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Ontology Based Data Access (OBDA)

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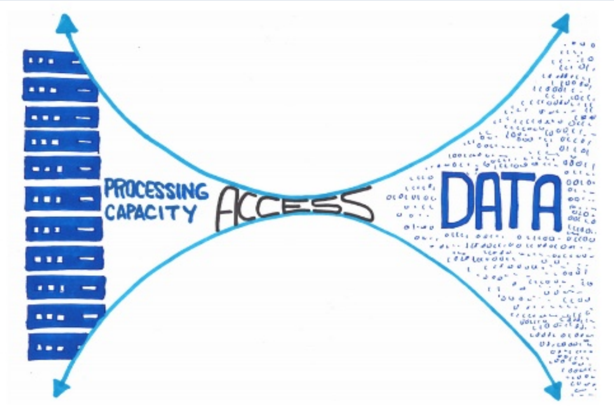
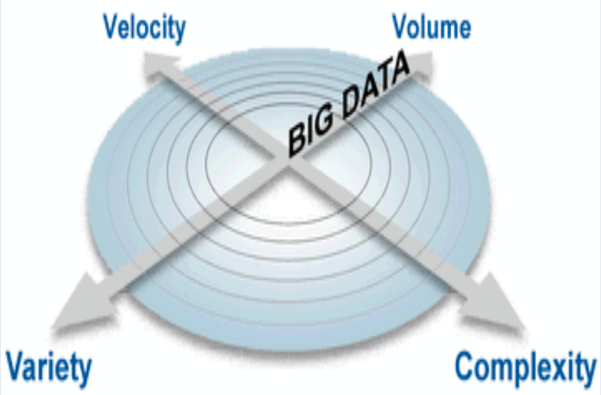
Motivation

- Huge **quantity** of data increasing at an exponential rate
- Identifying & accessing **relevant** data is of critical importance



- Handling data **variety & complexity** often turns out to be main challenge
- **Semantic Technology** can seamlessly integrate heterogeneous data sources



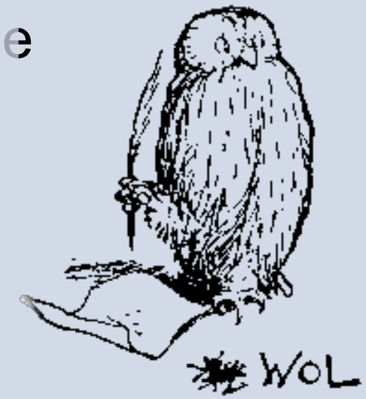
Semantic Technology

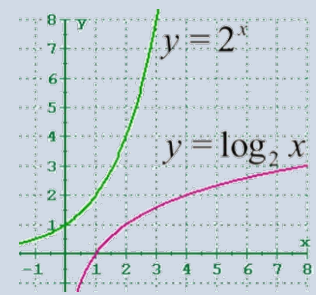
Rich **conceptual schemas** used to integrate heterogeneous sources

- **User Centric**
  - Schema modelled according to user intuitions
  - Independent of physical structure/storage of data
- **Declarative**
  - Improved understandability
  - Easier design, maintenance and evolution
- **Logic-based semantics**
  - Precise and formally specified meaning
  - Machine processable
- **Used at both design and query time**
  - Check validity and consequences of design
  - Easier query formulation and enriched query answers

Semantic Technology: Scalability Challenge

- Conceptual sche… …se OW… …ology language
- OWL based o… …cr… …gic S… …OIQ
  - ✔ Declarati…
  - ✔ Clear se… …ntic…
  - ✔ Well und… …too… …c… …ertie…
    (e.g., alg… …m… …d… …p… …exit…
  - ✗ N2ExpTim… …mplete co… …ined c… …y
  - ✗ NP-hard data… …plexity (-v- AC^0… …atabases)





How can we provide (empirically) scalable query answering?

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OWL Profiles

OWL 2 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)


Pipelines from oil facilities?

$$
\begin{aligned}
Q(?x) \leftarrow\ & (?x, \text{rdf:type}, \text{:Pipeline}) \wedge \\
& (?x, \text{:fromFacility}, ?y) \wedge \\
& (?y, \text{rdf:type}, \text{:OilFacility})
\end{aligned}
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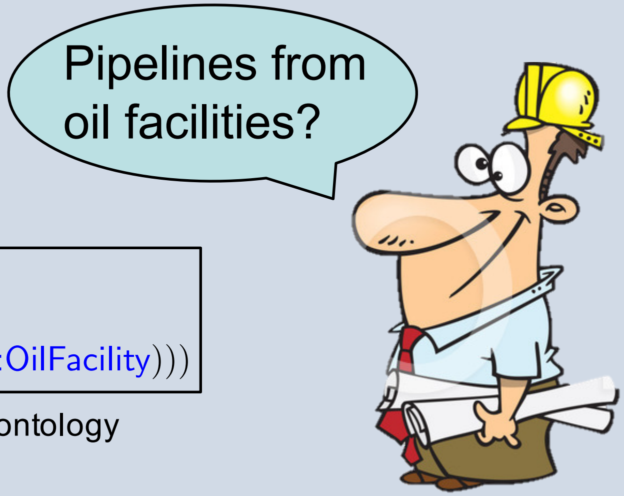

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Pipeline

ID	Oil	From
p1	N	f1
p2	Y	f2
p3	Y	Null

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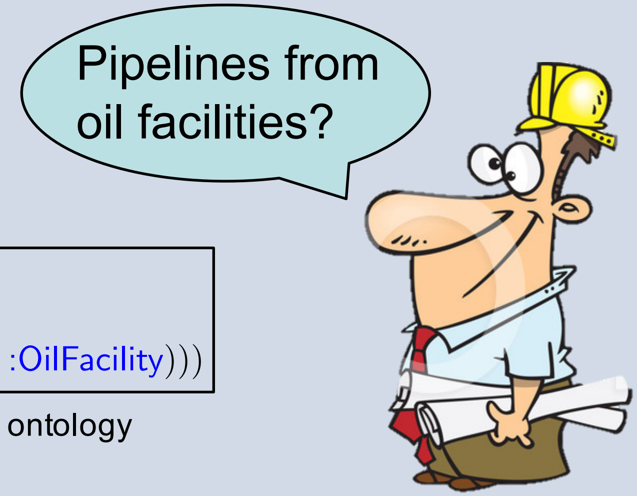

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$\vee\ (?x, \text{rdf:type}, \text{:OilPipeline})$

(R2RML) mappings

:OilPipeline = select ID from Pipeline
where Oil = "Y"
⋮

map

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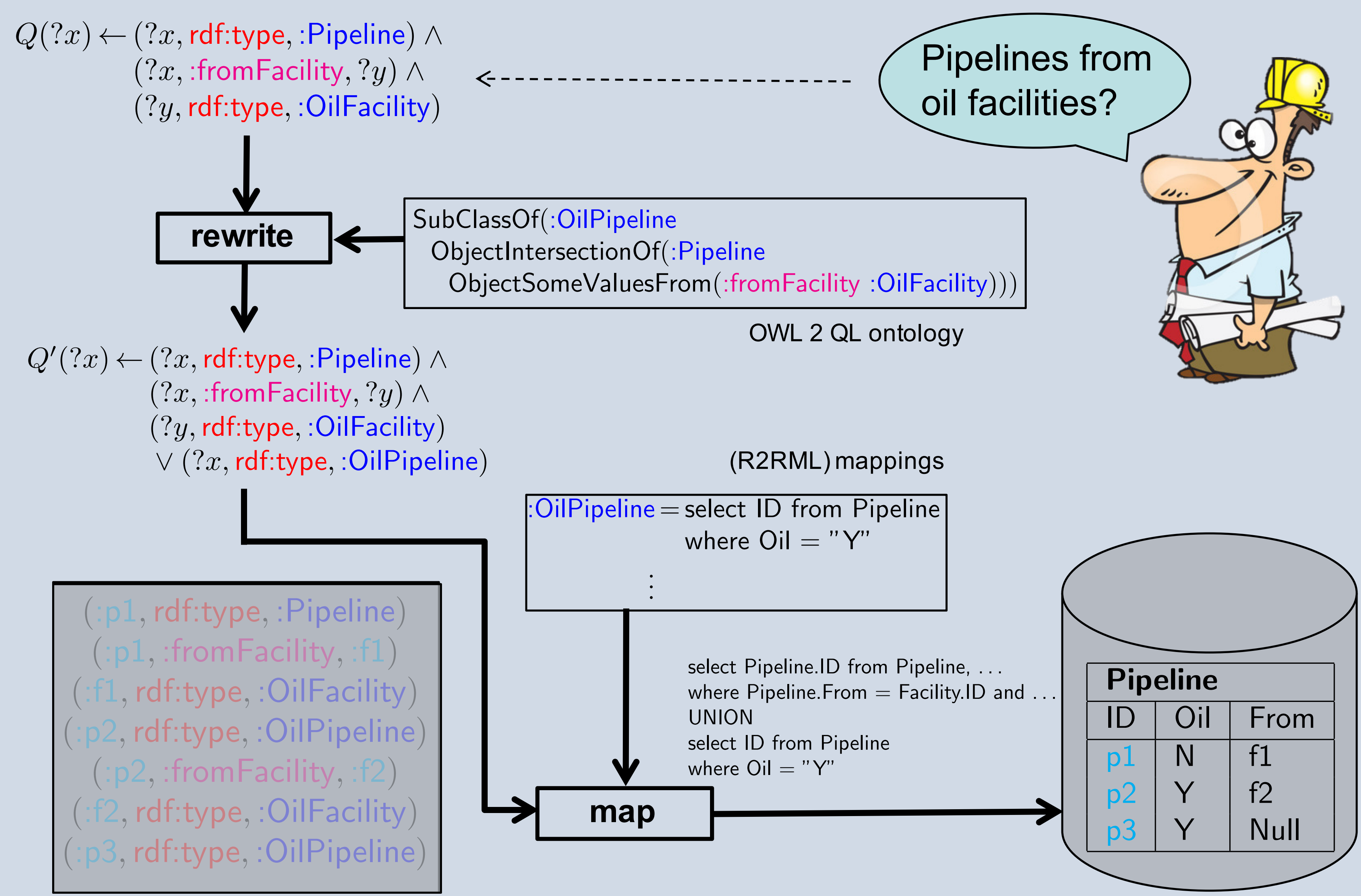

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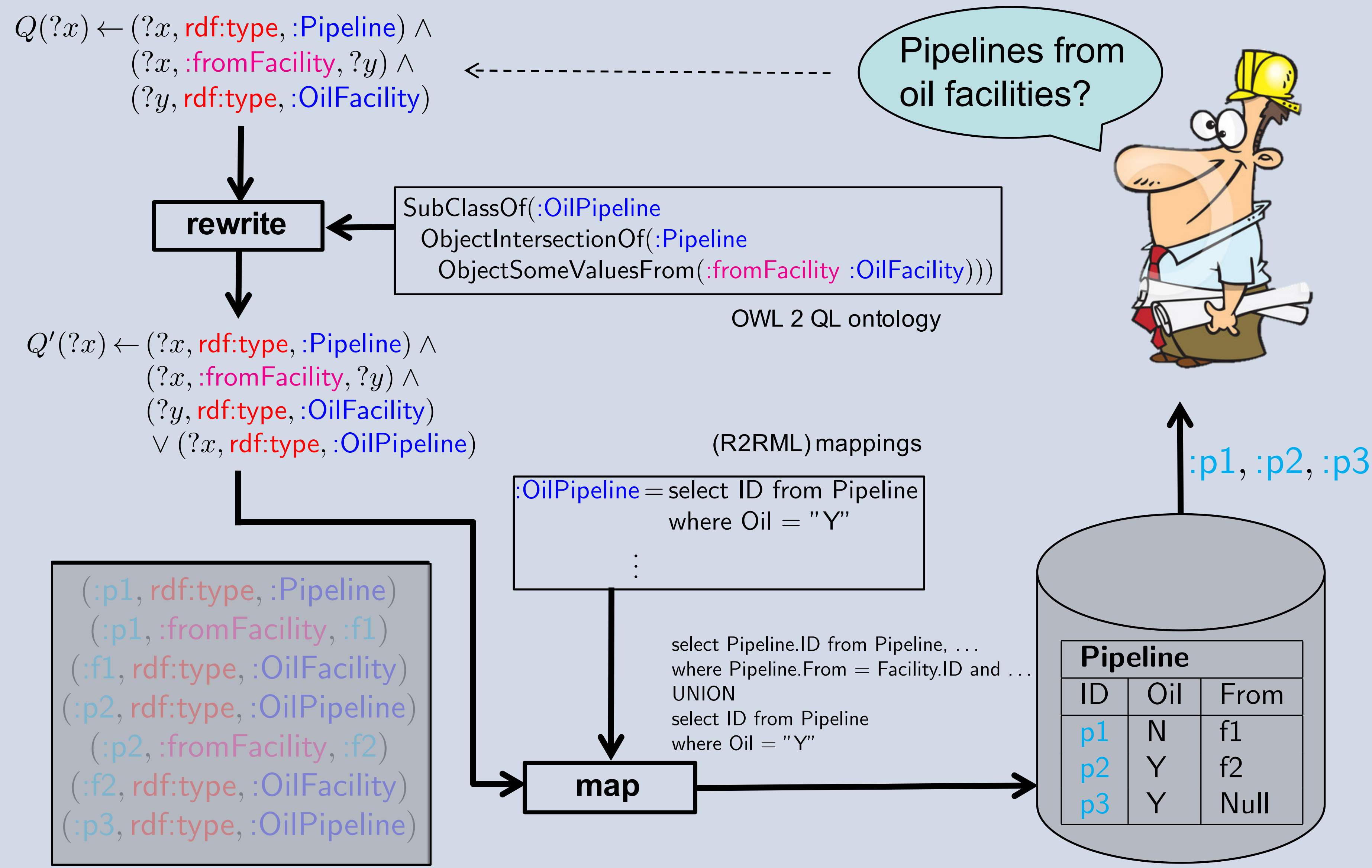

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OWL 2 QL and Query Rewriting

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

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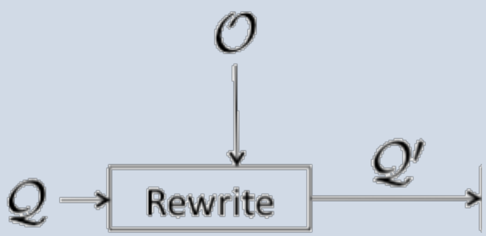
- Use $\mathcal{O}$ to **rewrite** $\mathcal{Q} \rightarrow \mathcal{Q}'$ s.t. answering $\mathcal{Q}'$ without $\mathcal{O}$ is equivalent to answering $\mathcal{Q}$ w.r.t. $\mathcal{O}$ *for any dataset*



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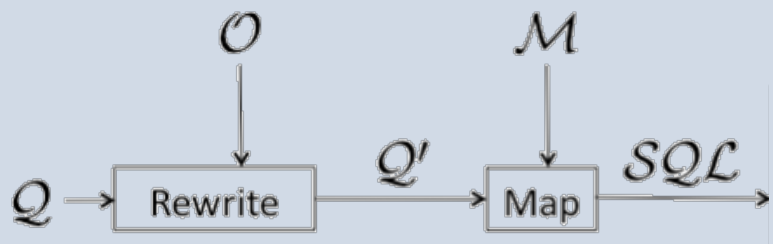

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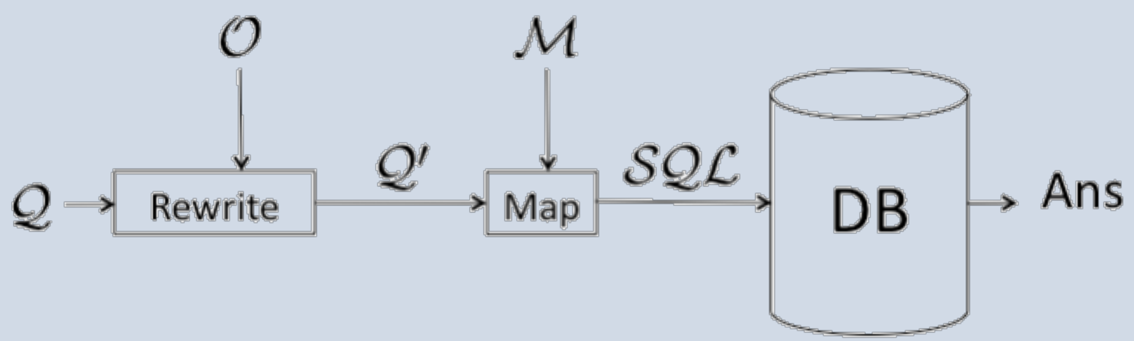
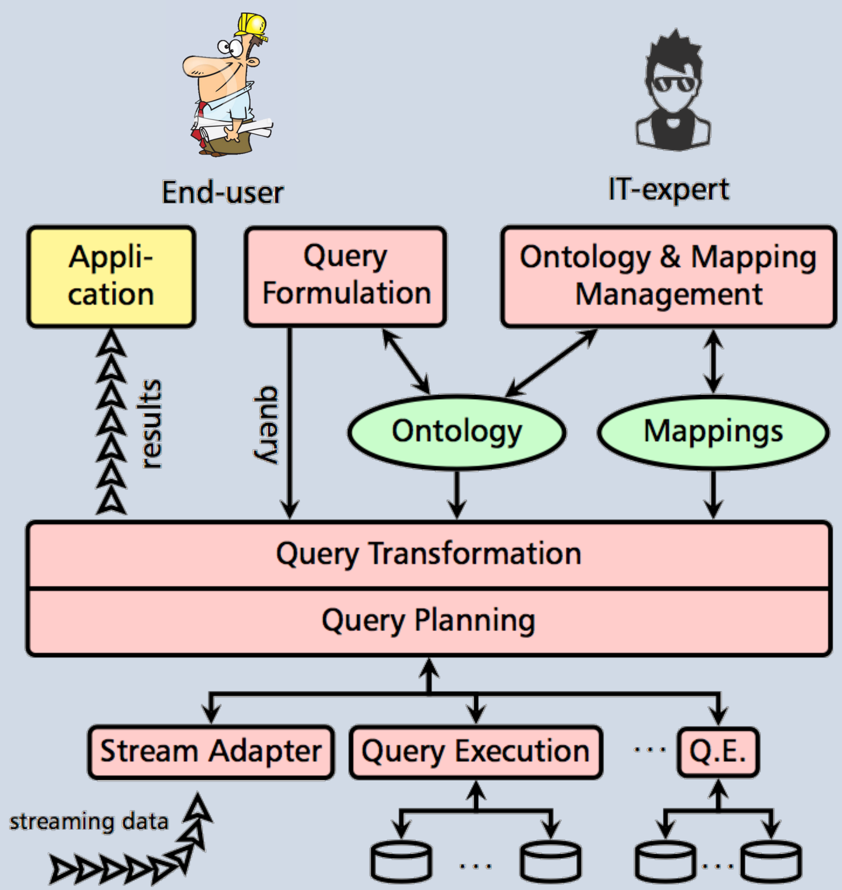
- **Evaluate** (SQL) query against DB



Optique Architecture



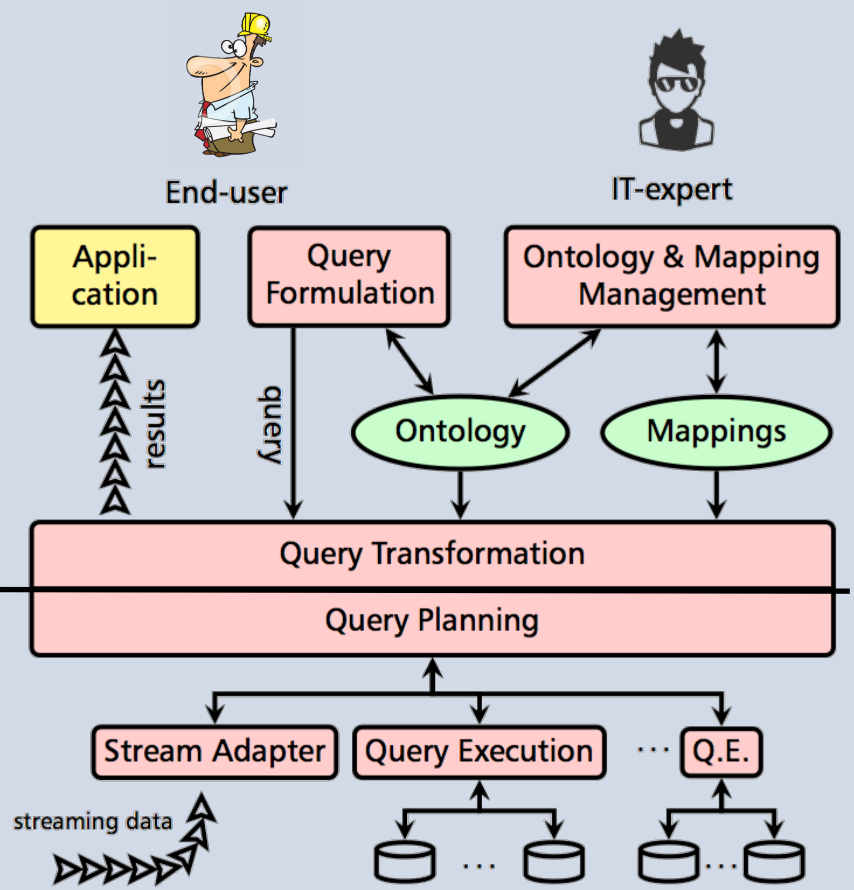
Optique Architecture

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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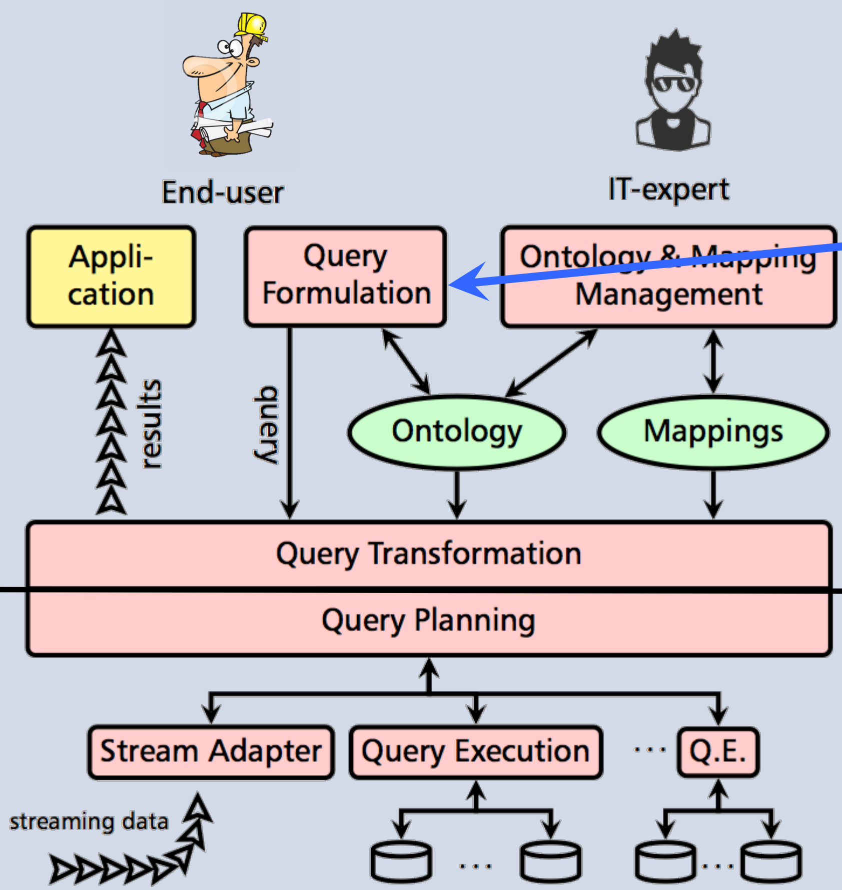

Other features:

support for query formulation

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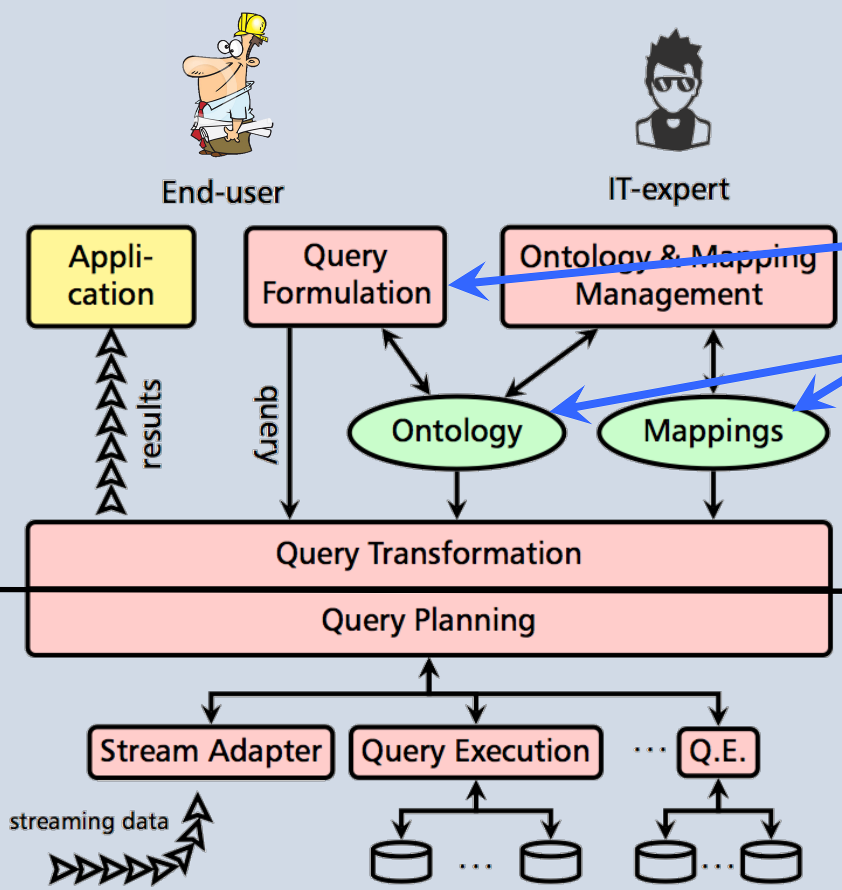

Other features:

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"Bootstrapping" Ontology & mappings

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Query Rewriting — Issues

1 Rewriting

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

2 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 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"

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RL/Datalog Query Ans. via Materialisation

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

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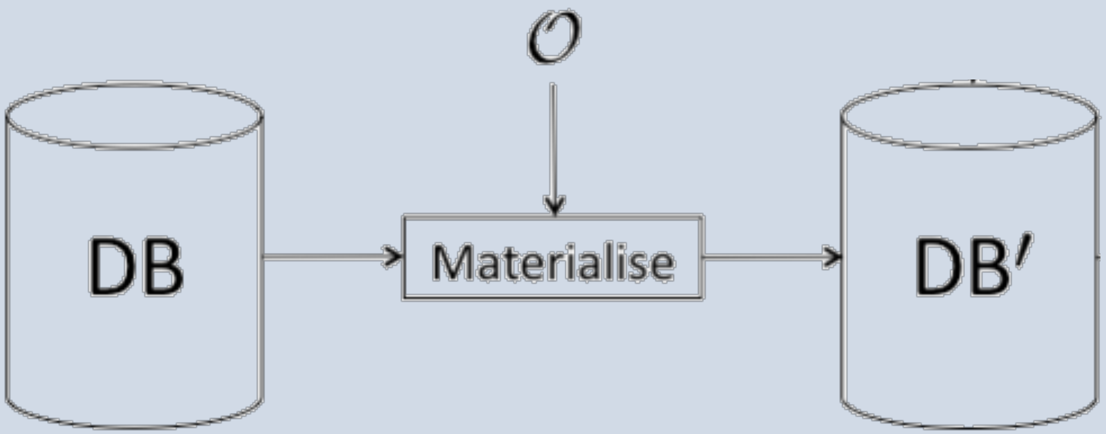
  nb: Closely related to **chase** procedure used with DB dependencies



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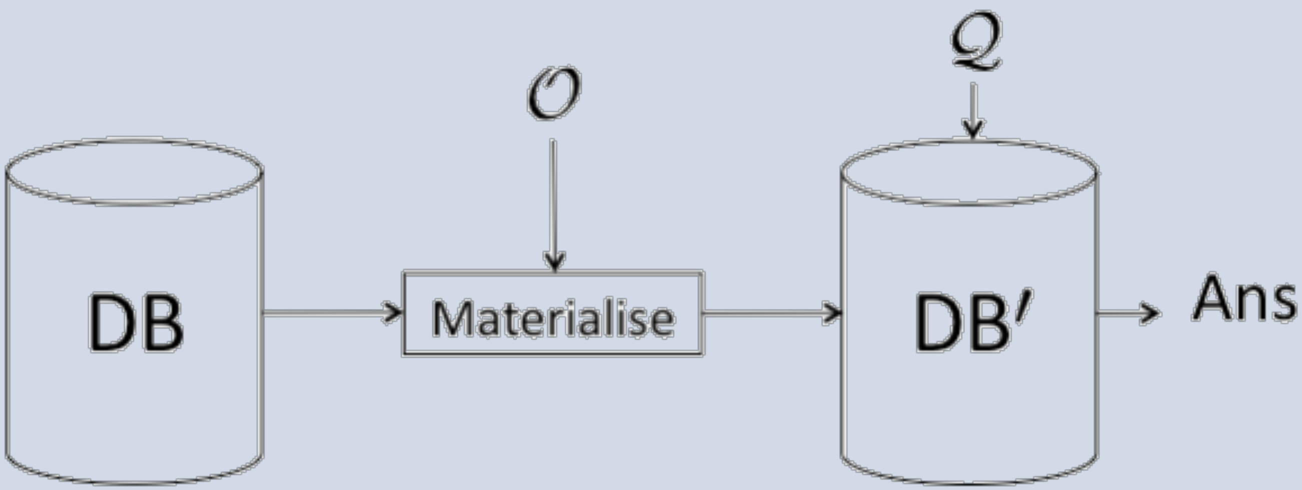
- **Evaluate** $\mathcal{Q}$ against DB$'$



Materialisation — Example

$$\mathcal{O}\left\{\ \mathsf{OilEquip} \sqsubseteq \forall \mathsf{hasPart}.\mathsf{OilEquip}\right.$$

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$\mathcal{Q}_1 \quad Q(x) \leftarrow \mathsf{OilEquip}(x)$

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$$\mathcal{Q}_1 \quad Q(x) \leftarrow \mathsf{OilEquip}(x)$$

Materialisation — Example

$\mathcal{O} \left\{ \mathsf{OilEquip} \sqsubseteq \forall \mathsf{hasPart}.\mathsf{OilEquip} \qquad \mathsf{OilEquip}(x) \wedge \mathsf{hasPart}(x, y) \rightarrow \mathsf{OilEquip}(y) \right.$

$$\mathsf{DB} \left\{ \begin{array}{l} \mathsf{OilEquip}(\mathsf{a}) \\ \mathsf{hasPart}(\mathsf{a}, \mathsf{b}) \\ \mathsf{hasPart}(\mathsf{b}, \mathsf{c}) \end{array} \right. \qquad \mathsf{DB}' \left\{ \begin{array}{l} \mathsf{OilEquip}(\mathsf{a}) \\ \mathsf{hasPart}(\mathsf{a}, \mathsf{b}) \\ \mathsf{hasPart}(\mathsf{b}, \mathsf{c}) \\ \mathsf{OilEquip}(\mathsf{b}) \\ \mathsf{OilEquip}(\mathsf{c}) \end{array} \right.$$

$\mathcal{Q}_1 \quad Q(x) \leftarrow \mathsf{OilEquip}(x) \qquad \rightsquigarrow \qquad \{a, b, c\}$

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?

4 Expressivity

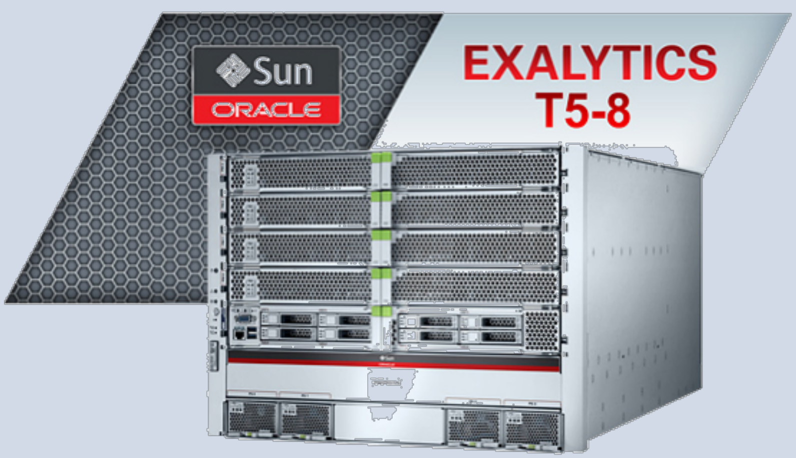
- $\mathcal{QL} \not\subseteq \mathcal{RL}$; in particular, no invention of new individuals

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 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)

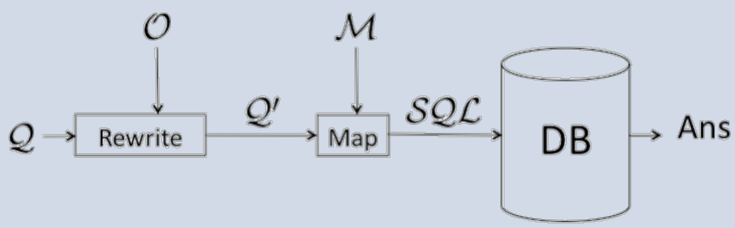


RDFox Datalog Engine

- **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: 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

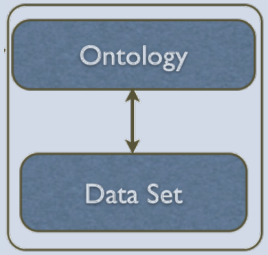
Materialisation: Expressivity

- RL is more powerful than QL, but QL $\not\subseteq$ RL
  - In particular, no "individual creation" (RHS existentials)
  - 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

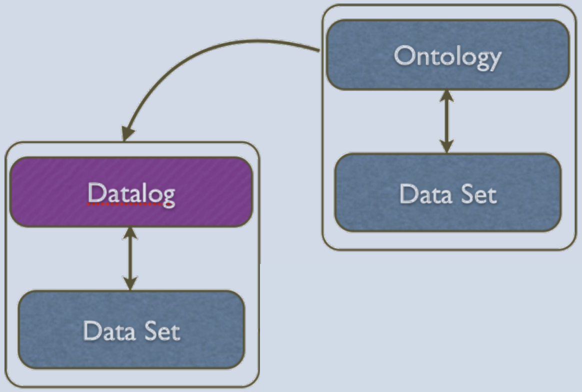
Given (RDF) Data Set, EL ontology $\mathcal{O}$ and query $\mathcal{Q}$:



OWL 2 EL via Datalog + Filtration

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

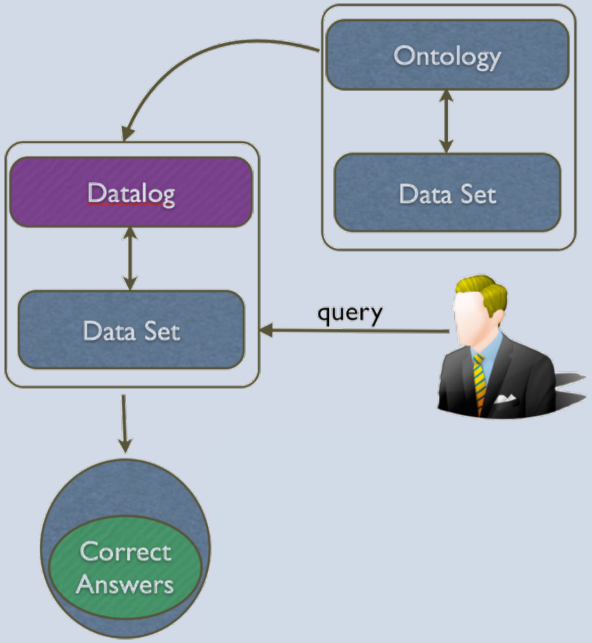
- **Over-approximate** $\mathcal{O}$ into Datalog program D



OWL 2 EL via Datalog + Filtration

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

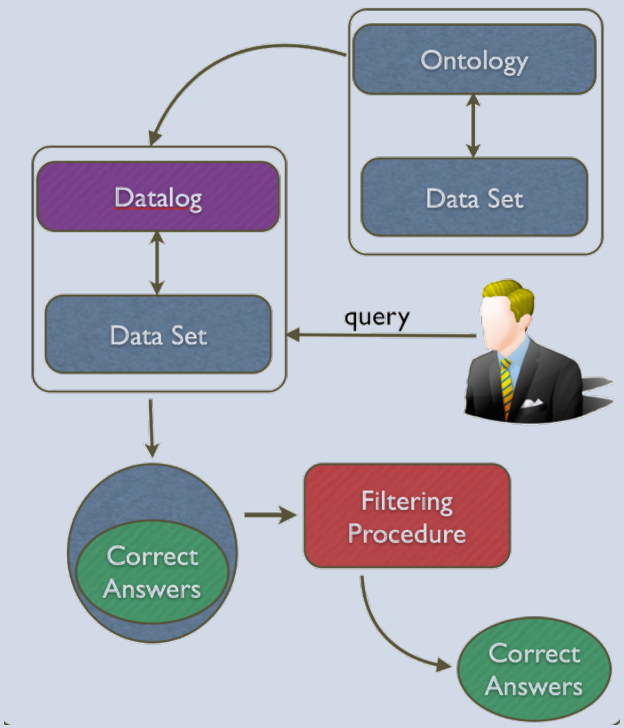
- **Over-approximate** $\mathcal{O}$ into Datalog program D
- **Evaluate** $\mathcal{Q}$ over D + Data Set (via materialisation)



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 (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
- …

Acknowledgements

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Thank you for listening

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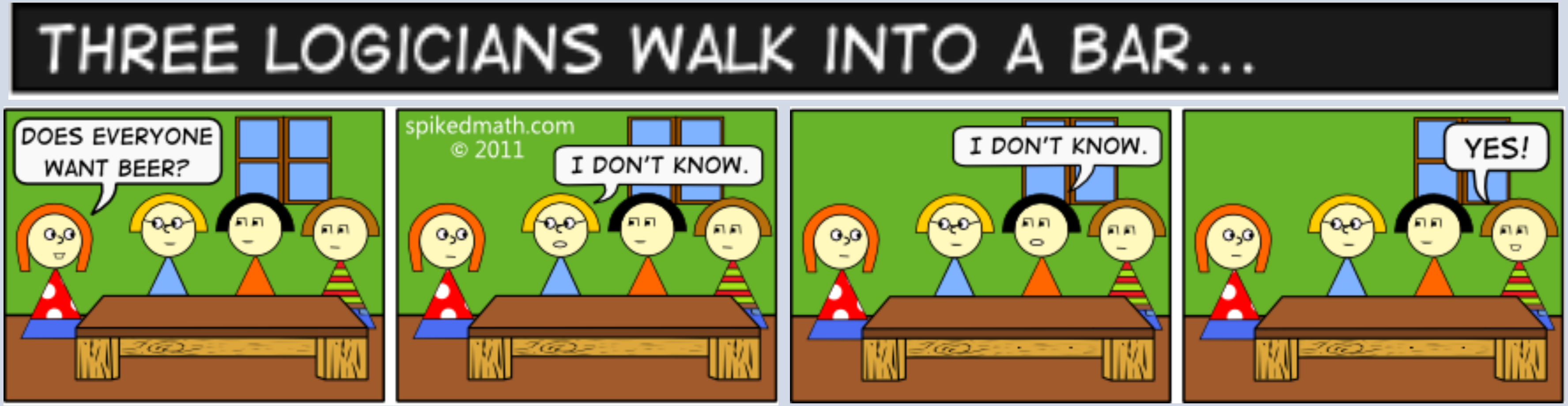

Any questions?

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