DEPARTMENT OF COMPUTER SCIENCE

UNIVERSITY OF OXFORD

Beyond DL-Lite: Big Data meets Heavy Ontologies

Ian Horrocks
Information Systems Group
Department of Computer Science
University of Oxford

Applications: HCLS

- **SNOMED-CT** (Clinical Terms) ontology
  - provides common vocabulary for recording clinical data
  - used in healthcare systems of more than 15 countries, including Australia, Canada, Denmark, Spain, Sweden and the UK
  - “classified and checked for equivalencies” using ontology reasoners
- **OBO foundry** includes more than 100 biological and biomedical ontologies
  - “continuous integration server running Elk and/or HermiT 24/7 checking that multiple independently developed ontologies are mutually consistent”

Focus is mainly on **schema reasoning**

OBDA: Motivational Example

- **Statoil** use data to inform production and exploration management
  - Large and complex data sets are difficult and time consuming to use

- Ontology Based Data Access (OBDA) can **improve access** to relevant data
  - Intuitive queries over ontology
  - Answers reflect data and knowledge

Focus is mainly on **query answering**

OBDA: Theory $\rightsquigarrow$ Practice

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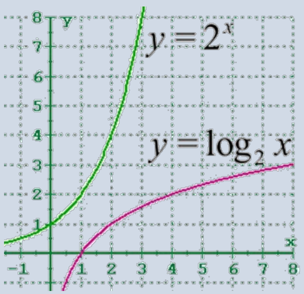
- Most ontologies use **OWL** ontology language
- OWL based on **description logic SROIQ**
  - ✔ Clear semantics
  - ✔ Well understood computational properties (e.g., decidability, complexity)
  - ✔ Simple goal directed reasoning algorithms
  - ✗ N2ExpTime-comlete combined complexity
  - ✗ NP-hard data complexity (-v- logspace for databases)



How can we provide (robustly) scalable query answering?

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
  - AC^0 data complexity (same as DBs)
- **OWL 2 EL**
  - Based on **EL^{++}**
  - PTime-complete for combined and data complexity
- **OWL 2 RL**
  - Based on "**Description Logic Programs**" ($\approx$ DL $\cap$ LP)
  - PTime-complete for combined and data complexity

OWL 2 QL and Query Rewriting

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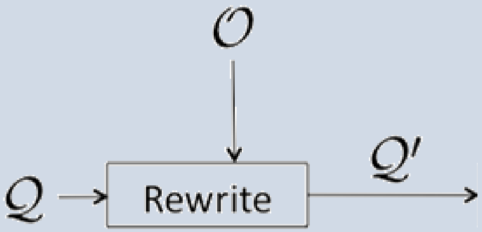

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$$\mathsf{OilPipeline} \sqsubseteq \mathsf{Pipeline} \sqcap \exists \mathsf{fromFacility}.\mathsf{OilFacility}$$

$$\begin{array}{c} \mathcal{O} \\ \downarrow \\ \mathcal{Q} \longrightarrow \boxed{\mathsf{Rewrite}} \xrightarrow{\mathcal{Q}'} \end{array}$$

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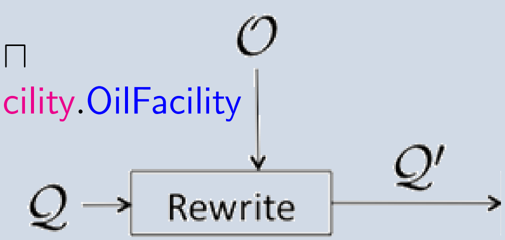

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- **Rewrite Q** → **Q⁰** s.t. answering **Q⁰** without **O** equivalent to answering **Q** w.r.t. **O** *for any dataset*
- **Map** ontology queries → DB queries (typically SQL) using mappings **M** to rewrite **Q**' into a DB query

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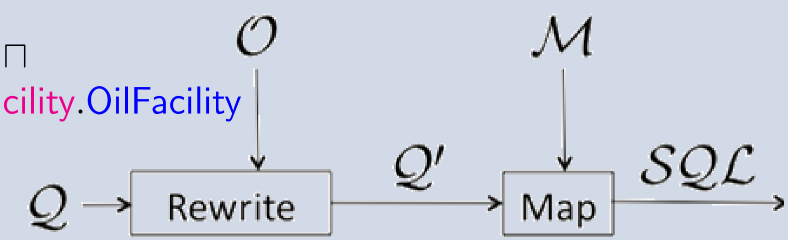

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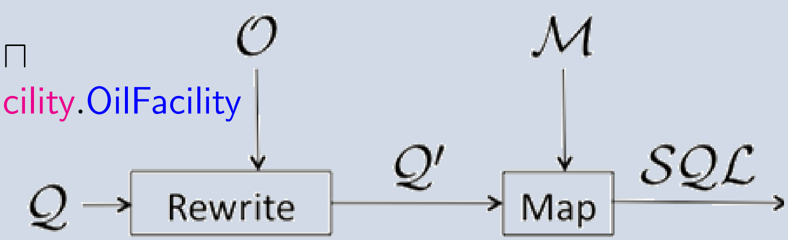

SELECT name FROM pipeline,fromfac,facility . . .
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- **Evaluate** (SQL) query against DB

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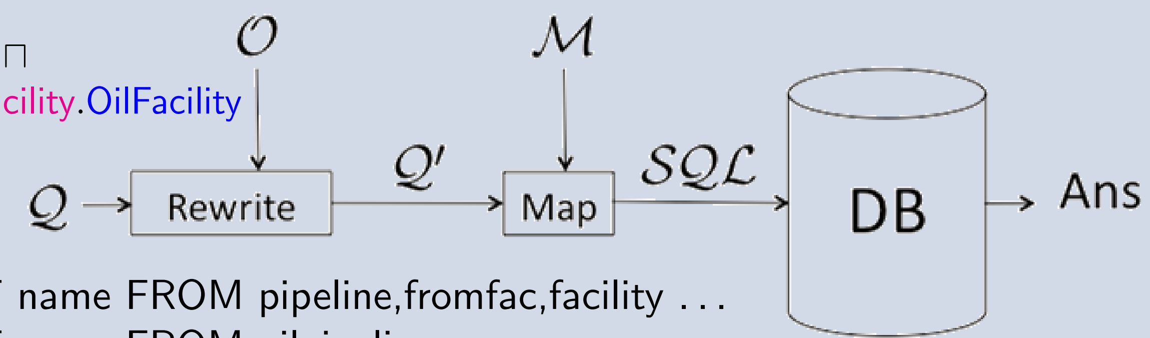

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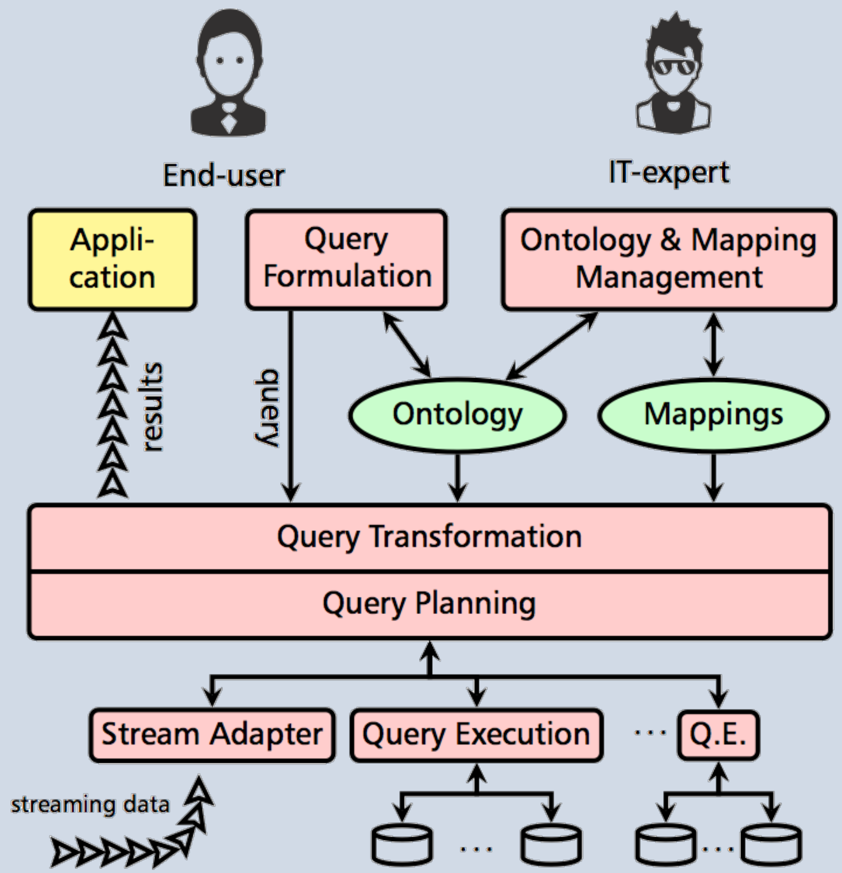
SEVENTH FRAMEWORK PROGRAMME

Optique Platform Architecture



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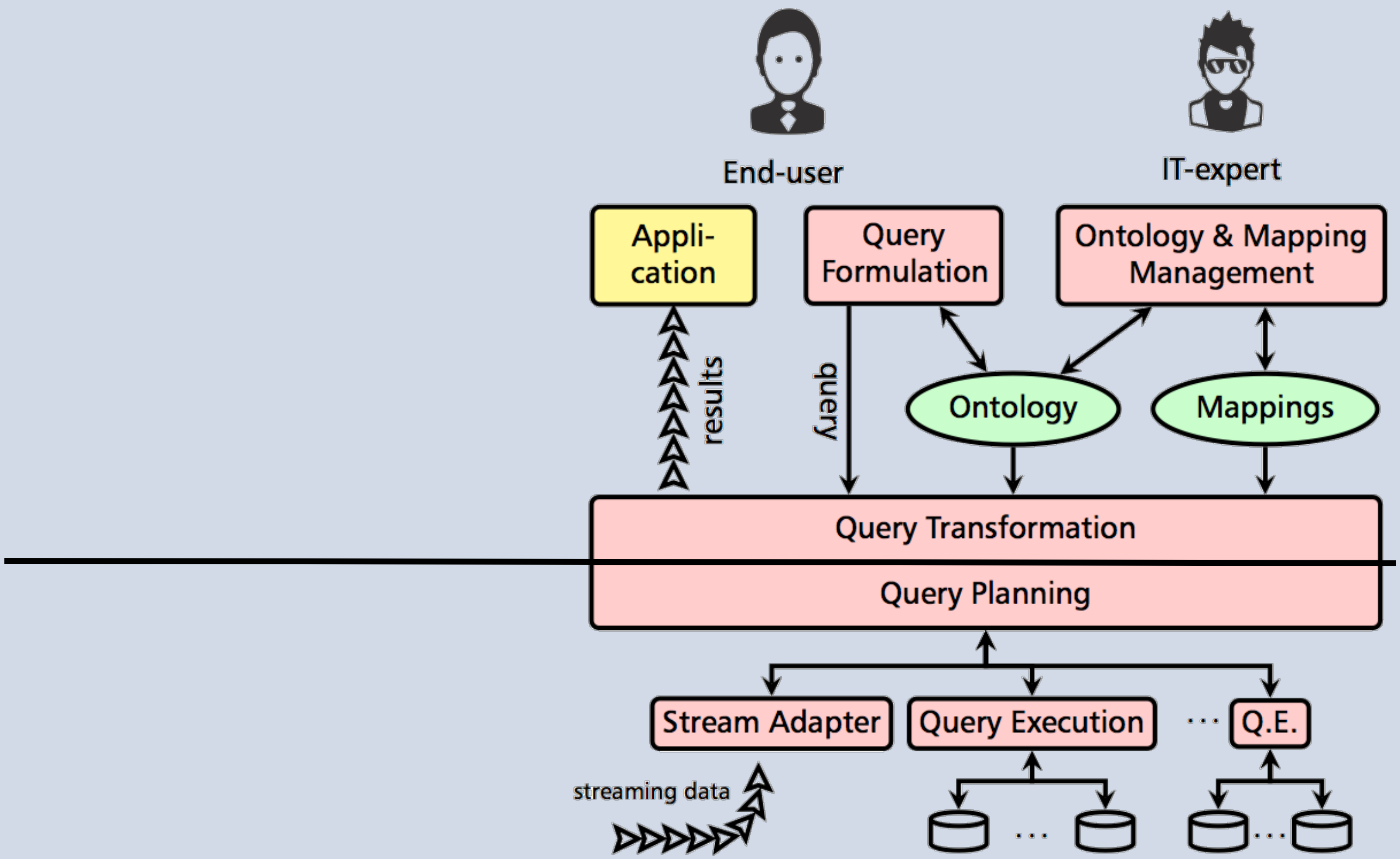
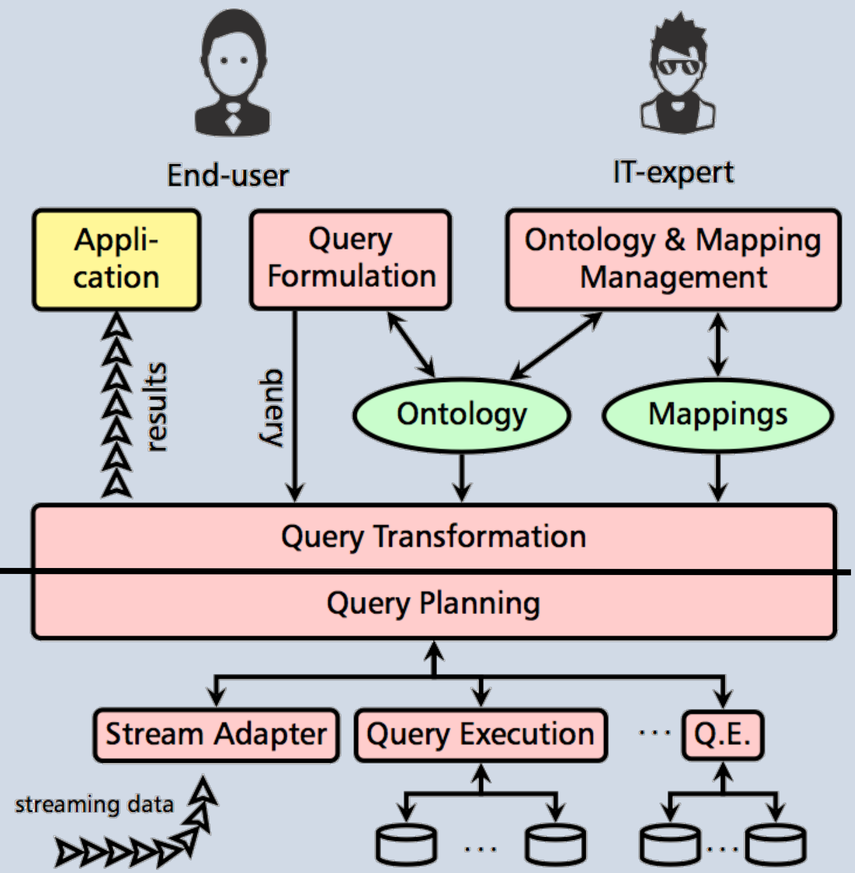


Optique Platform Architecture

Query rewriting:

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



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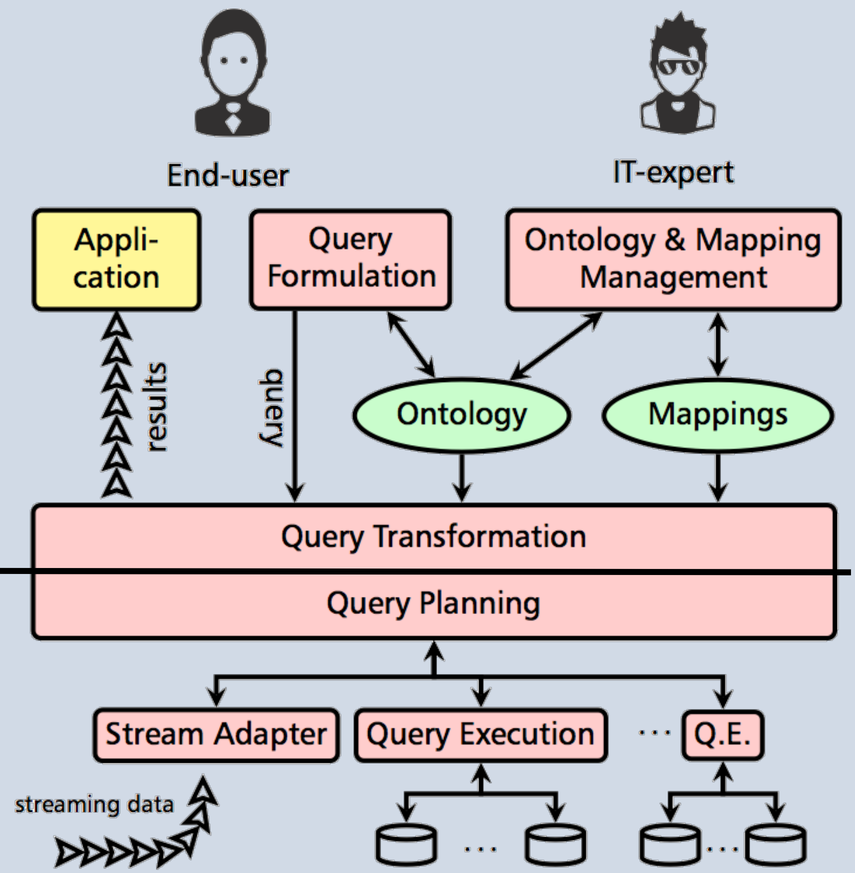
Query evaluation:

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



Query Rewriting — Issues

1 **Expressivity**

- QL (necessarily) has (very) restricted expressive power

2 **Rewriting**

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

3 **Mappings**

- May be difficult to develop and maintain
- Relatively little work in this area to date

OWL 2 EL and Combined Approach

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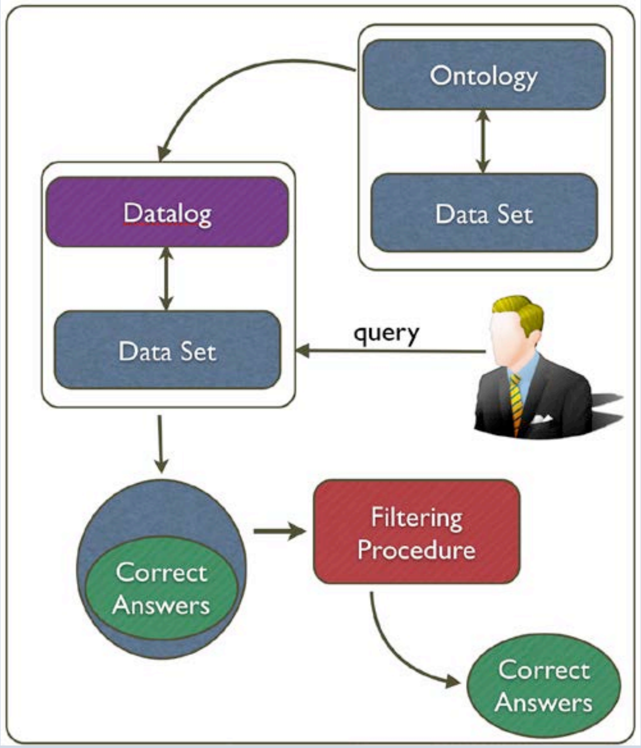

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Given (RDF) data DB, EL ontology O and query Q:

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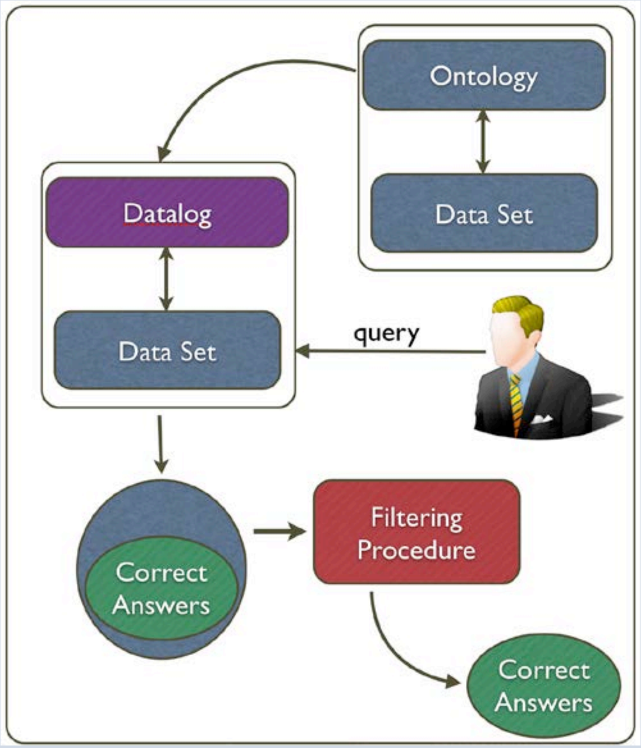

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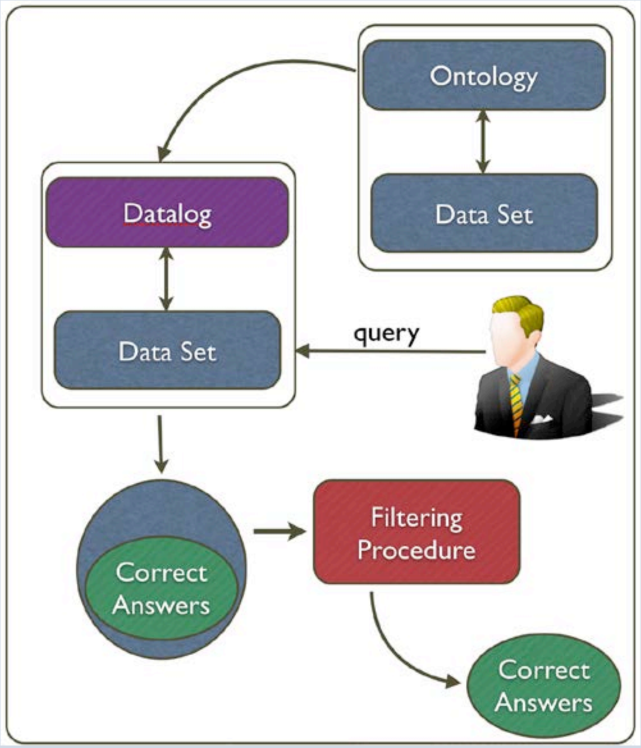
- **Evaluate** Q over D + DB
- **Filter** result to eliminate spurious answers



Combined Approach — Issues

1 **Expressiveness**

- OWL 2 EL still relatively weak
- Lacks, e.g., counting, inverse, negation, disjunction

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1. **Expressiveness**
   - OWL 2 EL still relatively weak
   - Lacks, e.g., counting, inverse, negation, disjunction
2. **Scalability**
   - Dependent on performance of Datalog engine and/or blowup in size of data

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Seventh Framework Programme

OWL 2 RL and Materialisation

Given (RDF) data DB, RL ontology **O** and query **Q**:

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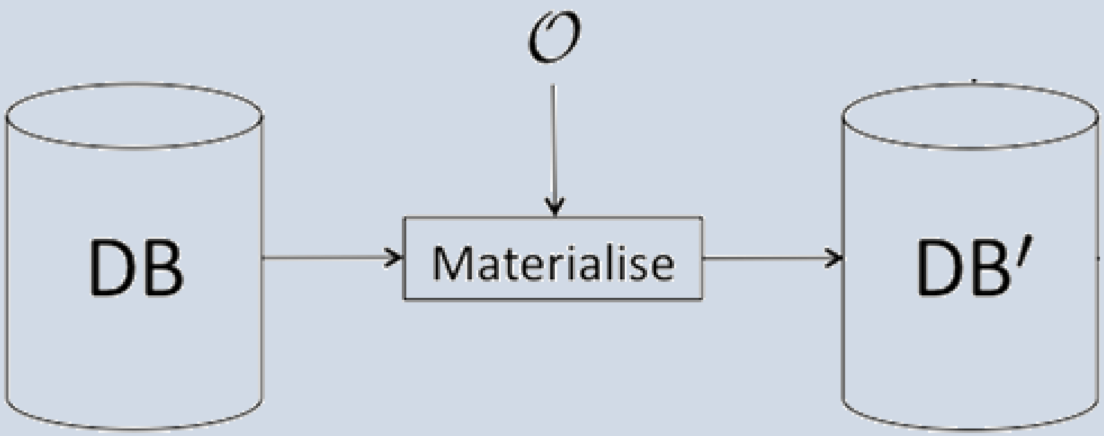
- **Materialise** (RDF) data DB $\rightarrow$ DB^0 s.t. evaluating Q w.r.t. DB^0 equivalent to answering Q w.r.t. DB and O

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



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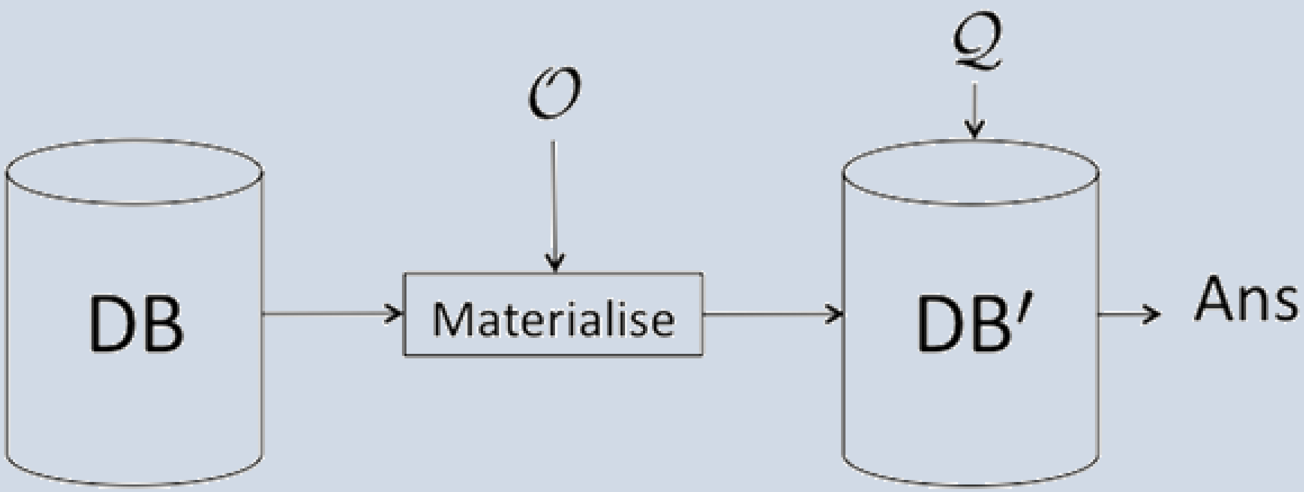
- **Evaluate** Q against DB^0



Materialisation — Example

$$\mathcal{O} \left\{ \begin{array}{r} \exists \mathsf{treats}.\mathsf{Patient} \sqsubseteq \mathsf{Doctor} \\ \mathsf{Consulatant} \sqsubseteq \mathsf{Doctor} \end{array} \right.$$

$$\mathrm{DB} \left\{ \begin{array}{l} \mathsf{treats}(d_1, p_1) \\ \mathsf{Patient}(p_1) \\ \mathsf{Doctor}(d_2) \\ \mathsf{Consultant}(c_1) \end{array} \right.$$

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Materialisation — Issues

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- Dependent on performance of Datalog engine

Scalability: RDFox Datalog Engine

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  - high communication overhead
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Scalability: RDFox Datalog Engine

- Efficient **Datalog/RL** engine critical for both RL and EL
- Existing approaches mainly focus on **map reduce**
  - high communication overhead
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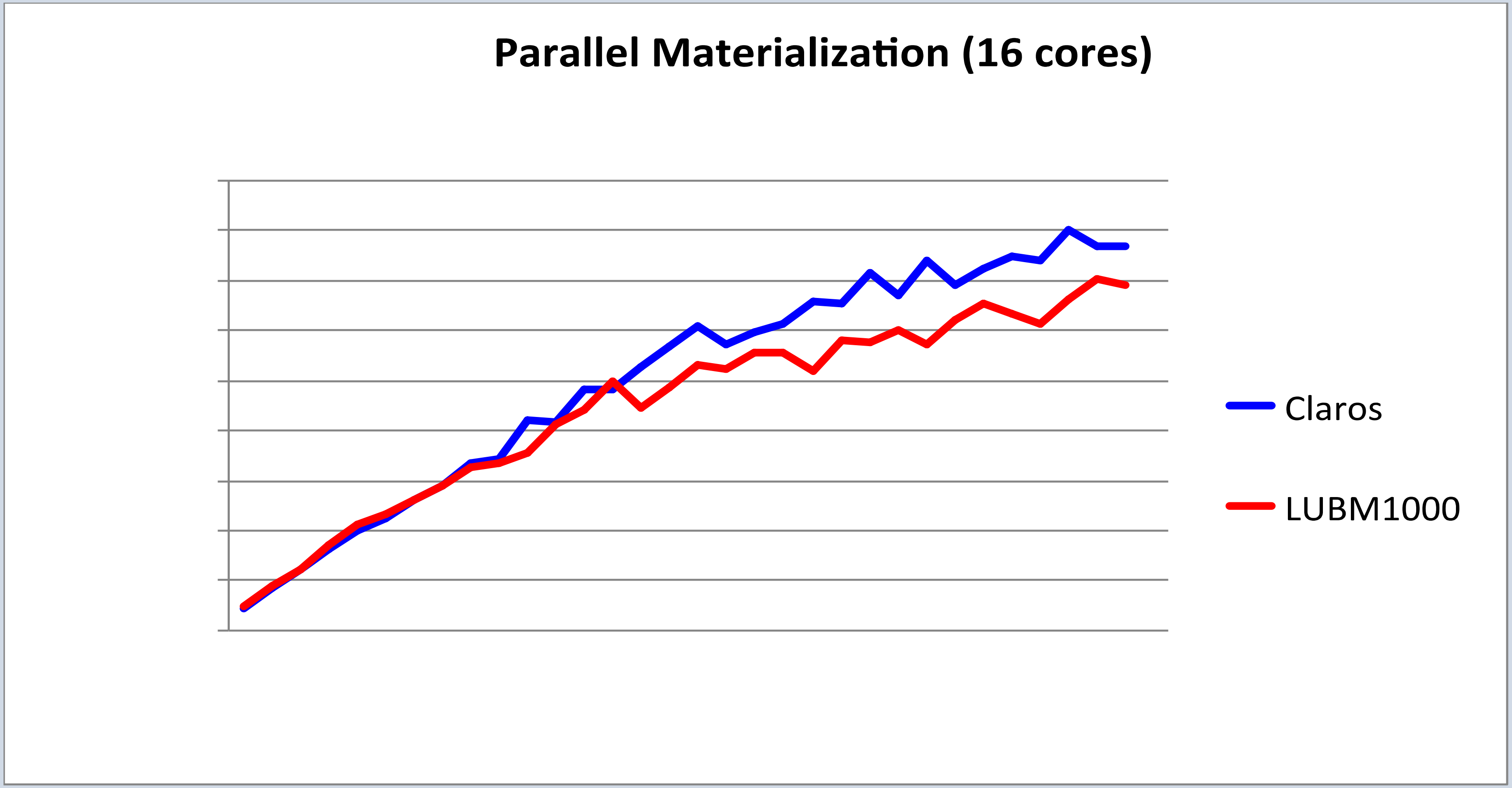
- **RDFox** is a new Datalog/RL engine with novel features
  - parallel materialization with fine-grained load balancing
  - highly optimized in-memory data storage with ‘mostly’ lock-free parallel inserts
  - £4,000 desktop with 128 GB can store around 2×10^9 triples

Scalability: RDFox Datalog Engine

	Claros	LUBM1000-UB
Memory Usage		
Base Triples	19M	134M
Base Mem	1GB	9GB
Mat. Triples	96M	333M
Mat. Mem	5GB	16GB
Time (16 cores)		
1 thread	2274s	942s
16 thread	180s	96s
32 thread	132s	66s

Scalability: RDFox Datalog Engine



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Expressiveness: Chase Materialisation

- Applicable to **acyclic** ontologies
  - Acyclicity can be checked using, e.g., graph based techniques (weak acyclicity, joint acyclicity, etc.)
  - Many realistic ontologies turn out to be acyclic
- Given acyclic ontology **O**, can apply chase materialisation:
  - Ontology translated into existential rules (aka dependencies)
  - Existential rules can introduce fresh Skolem individuals
  - Termination guaranteed for acyclic ontologies

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  - Transform ontology into Datalog$^{\pm,\vee}$ rules
  - Eliminate $\vee$ by transforming to $\wedge$
  - Eliminate existentials by replacing with Skolem constants
  - Discard rules with empty heads (assuming **O** satisfiable)
  - Transform rules into OWL 2 RL ontology $\mathbf{O}^{\mathbf{0}}$

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- Datalog/RL reasoning w.r.t. $\mathbf{O}^{\mathbf{0}}$ gives upper bound answer ***U***

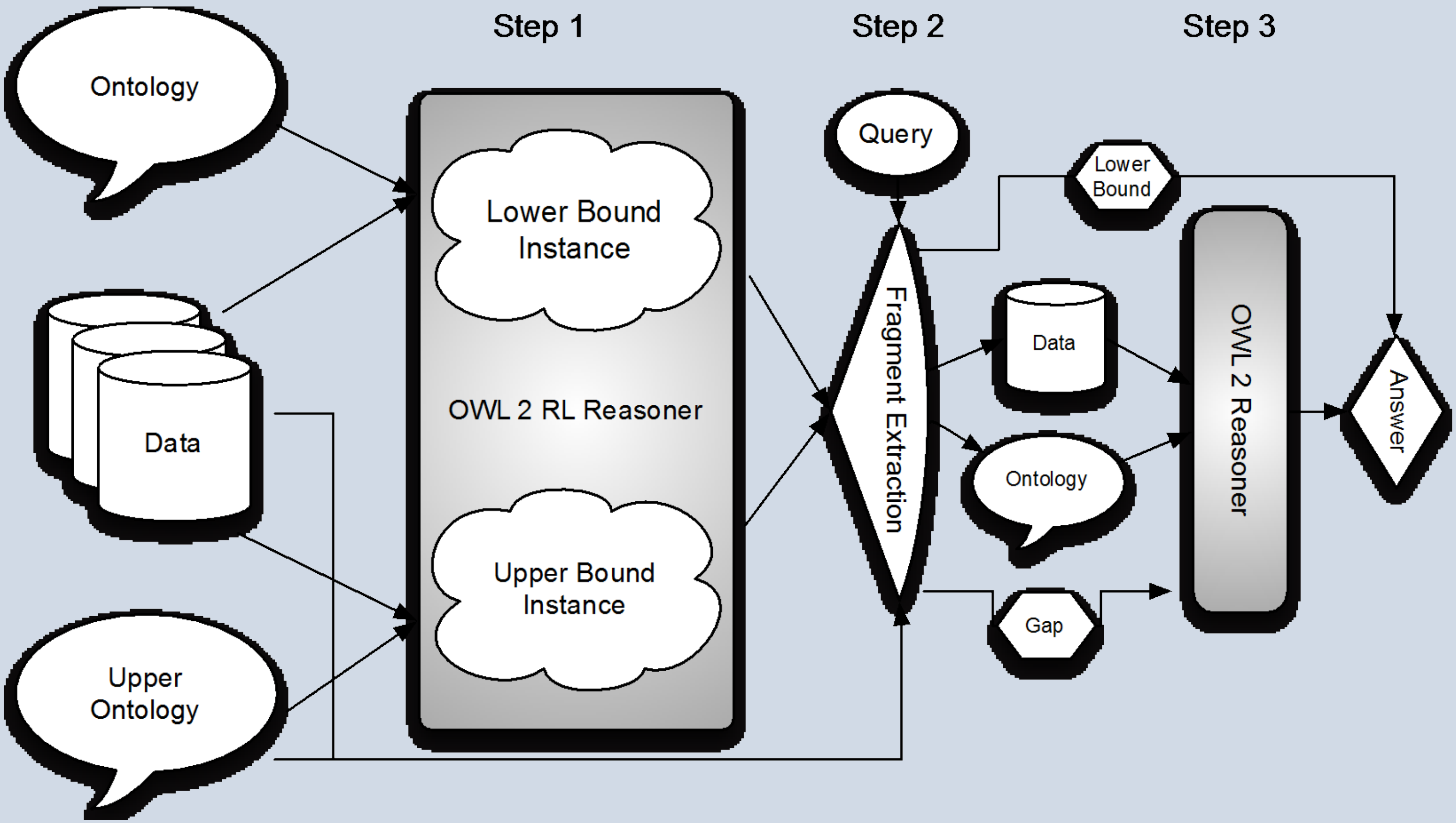
Expressiveness: Lower and Upper Bounds

- If ***L*** = ***U***, then both answers are sound and complete

Expressiveness: Lower and Upper Bounds

- If $L = U$, then both answers are sound and complete
- If $L \neq U$, then $U \setminus L$ identifies a (small) set of "possible" answers
  - Delineates range of uncertainty
  - Can more efficiently check possible answers using, e.g., HermiT (but still infeasible if dataset is large)
  - Can use $U \setminus L$ to identify small(er) "relevant" subset of axioms/data needed to check possible answers

Expressiveness: Lower and Upper Bounds



Performance on LUBM 40

time to extract the fragment

Time to check all tuples in U\L by an OWL 2 reasoner using the fragment

triples in the query

Query	$\lvert V \rvert$	n	$\lvert G \rvert$	t_f	$\lvert \mathcal{O}_f \rvert$	$\lvert \mathcal{D}_f \rvert$	t_{check}	t_{total}
M_1	2	3	39	36.4	6	29041	H: 23.3	H: 60.7
M_2	3	4	1	37.1	6	29004	H: 4.0	H: 42.1
M_3	4	6	16	38.2	6	29054	H: 8.4	H: 47.6
M_4	2	3	30	36.0	6	29032	H: 23.3	H: 60.2
M_5	3	4	4	39.4	6	29010	H: 24.0	H: 64.3
M_6	4	6	29	2,845.8	10	87209	H: 483.0	H: 3339.4
M_7	3	5	15	38.0	6	29033	H: 10.3	H: 49.3
M_8	3	5	14	39.3	6	29038	H: 11.9	H: 52.2
M_9	3	4	10	328.9	12	86785	H: 556.2	H: 886.7
S	1	2	39	310.0	12	86802	H: 1,780.0 P: 16,592.1	H: 2,126.5 P: 16,870.0

answers in the gap U\L

variables in the query

total time to compute answers for the query

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Performance on Fly

Query	$\lvert V\rvert$	n	$\lvert G\rvert$	t_f	$\lvert \mathcal{O}_f\rvert$	$\lvert \mathcal{D}_f\rvert$	t_{check} (H)	t_{total}	t_{HermiT}
Q_1	2	3	803	108.9	224	4515	45.9	155.2	3,465.9
Q_2	3	5	342	97.7	224	4054	16.0	114.0	3,179.0
Q_3	1	1	28	91.0	217	3712	0.9	92.3	5,863.3
Q_4	2	3	25	94.3	233	3762	4.7	99.2	2,944.3
Q_5	2	2	518	100.3	222	3712	24.0	124.6	3,243.7

Time to check all tuples in U\L by an OWL 2 reasoner using the original ontology

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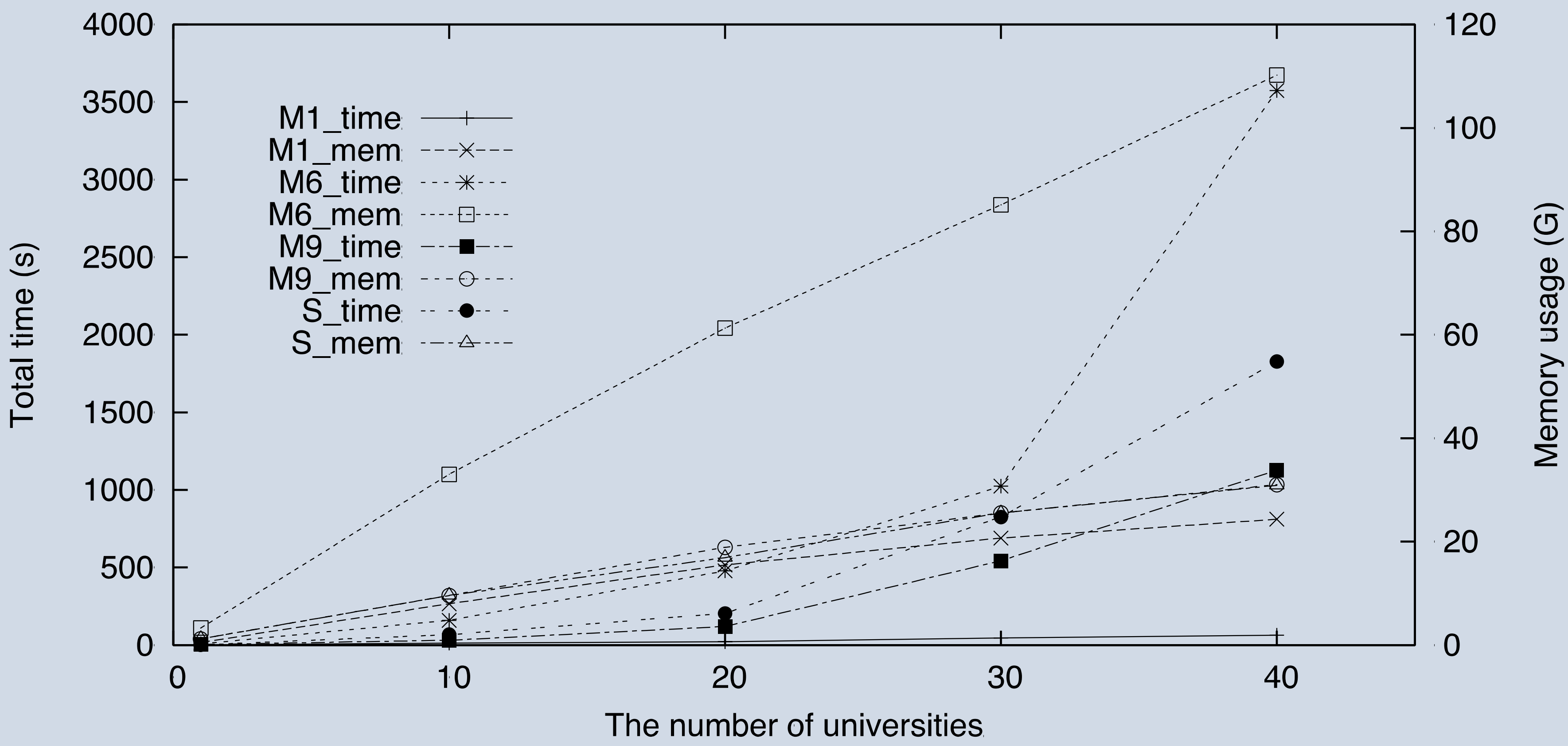
Scalability on LUBM



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Future Work

- Tighten lower and upper bounds
- Use Datalog reasoner to compute relevant subsets
- Hybrid approaches, e.g., exploiting ELHO filtering

Discussion

- QL-Rewriting has many advantages
  - Data can be left untouched and in legacy storage
  - Exploits existing DB infrastructure and scalability
  - …

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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 is needed?
  - Query answering for EL and RL still tractable (polynomial)
  - Critically depend on Datalog scalability – RDFox to the rescue!
  - Chase and LB/UB techniques offer potential for empirical scalability beyond EL and RL fragments

Acknowledgements

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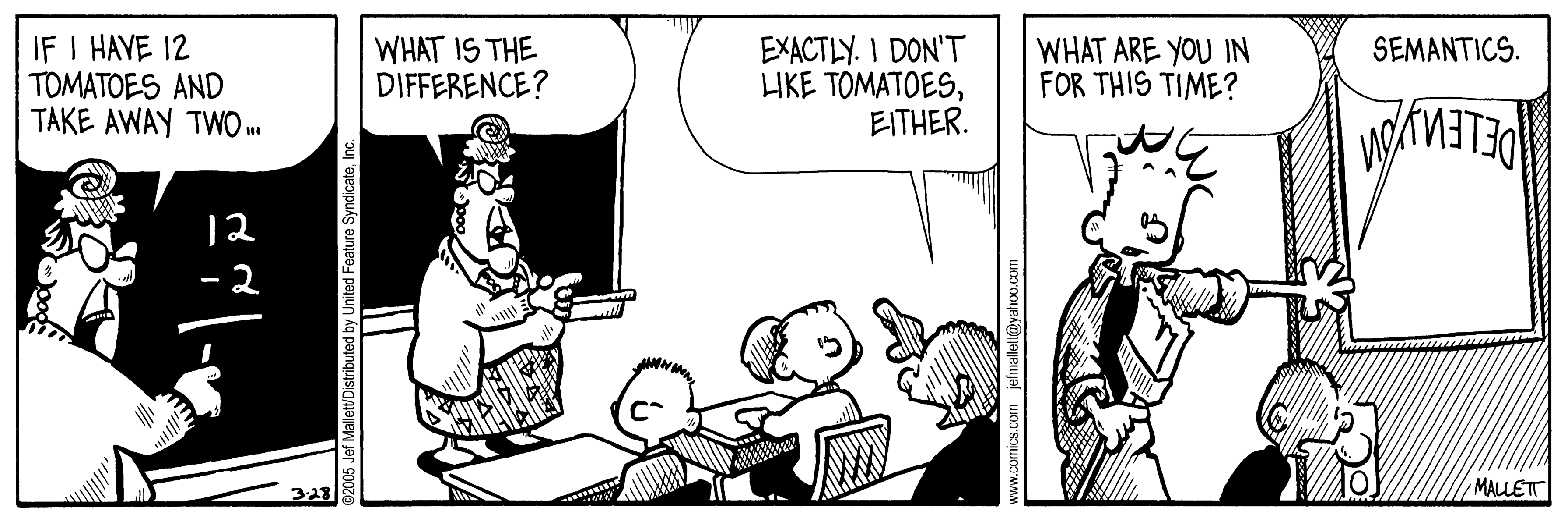
Thank you for listening



Any questions?