

Extending NoHR for OWL 2 QL

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Motivation: OWA vs. CWA

- ▶ Open World Assumption (OWA)
 - ▶ Model taxonomic knowledge
 - ▶ Ontologies (in Description Logics (DL), such as \mathcal{EL} , $DL-Lite_R$)
 - ▶ Example: results of clinical tests
- ▶ Closed World Assumption (CWA)
 - ▶ Model defaults and exceptions
 - ▶ Non-monotonic rules well-suited
 - ▶ Example: patient's medication

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Requirements for Integration

1. Flexible framework

- ▶ Expressive language, yet simple to use
- ▶ Full two-way interaction between ontologies and rules
- ▶ As little restrictions as possible

2. Low complexity

- ▶ Large amount of data (on the Web; in applications, e.g., patient records)
- ▶ Interactive response time on reasoning

3. Top-down querying

- ▶ Avoid up-front computation of the entire model
- ▶ Restrict computation to the relevant part

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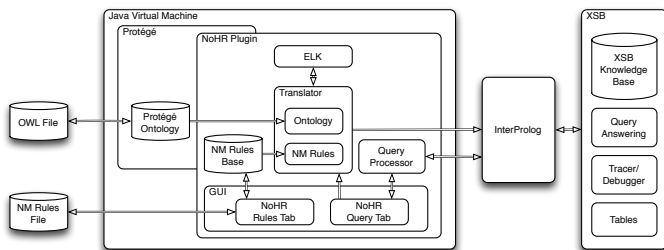
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NoHR: EL Ontologies and Non-Monotonic Rules

1. Hybrid MKNF [Motik and Rosati, J. ACM 2010]
2. Its Well-Founded Semantics (WFS) [Knorr et al., AI 2011]
3. Top-down procedure **SLG(O)** [Alferes et al., ACM TOCL 2013]



Motivation: Extension to QL

- ▶ Applications require DL language features (e.g., inverses) [Calvanese et al., 2011] not covered by OWL EL
- ▶ OWL QL based on *DL-Lite_R* would serve
 - ▶ Covers basic DL languages, the entity relationship model, and basic UML class diagrams
 - ▶ Query-answering by rewriting queries by means of the ontology s.t. SQL engines can be used over the data
 - ▶ Very low data complexity
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Problem

- ▶ Negation present in OWL QL requires classification of negated concepts
- ▶ Currently no classifier for OWL QL including negated concepts
- ▶ Naive adaptation inefficient due to large number of created axioms

Objective

Adapt NoHR to OWL QL

- ▶ Direct translation (no prior classification)
- ▶ Ensure identical derivation of ground queries
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$B \rightarrow A \mid \exists Q \quad C \rightarrow B \mid \neg B \quad Q \rightarrow P \mid P^- \quad R \rightarrow Q \mid \neg Q$

$A \in N_C$ concept name, $P \in N_R$ role name, and P^- its inverse

- ▶ GCIs $B \sqsubseteq C$ and RIs $Q \sqsubseteq R$
- ▶ Standard DL semantics based on interpretations $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$

$\exists HasArtist^- \sqsubseteq Artist$

$Piece \sqsubseteq \exists HasArtist$

$\exists HasComposed^- \sqsubseteq Piece$

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Direct Translation

$Piece \sqsubseteq \exists HasArtist$ cannot be translated naively

- ▶ $HasArtist(x, y) \leftarrow Piece(x)$ would yield $HasArtist(x, y)$ for any $Piece(x)$ and y
- ▶ $HasArtist(x, c) \leftarrow Piece(x)$ would yield $HasArtist(x, c)$ for any $Piece(x)$ for the same c
- ▶ Skolemization would cause difficulties for termination

Special predicates for domain and range

$DHasArtist(x) \leftarrow Piece(x)$ with $DHasArtist$ the domain of $HasArtist$
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- ▶ $DHasArtist(x) \leftarrow HasArtist(x, y)$ associating domains (and ranges) to binary atoms
- ▶ For inverses $HasComposed^- \sqsubseteq HasArtist$, translate to

$$HasArtist(x, y) \leftarrow HasComposed(y, x)$$

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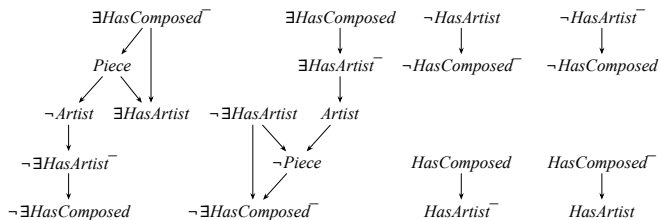
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Graph Representation Including Negation

Nodes all general concepts and roles, edges GCIs and RIs (including, e.g., implicit contrapositives)

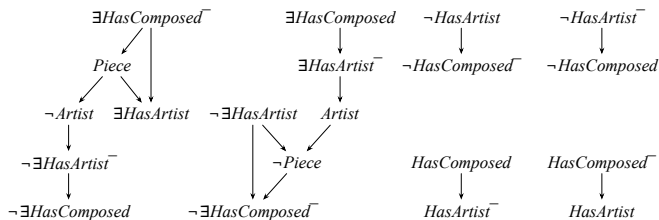


HasComposed irreflexive: $\exists HasComposed \sqsubseteq \neg \exists HasComposed^-$

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Results

- ▶ Sound and complete translation w.r.t. answering (ground) queries
- ▶ Data complexity in P
- ▶ Extension of classification on graphs to negated concepts a contribution in its own right
- ▶ Implementation as an alternative translator module in NoHR for OWL QL

Evaluation Settings

LUBM benchmark

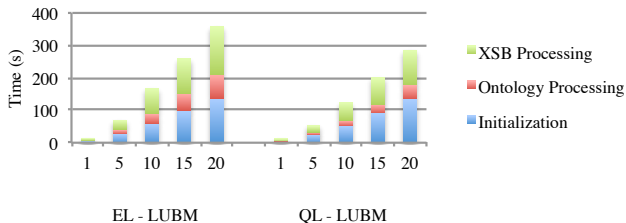
- ▶ Small TBox
- ▶ Data generator for creating instance data of large sizes
- ▶ 14 test queries

Here:

- ▶ TBox slightly simplified to match the OWL profile(s)
- ▶ Three queries omitted whose results are affected by the simplifications

Evaluation: Preprocessing

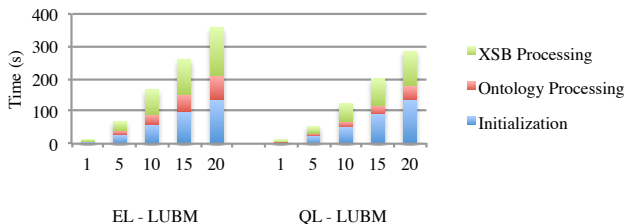
Direct translation approach vs. classification-based – LUBM reduced to fit OWL QL and EL to compare NoHR QL and EL approaches



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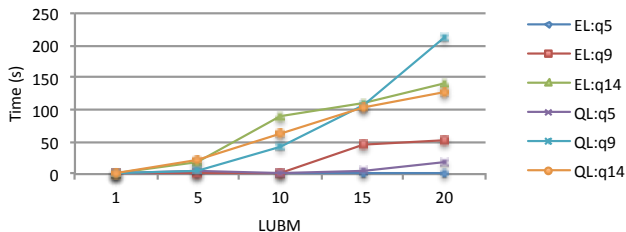
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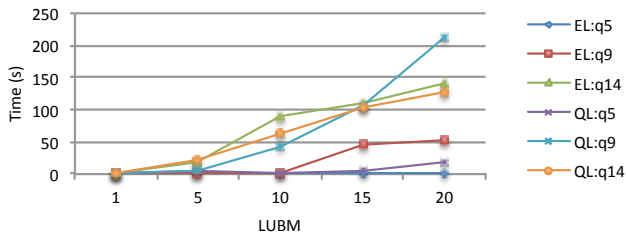
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- ▶ Often interactive response time with slight advantage for EL (q_5)
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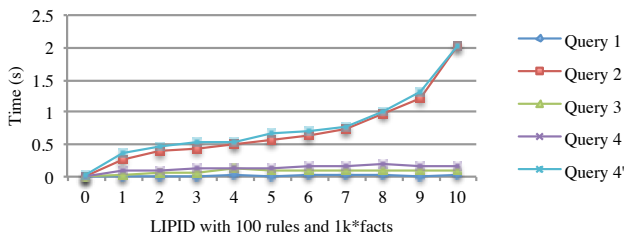
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Evaluation: Lipid with Rules

749 subclass axioms, 1,486 class disjointness axioms and 20 inverse object properties in combination with non-monotonic rules



- ▶ Preprocessing very fast and only linearly increasing
- ▶ Four atomic queries in different levels of the hierarchy with interactive response time
- ▶ 4' – query 4 without the other queries beforehand (tabling)

Conclusions

- ▶ NoHR extended to OWL 2 QL based on direct translation
- ▶ Theoretically sound and complete including novel extension of graph-based reasoning with negated concepts
- ▶ Evaluation results of implementation encouraging as all previously observed results (for EL) persist
- ▶ QL is even faster on pre-processing and only slightly slower on average when answering queries

Future Work

- ▶ Further comparisons to alternative versions for QL based on, e.g., ontop, Konclude
- ▶ OWL RL
- ▶ Paraconsistent Semantics