
Data Access: Optique Approach



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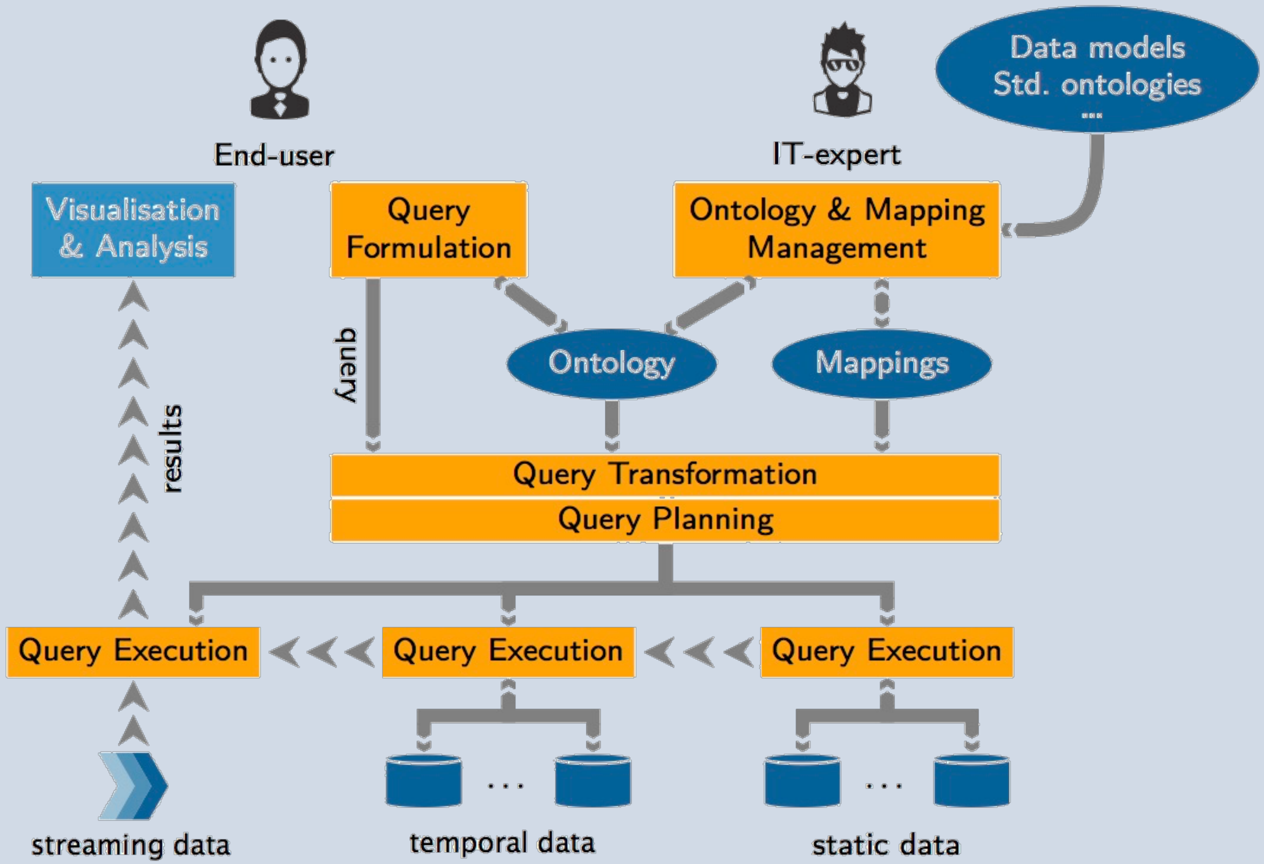

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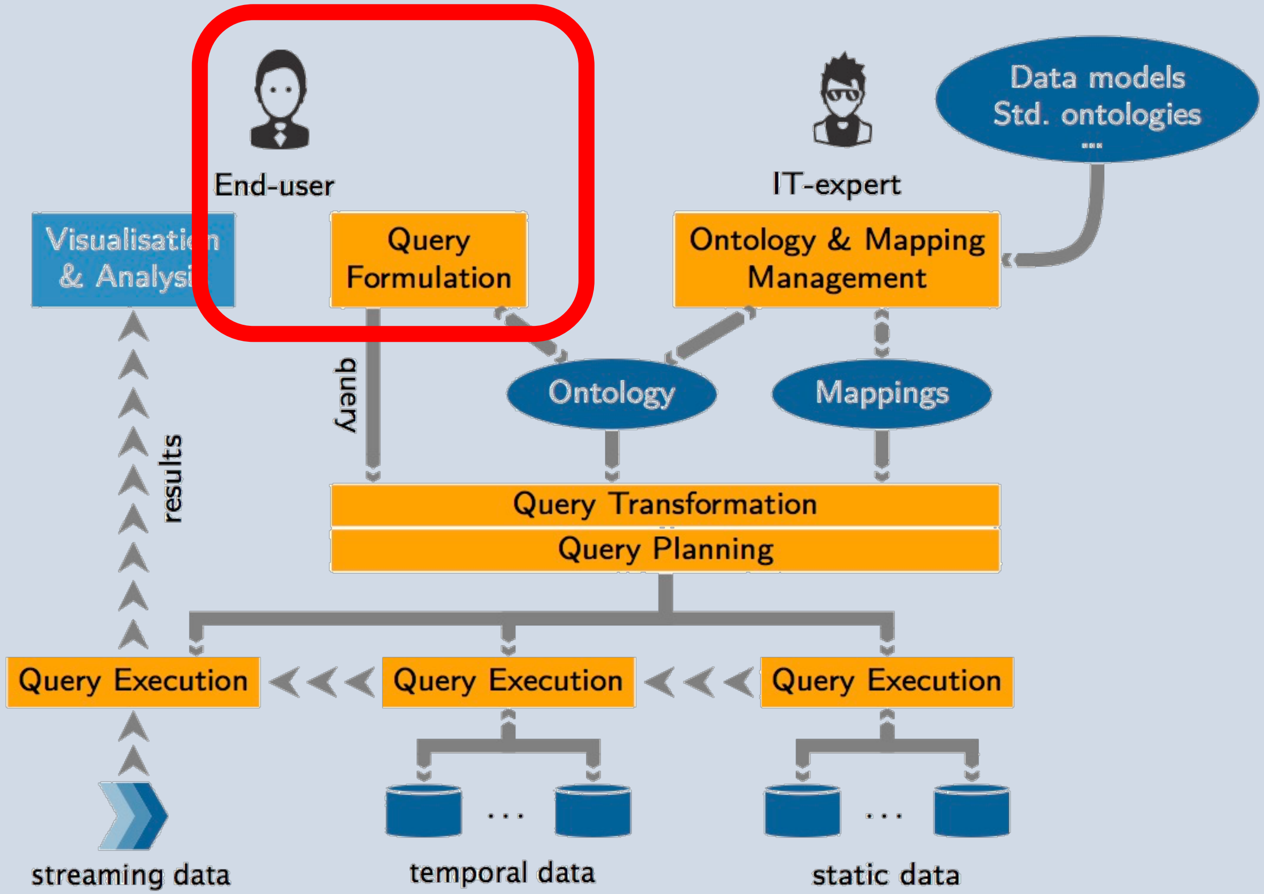

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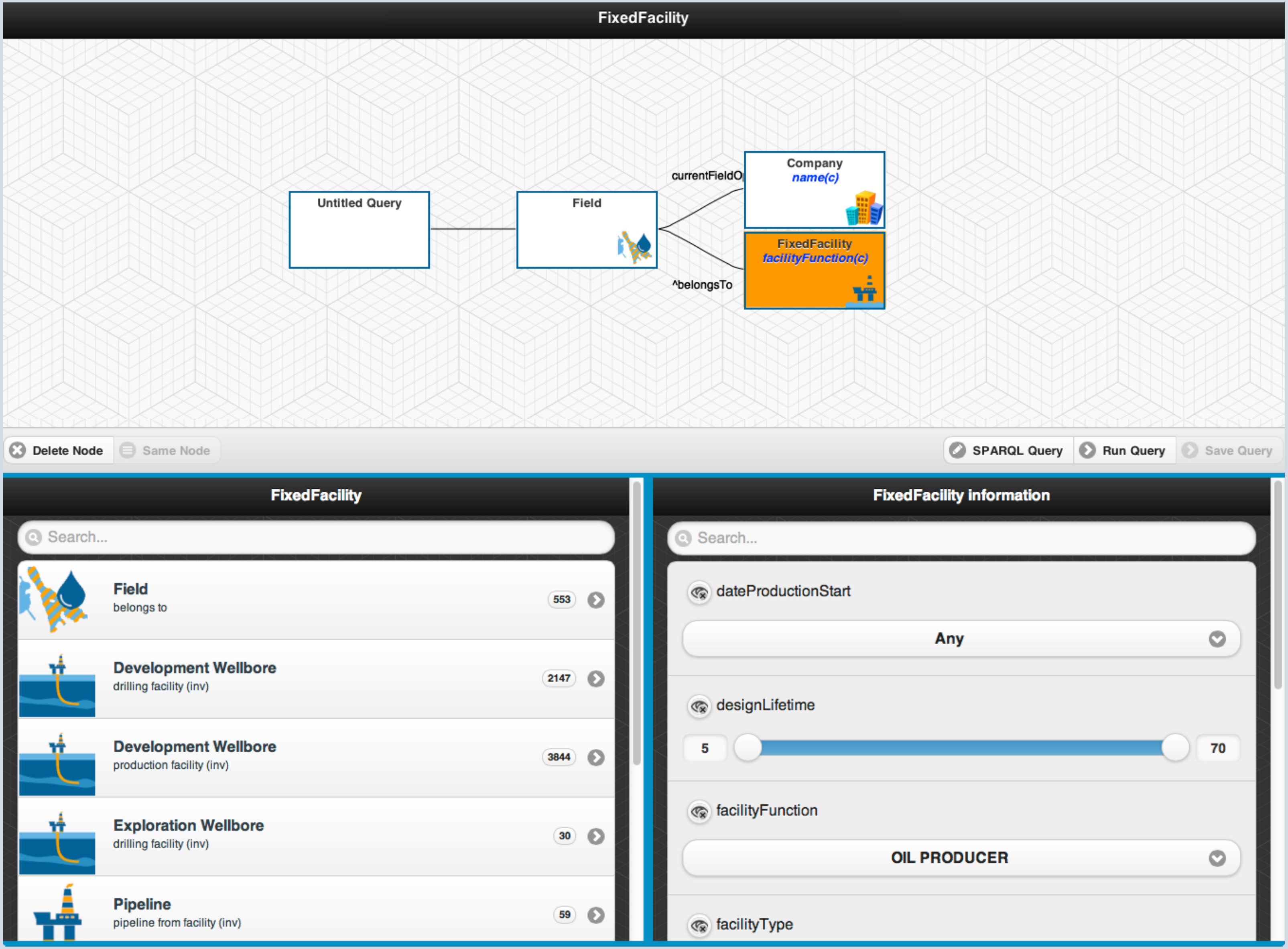

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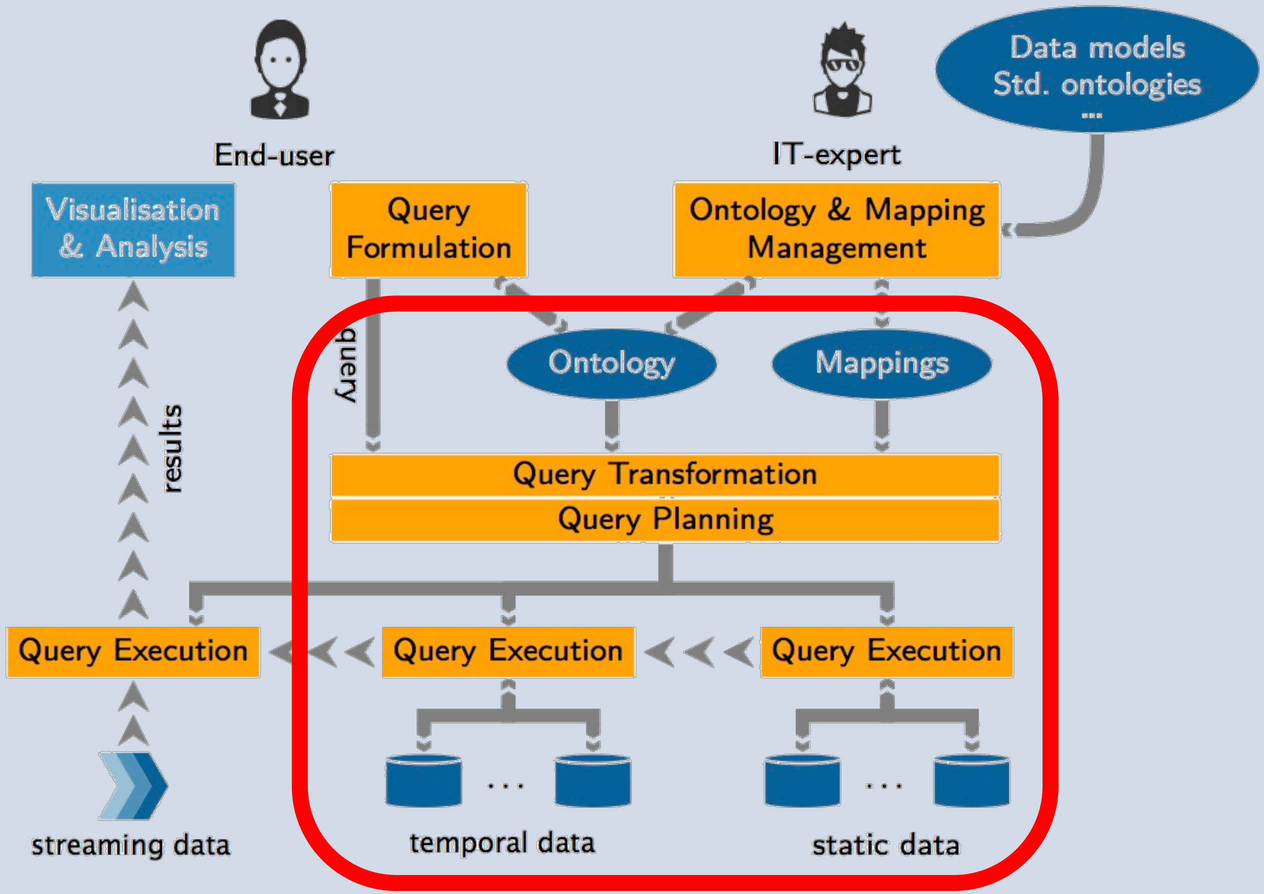


OWL Profiles

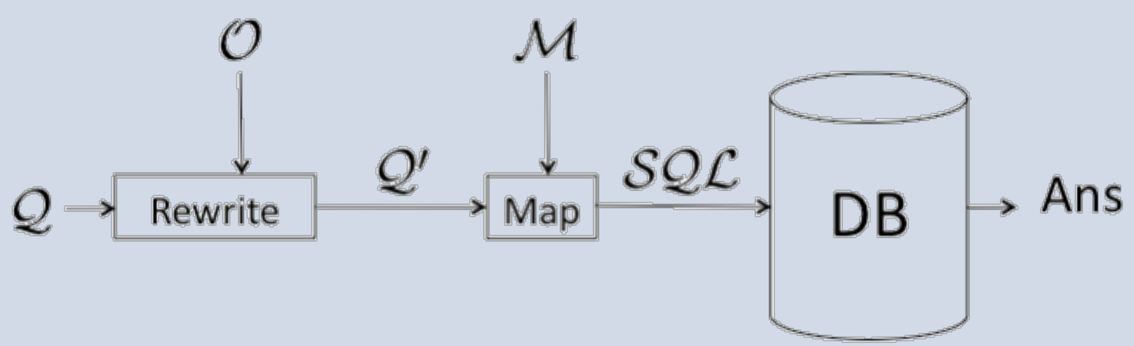
OWL 2 (2009) defines language subsets, aka **profiles** that can be "more simply and/or efficiently implemented"

- **OWL 2 QL**
  - Based on DL-Lite
  - Efficiently implementable via rewriting into relational queries (OBDA)

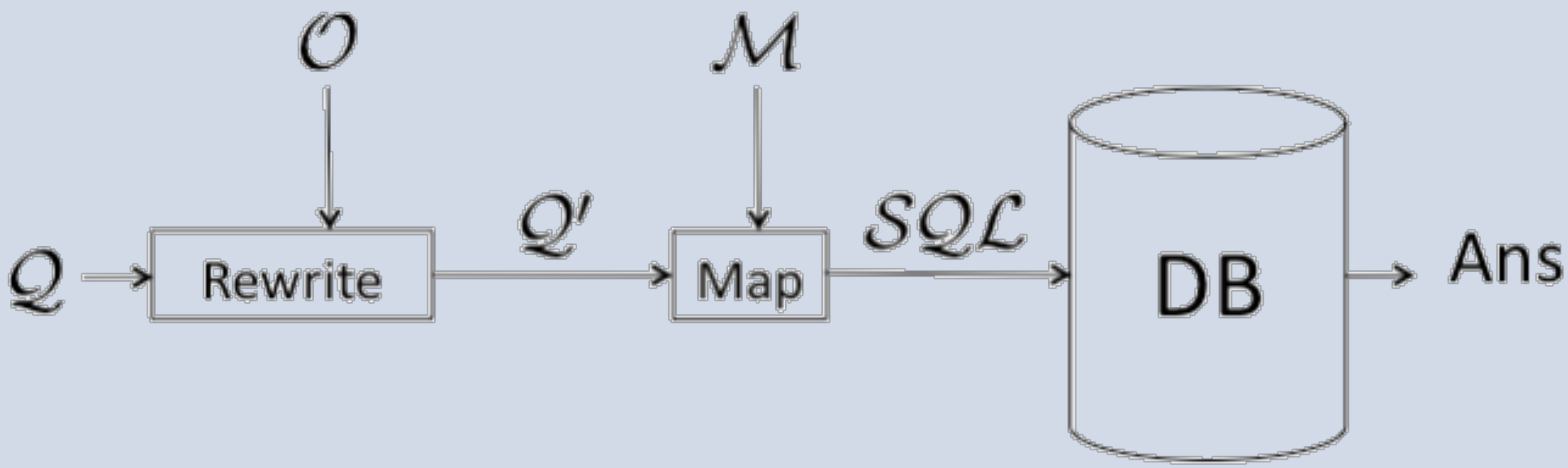
OWL 2 QL and Query Rewriting

Given QL ontology $\mathcal{O}$ query $\mathcal{Q}$ and mappings $\mathcal{M}$:

- Use $\mathcal{O}$ to **rewrite** $\mathcal{Q} \rightarrow \mathcal{Q}'$ s.t. answering $\mathcal{Q}'$ without $\mathcal{O}$ is equivalent to answering $\mathcal{Q}$ w.r.t. $\mathcal{O}$ *for any dataset*
- **Map** ontology queries $\rightarrow$ DB queries (typically SQL) using mappings $\mathcal{M}$ to rewrite $\mathcal{Q}'$ into a DB query
- **Evaluate** (SQL) query against DB



OWL 2 QL and Query Rewriting



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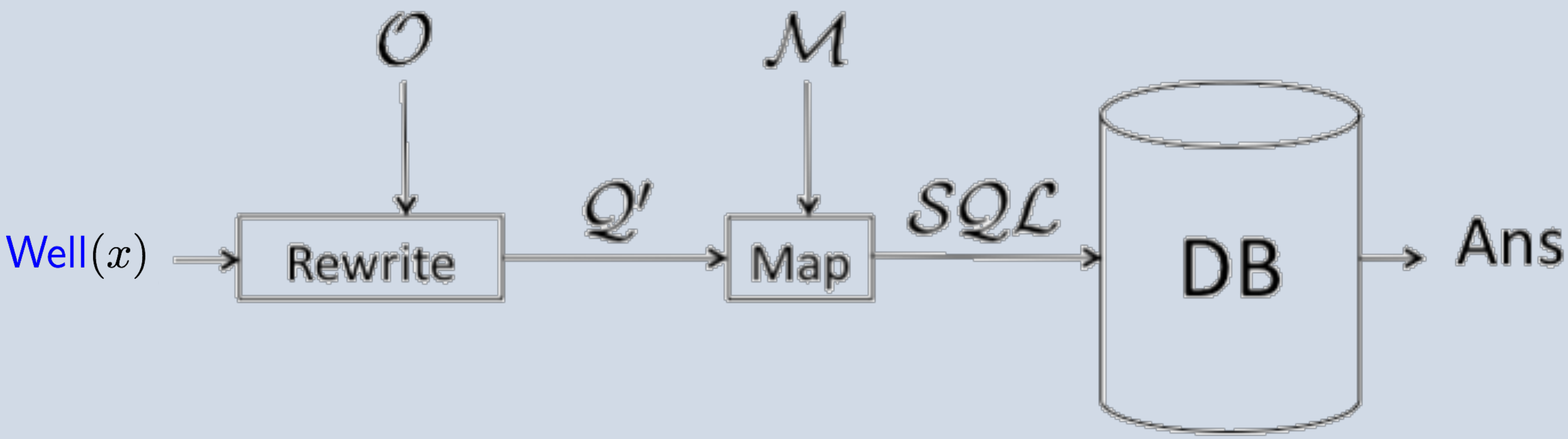
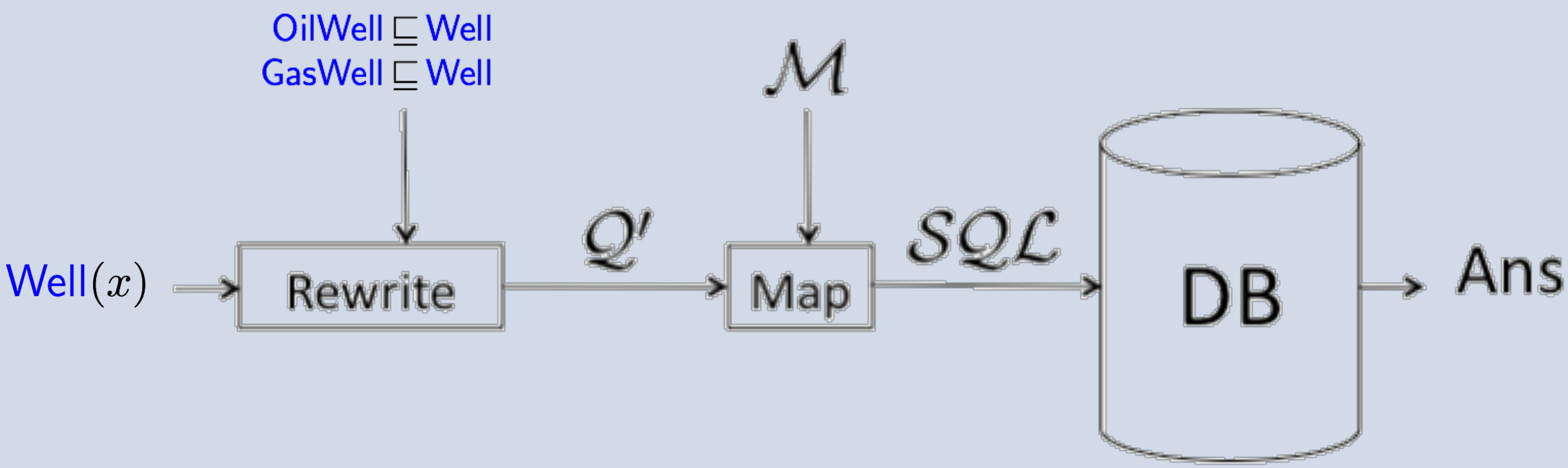


OWL 2 QL and Query Rewriting



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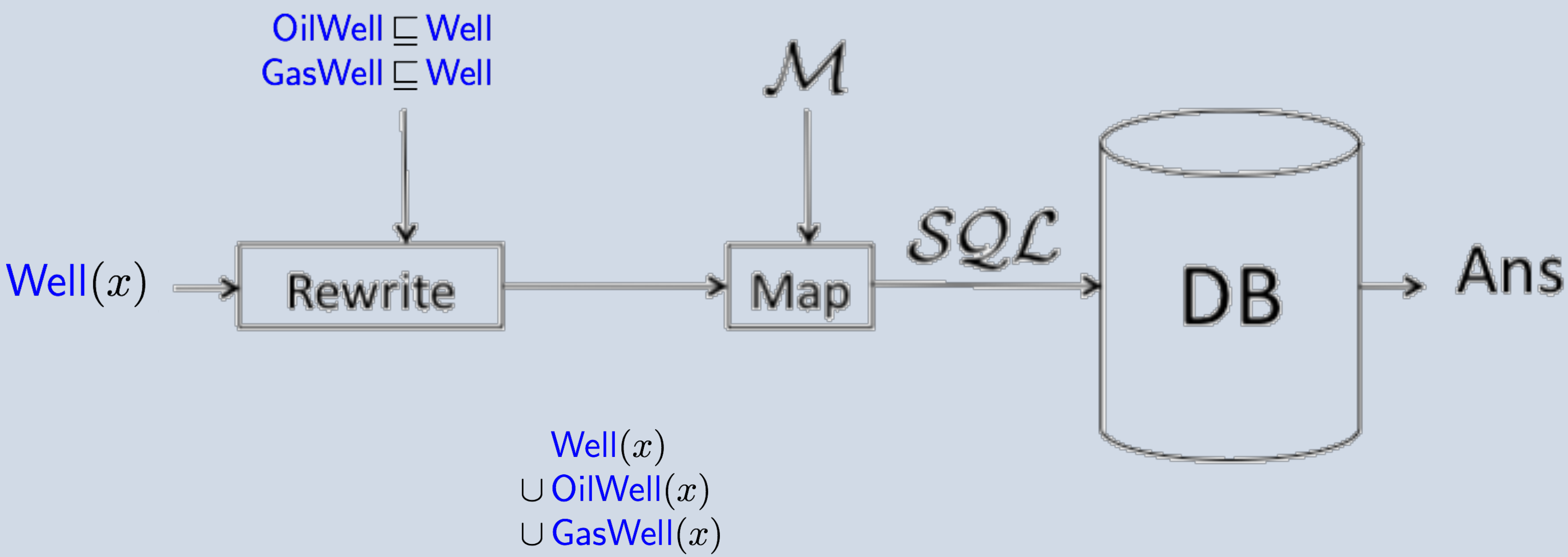
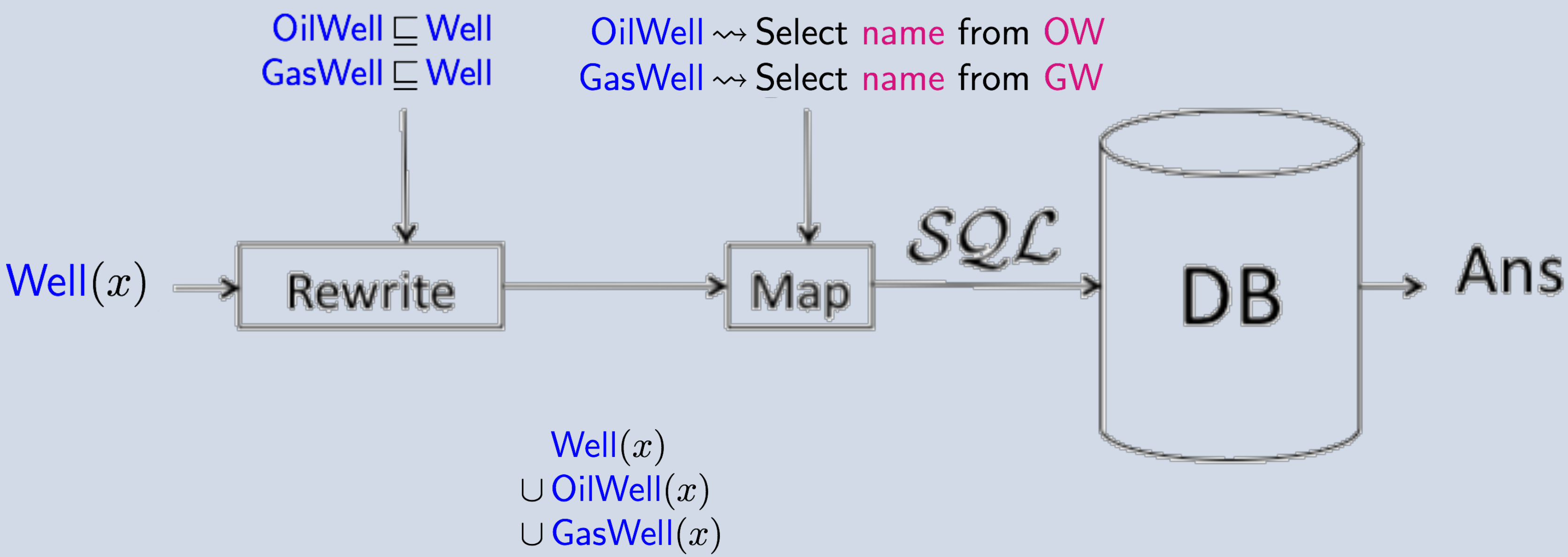


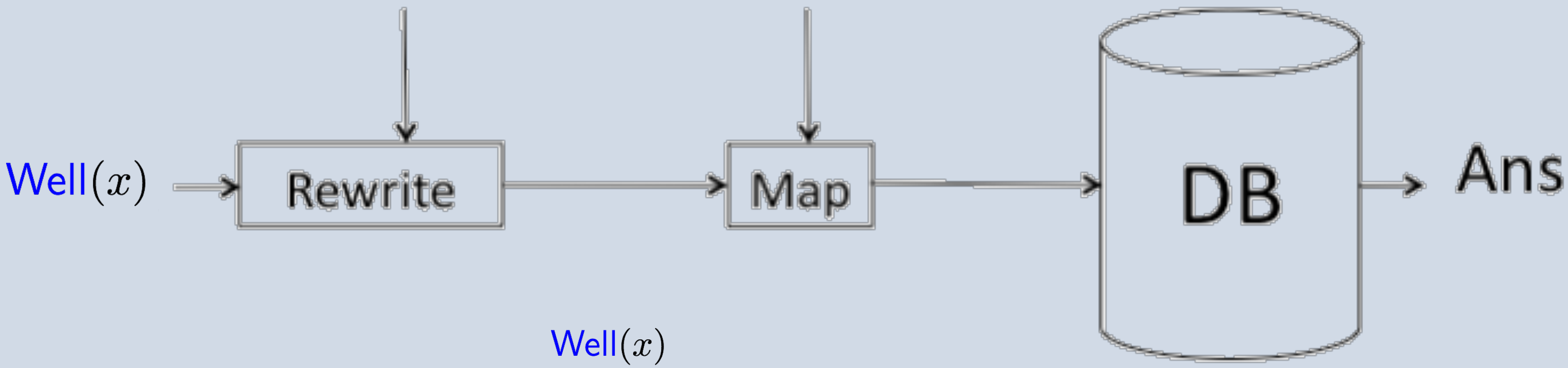
OWL 2 QL and Query Rewriting



OWL 2 QL and Query Rewriting

$\text{OilWell} \sqsubseteq \text{Well}$
$\text{GasWell} \sqsubseteq \text{Well}$

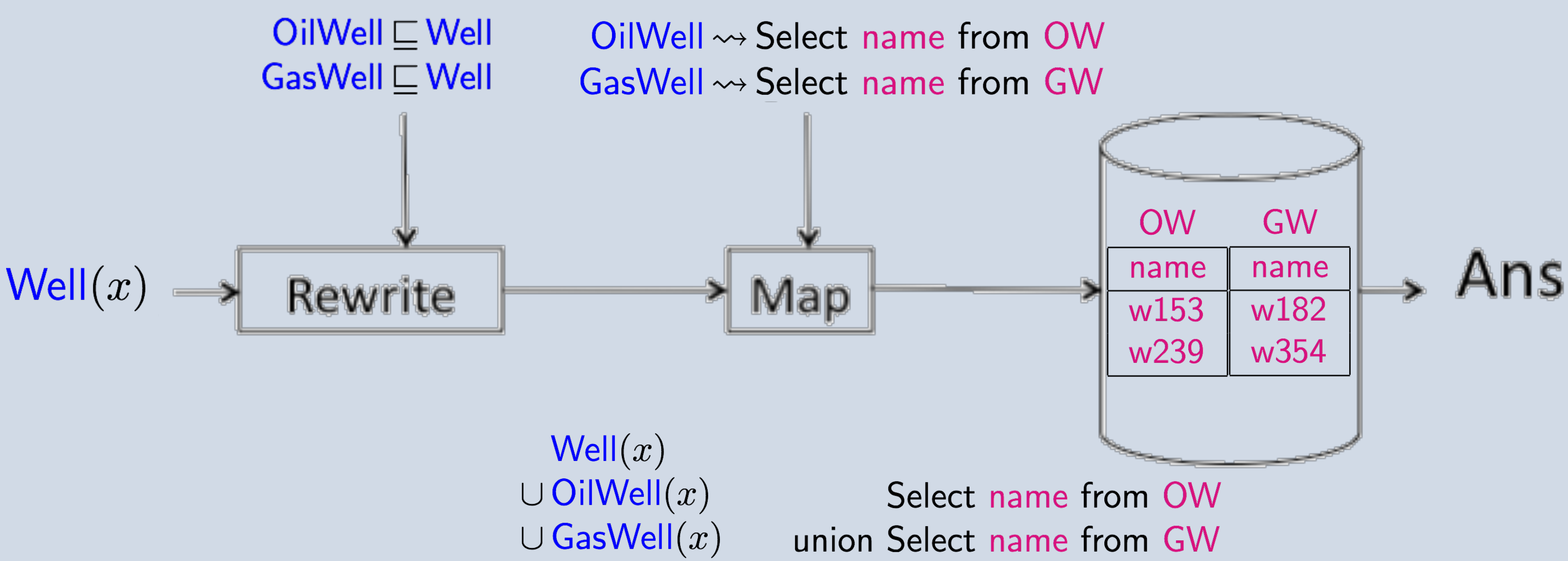
$\text{OilWell} \rightsquigarrow$ Select name from OW
$\text{GasWell} \rightsquigarrow$ Select name from GW



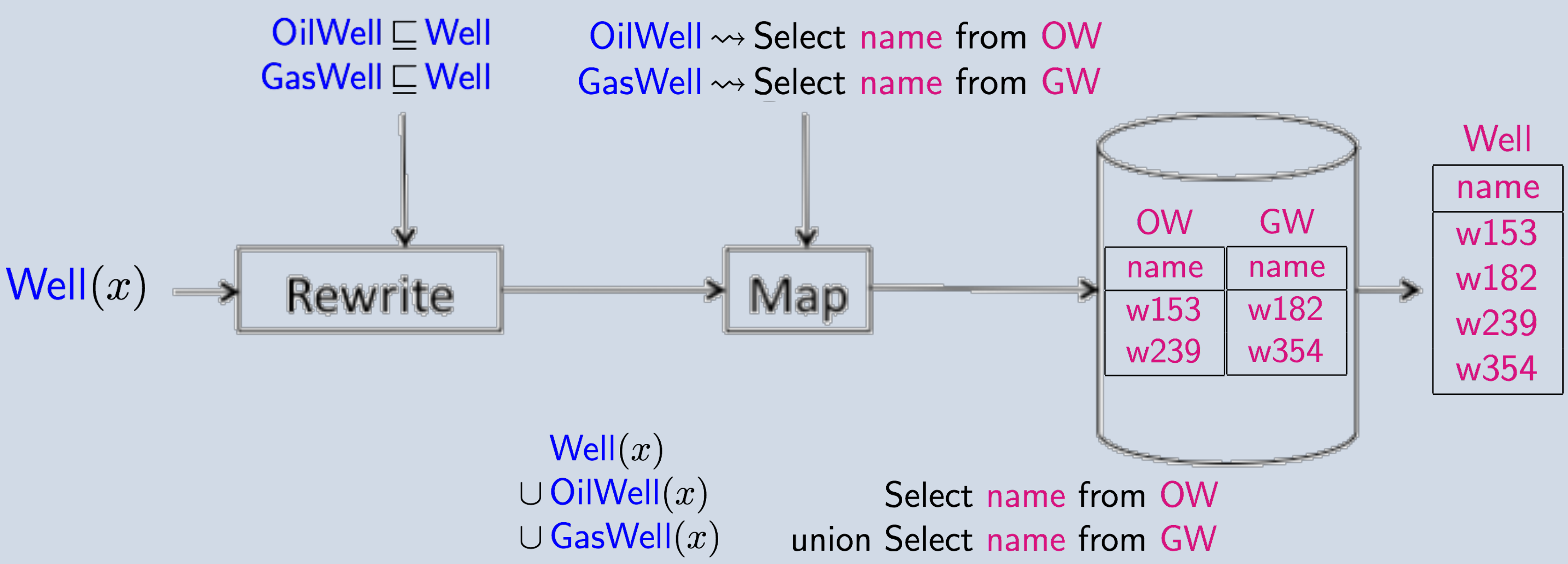
$\text{Well}(x)$
$\cup\, \text{OilWell}(x)$
$\cup\, \text{GasWell}(x)$

Select name from OW
union Select name from GW

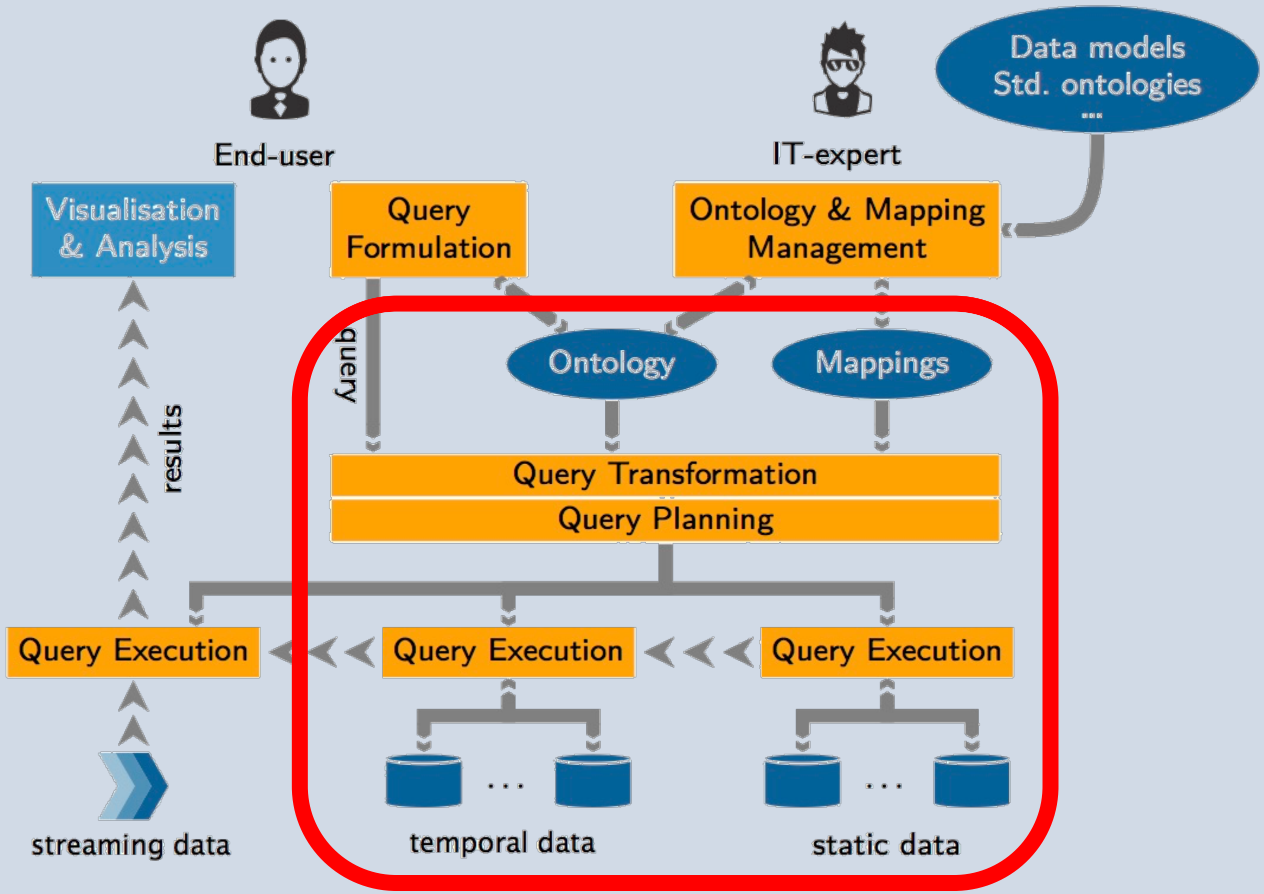
OWL 2 QL and Query Rewriting



OWL 2 QL and Query Rewriting



Data Access: Optique Approach



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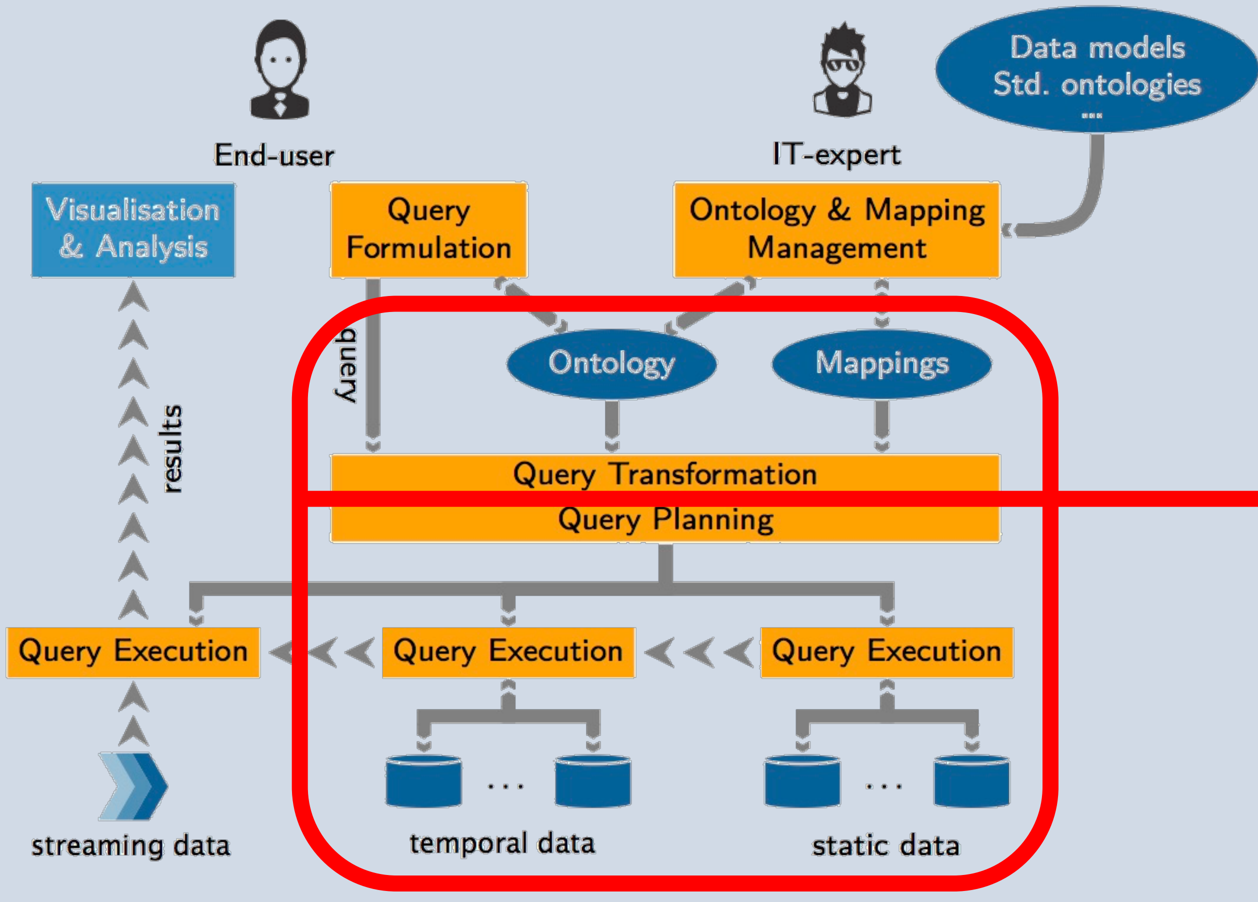
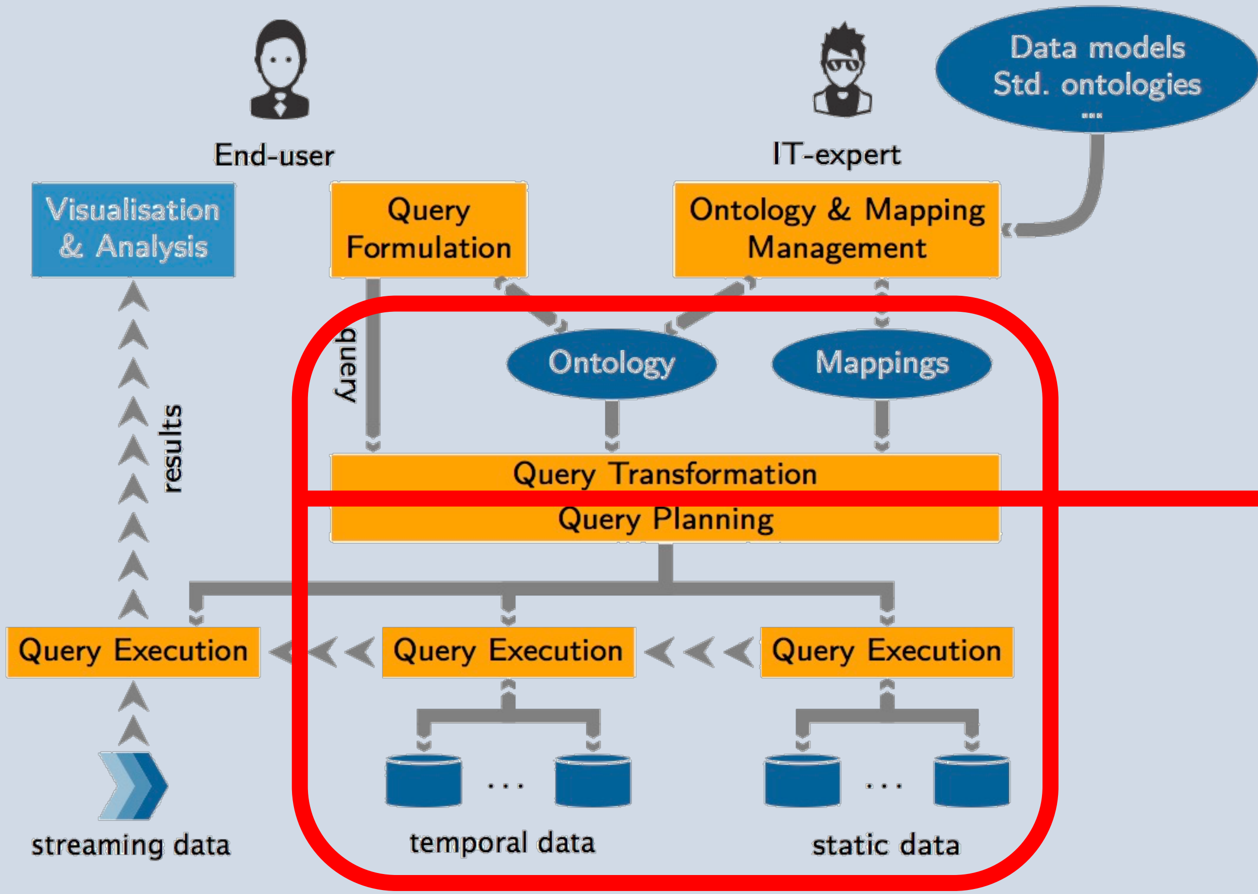


Query rewriting

- uses ontology & mappings
- computationally hard
- ontology & mappings small

Data Access: Optique Approach



Query rewriting

- uses ontology & mappings
- computationally hard
- ontology & mappings small

Query evaluation

- ind. of ontology & mappings
- computationally tractable
- data sets very large

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Data Access: Optique Approach

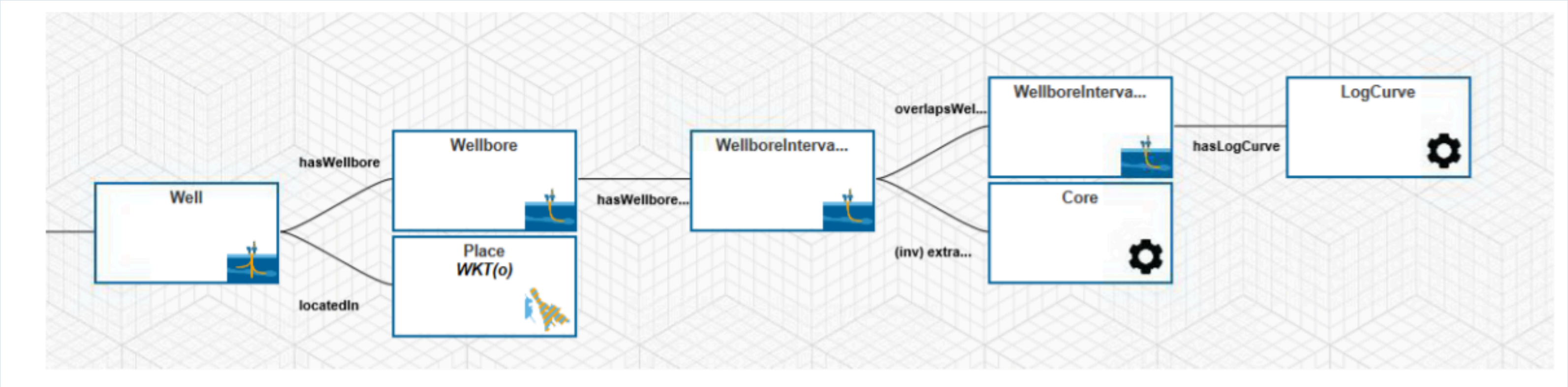
Problem Solved ?

Query Rewriting — Issues

1 Rewriting

- May be large (worst case exponential in size of ontology)
- Queries may be hard for existing DBMSs

Query: Wellbores with cores that overlap log curves



Query: Wellbores with cores that overlap log curves

```
PREFIX ns1: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX ns2: <http://www.optique-project.eu/ontology/subsurface-exploration/>

SELECT DISTINCT ?Wellbore_c2 ?WKT_a1
WHERE {
  ?Well_c1 ns1:type ns2:Well.
  ?Wellbore_c2 ns1:type ns2:Wellbore.
  ?Place_c7 ns1:type ns2:Place.
  ?WellboreInterval_c3 ns1:type ns2:WellboreInterval.
  ?WellboreInterval_c4 ns1:type ns2:WellboreInterval.
  ?Core_c6 ns1:type ns2:Core.
  ?LogCurve_c5 ns1:type ns2:LogCurve.

  ?Well_c1 ns2:hasWellbore ?Wellbore_c2.
  ?Well_c1 ns2:locatedIn ?Place_c7.
  ?Place_c7 ns2:WKT ?WKT_a1.
  ?Wellbore_c2 ns2:hasWellboreInterval ?WellboreInterval_c3.
  ?WellboreInterval_c3 ns2:overlapsWellboreInterval ?WellboreInterval_c4.
  ?WellboreInterval_c3 ^ns2:extractedFrom ?Core_c6.
  ?WellboreInterval_c4 ns2:hasLogCurve ?LogCurve_c5.
}
```

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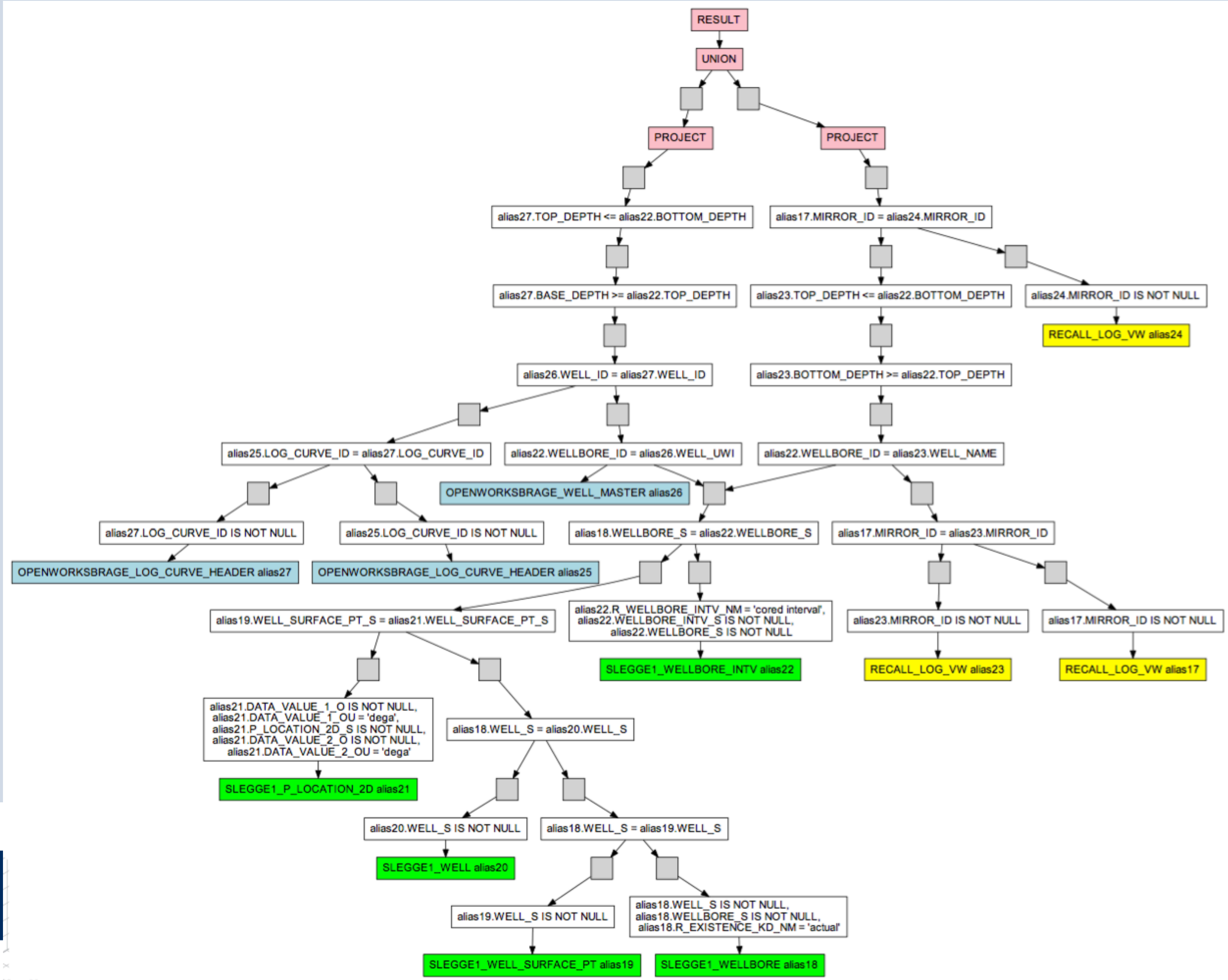
Query: Wellbores with cores that overlap log curves

```
SELECT * FROM (

SELECT
 1 AS "Wellbore_c2QuestType", NULL AS "Wellbore_c2Lang",
 ('http://.../subsurface-exploration/Wellbore-' || QVIEW2.WELLBORE_S) AS "Wellbore_c2",
 3 AS "WKT_a1QuestType", NULL AS "WKT_a1Lang",
 (((('POINT(' || QVIEW5.DATA_VALUE_2_O) || ' ') || QVIEW5.DATA_VALUE_1_O) || ')') AS "WKT_a1"

FROM ADP.SLEGGE1_WELLBORE QVIEW2,
     ADP.SLEGGE1_WELL_SURFACE_PT QVIEW3,
     ADP.SLEGGE1_WELL QVIEW4,
     ADP.SLEGGE1_P_LOCATION_2D QVIEW5,
     ADP.SLEGGE1_WELLBORE_INTV QVIEW6,
     ADP.RECALL_LOG_VW QVIEW1,
     ADP.RECALL_LOG_VW QVIEW7,
     ADP.RECALL_LOG_VW QVIEW8
WHERE QVIEW1.MIRROR_ID IS NOT NULL
  AND (QVIEW2.R_EXISTENCE_KD_NM = 'actual')
  AND QVIEW2.WELL_S IS NOT NULL
  AND QVIEW2.WELLBORE_S IS NOT NULL
  AND (QVIEW2.WELL_S = QVIEW3.WELL_S)
  AND (QVIEW2.WELL_S = QVIEW4.WELL_S)
  AND (QVIEW5.DATA_VALUE_1_OU = 'dega')
  AND (QVIEW5.DATA_VALUE_2_OU = 'dega')
  AND (QVIEW3.WELL_SURFACE_PT_S = QVIEW5.WELL_SURFACE_PT_S)
  AND QVIEW5.P_LOCATION_2D_S IS NOT NULL
  AND (QVIEW2.WELLBORE_S = QVIEW6.WELLBORE_S)
  AND (QVIEW6.R_WELLBORE_INTV_NM = 'cored interval')
  AND QVIEW6.WELLBORE_INTV_S IS NOT NULL
  AND (QVIEW1.MIRROR_ID = QVIEW7.MIRROR_ID)
  AND (QVIEW6.WELLBORE_ID = QVIEW7.WELL_NAME)
  AND ((QVIEW7.BOTTOM_DEPTH >= QVIEW6.TOP_DEPTH)
       AND (QVIEW7.TOP_DEPTH <= QVIEW6.BOTTOM_DEPTH))
  AND (QVIEW1.MIRROR_ID = QVIEW8.MIRROR_ID)
  AND QVIEW5.DATA_VALUE_1_O IS NOT NULL
  AND QVIEW5.DATA_VALUE_2_O IS NOT NULL

UNION
SELECT ...

FROM ADP.SLEGGE1_WELLBORE QVIEW2,
     ADP.SLEGGE1_WELL_SURFACE_PT QVIEW3,
     ADP.SLEGGE1_WELL QVIEW4,
     ADP.SLEGGE1_P_LOCATION_2D QVIEW5,
     ADP.SLEGGE1_WELLBORE_INTV QVIEW6,
     ADP.OPENWORKSBRAGE_LOG_CURVE_HEADER QVIEW1,
     ADP.OPENWORKSBRAGE_WELL_MASTER QVIEW7,
     ADP.OPENWORKSBRAGE_LOG_CURVE_HEADER QVIEW8
WHERE  QVIEW1.LOG_CURVE_ID IS NOT NULL
  AND  (QVIEW2.R_EXISTENCE_KD_NM = 'actual')
  AND  QVIEW2.WELL_S IS NOT NULL
  AND  QVIEW2.WELLBORE_S IS NOT NULL
  AND  (QVIEW2.WELL_S = QVIEW3.WELL_S)
  AND  (QVIEW2.WELL_S = QVIEW4.WELL_S)
  AND  (QVIEW5.DATA_VALUE_1_OU = 'dega')
  AND  (QVIEW5.DATA_VALUE_2_OU = 'dega')
  AND  (QVIEW3.WELL_SURFACE_PT_S = QVIEW5.WELL_SURFA(
  AND  QVIEW5.P_LOCATION_2D_S IS NOT NULL
  AND  (QVIEW2.WELLBORE_S = QVIEW6.WELLBORE_S)
  AND  (QVIEW6.R_WELLBORE_INTV_NM = 'cored interval')
  AND  QVIEW6.WELLBORE_INTV_S IS NOT NULL
  AND  (QVIEW6.WELLBORE_ID = QVIEW7.WELL_UWI)
  AND  (QVIEW1.LOG_CURVE_ID = QVIEW8.LOG_CURVE_ID)
  AND  (QVIEW7.WELL_ID = QVIEW8.WELL_ID)
  AND  ((QVIEW8.BASE_DEPTH >= QVIEW6.TOP_DEPTH)
         AND  (QVIEW8.TOP_DEPTH <= QVIEW6.BOTTOM_DEPTI
  AND  QVIEW5.DATA_VALUE_1_O IS NOT NULL
  AND  QVIEW5.DATA_VALUE_2_O IS NOT NULL)
SUB_QVIEW
```

Query: Wellbores with cores that overlap log curves



Query Rewriting — Issues

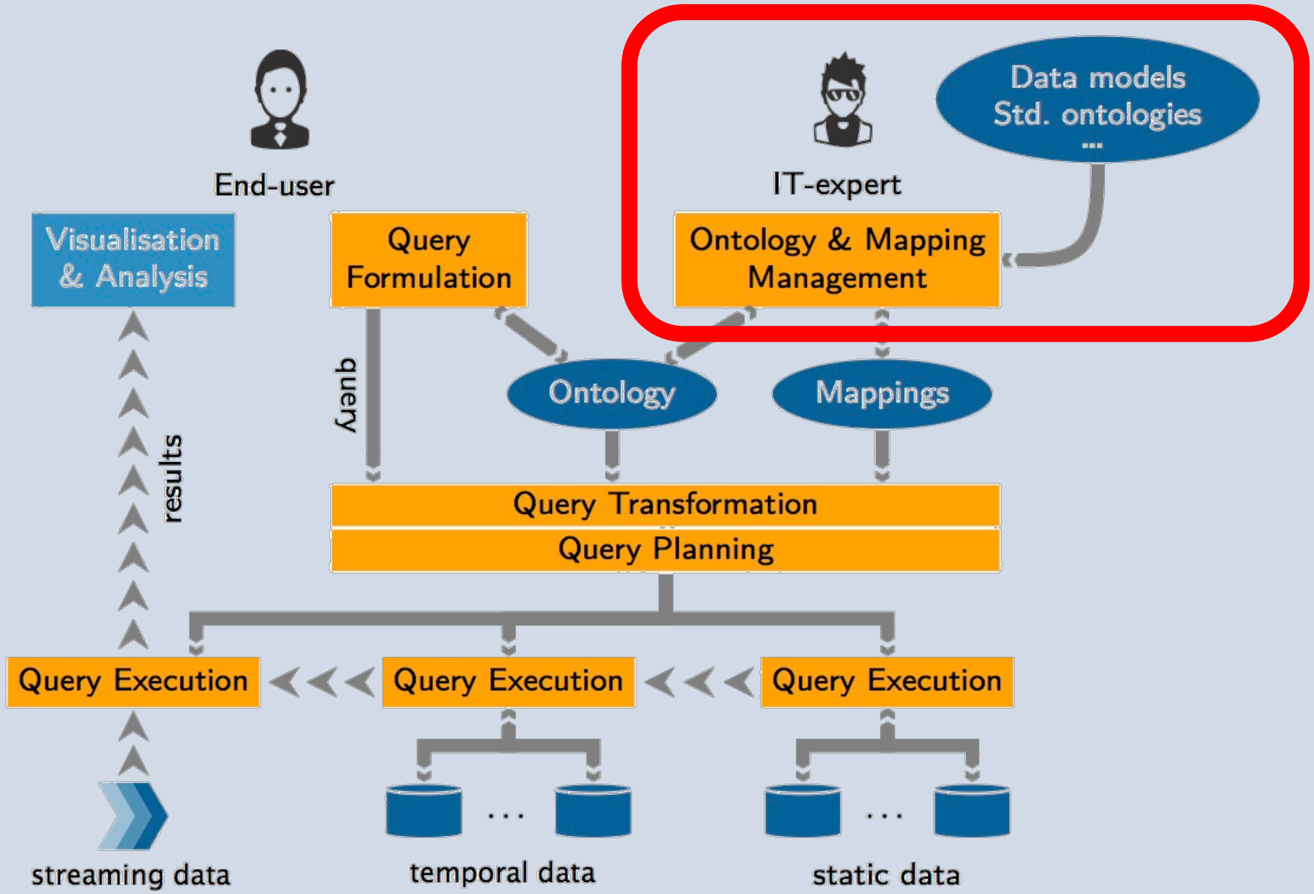
1 Rewriting

- May be large (worst case exponential in size of ontology)
- Queries may be hard for existing DBMSs

2 Ontology & Mappings

- May be difficult to develop and maintain

Data Access: Optique Approach



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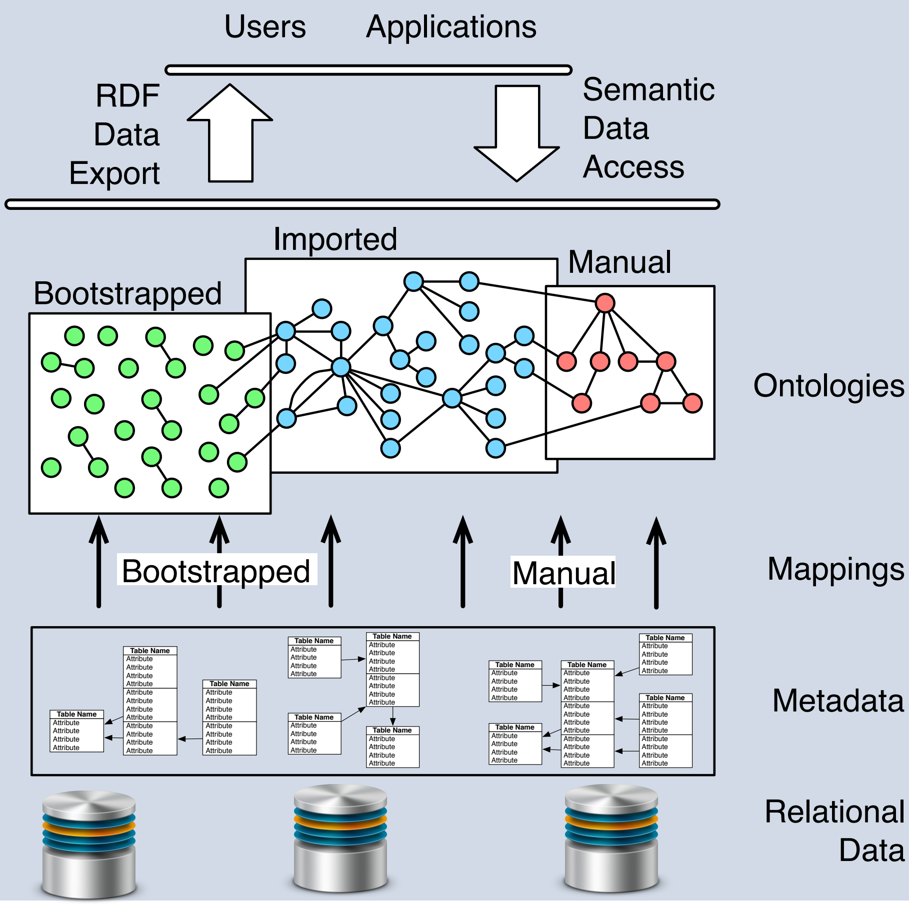
BootOX



Users
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Manual
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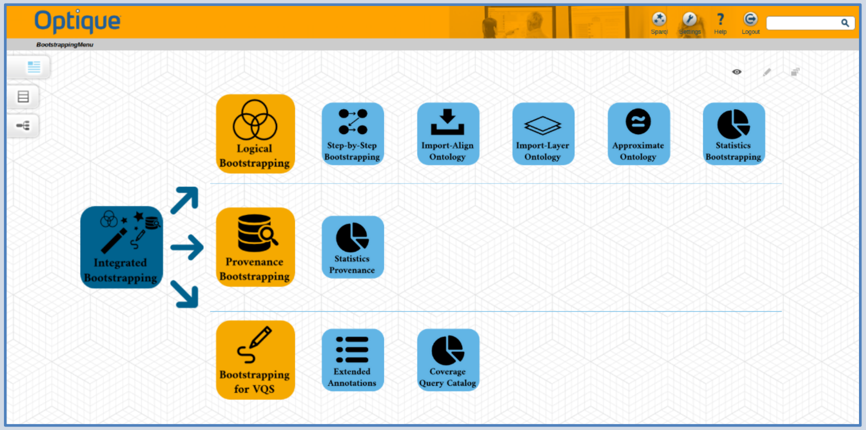
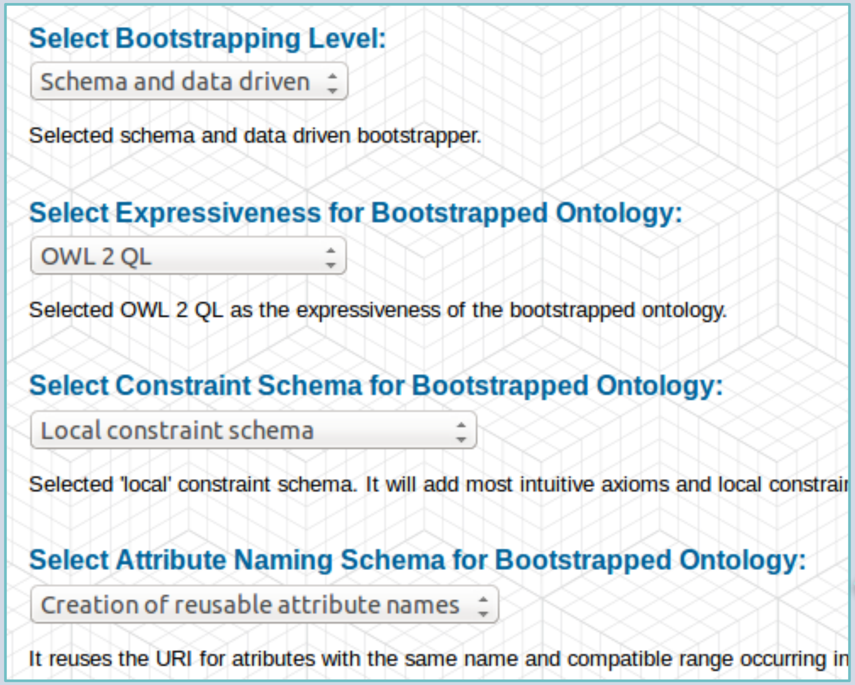
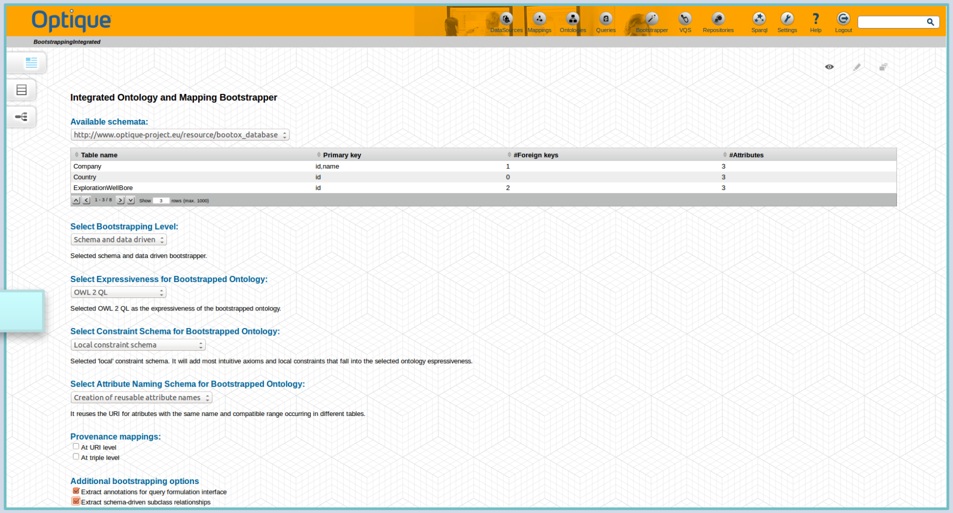
Data

BootOX







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Query Rewriting — Issues

1 Rewriting

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- Queries may be hard for existing DBMSs

2 Ontology & Mappings

- May be difficult to develop and maintain

3 Expressivity

- OWL 2 QL (necessarily) has (very) restricted expressive power, e.g.:
  - No functional or transitive properties
  - No universal (for-all) restrictions
  - …

OWL Profiles – Beyond QL?

OWL 2 (2009) defines language subsets, aka **profiles** that can be "more simply and/or efficiently implemented"

- **OWL 2 QL**
  - Based on DL-Lite
  - Efficiently implementable via rewriting into relational queries (OBDA)
- **OWL 2 RL**
  - Based on "**Description Logic Programs**" ($\approx$ DL $\cap$ Datalog)
  - Implementable via Datalog query answering
- **OWL 2 EL**
  - Based on $\mathcal{EL}^{++}$
  - Implementable via Datalog query answering plus "filtration"

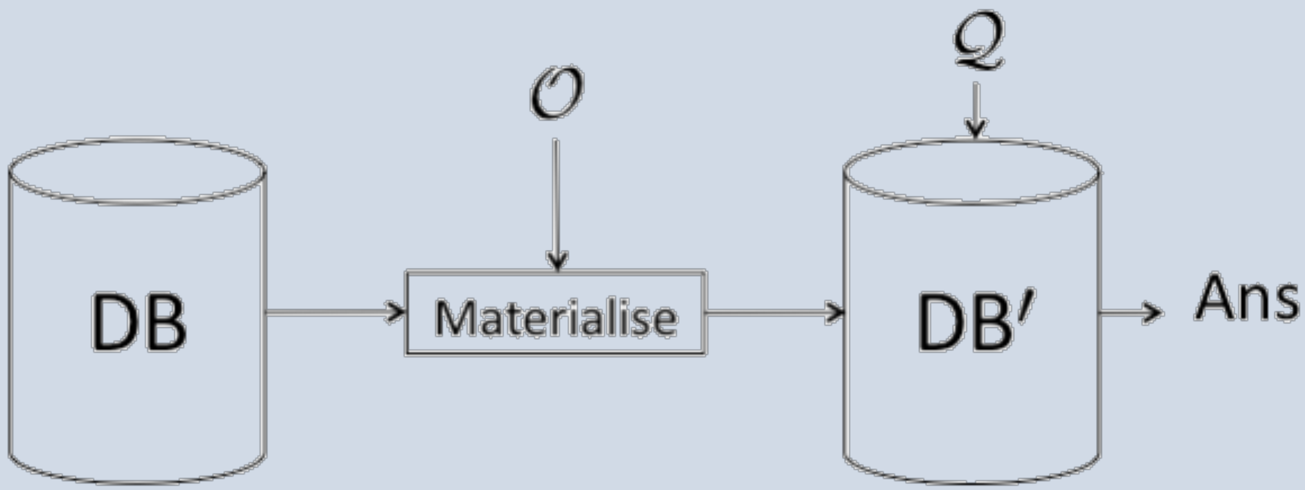
RL/Datalog Query Ans. via Materialisation

Given (RDF) data DB, RL/Datalog ontology $\mathcal{O}$ and query $\mathcal{Q}$:

- **Materialise** (RDF) data DB $\longrightarrow$ DB$'$ s.t. evaluating $\mathcal{Q}$ w.r.t. DB$'$ equivalent to answering $\mathcal{Q}$ w.r.t. DB and $\mathcal{O}$

  nb: Closely related to **chase** procedure used with DB dependencies

- **Evaluate** $\mathcal{Q}$ against DB$'$



Materialisation — Issues

1 Scalability

- Ptime complete
- Efficiently implementable in practice?

2 Updates

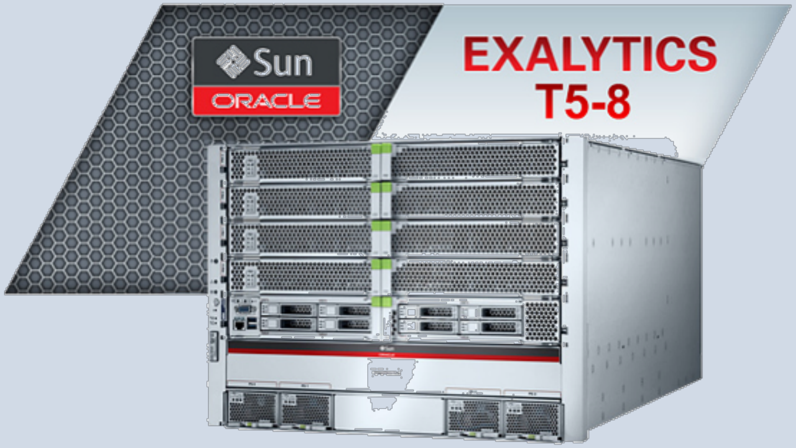
- Additions relatively easy (continue materialisation)
- But what about retraction?

Materialisation: Scalability

- Efficient **Datalog/RL** engine is critical
- Existing approaches mainly target distributed “shared-nothing” architectures, often via **map reduce**
  - High communication overhead
  - Typically focus on small fragments (e.g., RDFS), so don’t really address expressivity issue
  - Even then, query answering over (distributed) materialized data is non-trivial and may require considerable communication

RDFox Datalog/RL Engine

- Targets SOTA **main-memory, mulit-core** architecture
  - Optimized in-memory storage with ‘mostly’ lock-free parallel inserts
  - Memory efficient: commodity server with 128 GB can store $>10^9$ triples
  - Exploits multi-core architecture: 10-20 x speedup with 32/16 threads/cores
  - LUBM 120K ($>10^{10}$ triples) in 251s (20M t/s) on T5-8 (4TB/1024 threads)



RDFox Datalog/RL Engine

- **Incremental addition and retraction** of triples
  - Retraction via novel FBF “view maintenance” algorithm
  - Retraction of 5,000 triples from materialised LUBM 50k in less than 1s
- Many other **novel features**
  - Handles more general (than RL) Dalalog and SWRL rules
  - SPARQL features such as BIND and FILTER in rule bodies
  - Native equality handling (owl:sameAs) via rewriting
  - Stratified negation as failure (NAF)
  - …

Materialisation — Issues

1 Scalability

- Ptime complete
- Efficiently implementable in practice?

2 Updates

- Additions relatively easy (continue materialisation)
- But what about retraction?

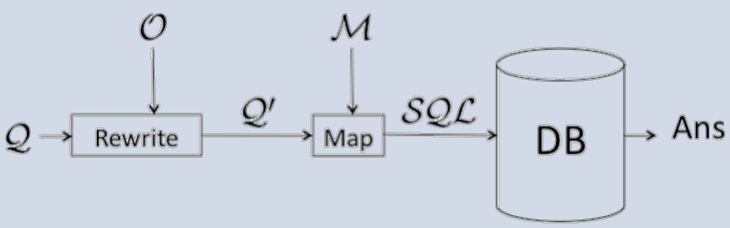
3 Migrating data to RDF

- Materialisation assumes data in “special” (RDF triple) store
- How can legacy data be migrated?

Materialisation: Data Migration

- Need to specify a suitable **migration** process
  - Use **R2RML** mappings to extract data and transform into RDF
  - But where do these mappings come from?

- Recall query rewriting:
  - **Mappings $\mathcal{M}$** *are* R2RML mappings
  - Run mappings **in reverse** to extract and transform data



- "**Lazy ETL**"
  - Deploy query rewriting (OBDA) system
  - Extend $\mathcal{O}$ and $\mathcal{M}$ as needed
  - Use $\mathcal{M}$ to ETL data into RDF store

Materialisation — Issues

1 Scalability

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4 Expressivity

- $\mathsf{QL} \not\subseteq \mathsf{RL}$; in particular, no RHS existentials (aka existential rules)

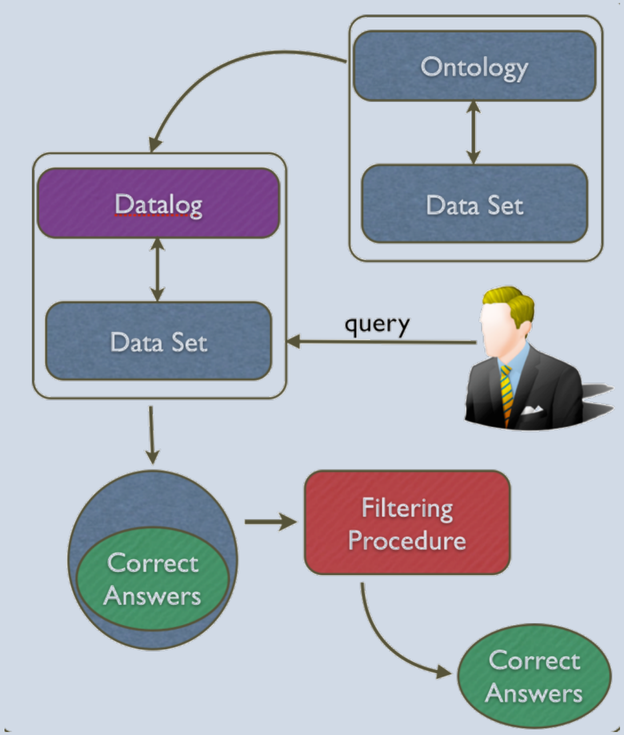
Materialisation: Expressivity

- RL is more powerful than QL, but $\mathsf{QL} \not\subseteq \mathsf{RL}$
  - In particular, no RHS existentials (aka existential rules)
  - Can't express, e.g., $\mathsf{OilPipeline} \sqsubseteq \mathsf{Pipeline} \sqcap \exists \mathsf{fromFacility}.\mathsf{OilFacility}$
- Recall **OWL 2 EL**
  - Based on $\mathcal{EL}^{++}$
  - Implementable via Datalog query answering plus "filtration"

OWL 2 EL via Datalog + Filtration

Given (RDF) Data Set, EL ontology $\mathcal{O}$ and query $\mathcal{Q}$:

- **Over-approximate** $\mathcal{O}$ into Datalog program D
- **Evaluate** $\mathcal{Q}$ over D + Data Set (e.g., via materialisation)
- Use (polynomial) **Filtering Procedure** to eliminate spurious answers



Discussion

- **QL-Rewriting** has many advantages
  - Data can be left untouched and in legacy storage
  - Exploits existing DB infrastructure and scalability
  - …
- But what if **more expressiveness/flexibility** is needed?
  - Query answering for EL and RL still tractable (polynomial)
  - Critically depend on Datalog scalability – RDFox to the rescue!
  - Easy migration path from QL-rewriting via “lazy ETL”

Future Work

- Piloting, evaluation and tuning
- Porting to other large-scale architectures
- Semantic (data) partitioning for distributed architectures
- (Incremental maintenance of) aggregations
- Improved query planning
- Stream reasoning
- Hybrid rewriting/materialisation (on demand) approach
- Expressiveness beyond RL/EL via PAGOdA techniques
- …

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SIXTH FRAMEWORK PROGRAMME

SEVENTH FRAMEWORK PROGRAMME

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欢迎提问！

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