The DReW System for Nonmonotonic DL-Programs

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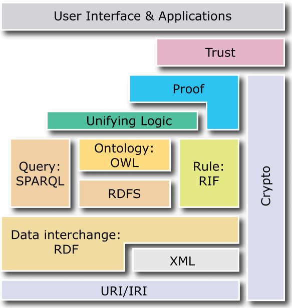
CSWS 2012 & CWSC 2012, Shenzhen, 29 Nov 2012

Background: Semantic Web (W3C)

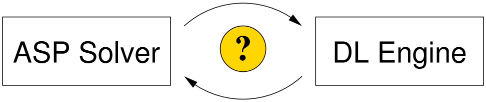


- *RDF (Resource Description Framework)* is the data model
- RDFS (Schema) enriches RDF by simple taxonomies and hierarchies
- More expressive: *OWL (Web Ontology Language)* (2004; 2009)
  - strongly builds on Description Logics
- Rule languages: *Rule Interchange Format (RIF)* (2010)

dl-Programs

- An extension of answer set programs with *queries to DL knowledge bases (KBs)* (through dl-*atoms*)
- dl-atoms allow to query a DL knowledge base differently

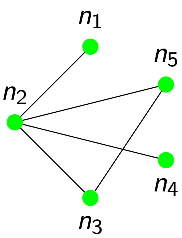
  bidirectional flow of information, with clean technical separation of DL engine and ASP solver ("loose coupling")



- Use DL-programs as "glue" for combining inferences on a DL KB.
- System Prototypes
  - NLP-DL `http://www.kr.tuwien.ac.at/research/systems/semweblp/`
  - dlvhex `http://www.kr.tuwien.ac.at/research/systems/dlvhex/`
  - #F-Logic programs (Ontoprise, extension to F-logic programs)

DL-Programs: Network Example

$KB = (L, P)$



Ontology L

$$\geq 1.wired \sqsubseteq Node \quad \top \sqsubseteq \forall wired.Node$$

$$wired = wired^{-};$$

$$n_1 \neq n_2 \neq n_3 \neq n_4 \neq n_5$$

$$wired(n_1, n_2) \; wired(n_2, n_3) \; wired(n_2, n_4)$$

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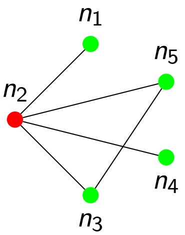

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$$\geq 4.wired \sqsubseteq HighTrafficNode$$

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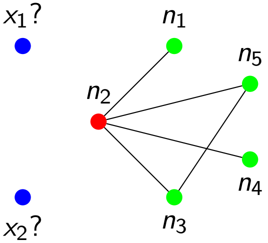

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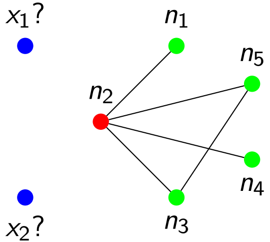

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$$overloaded(X) \leftarrow \mathrm{DL}[wired \uplus connect; HighTrafficNode](X).$$

- DL atom: $\mathrm{DL}[wired \uplus connect; HighTrafficNode](X)$.
- Intuition: extend DL predicate *wired* by *connect*, then query *HighTrafficNode*
  - E.g. Suppose $\{connect(x_1, n_3), connect(x_2, n_3)\} \subseteq I$
  - Then $I \models \mathrm{DL}[wired \uplus connect; HighTrafficNode](n_3)$
  - Thus $I \models overloaded(n_3)$

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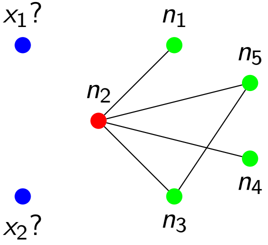

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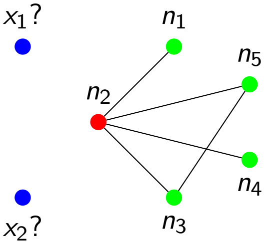

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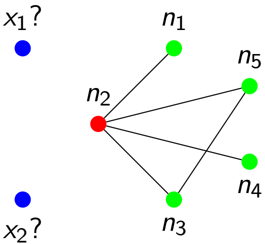

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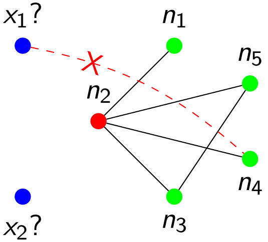

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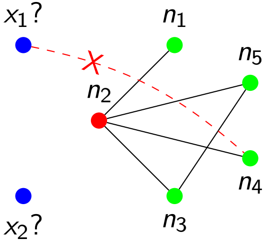
Semantics of DL-Programs



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  - Extension of answer set semantics for normal logical programming
  - Multi models

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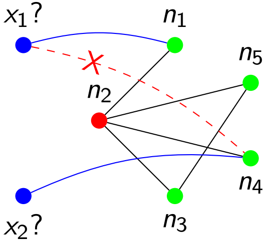

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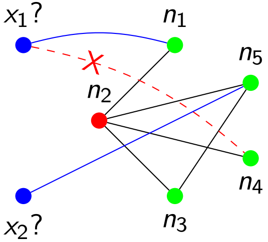

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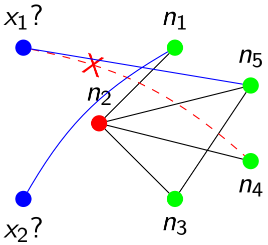

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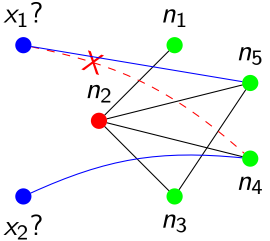

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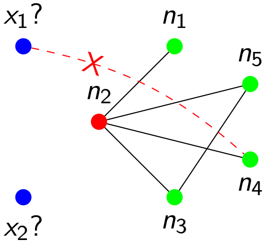
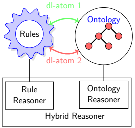


- Well-founded semantics
  - Extension of well-founded semantics for normal logical programming
  - Single model

- $M_0 = \{overloaded(n_2), \ldots\}$

Loose Coupling - Features

- **Advantage:**
  - Clean semantics, can use legacy systems
  - Fairly easy to incorporate further knowledge formats (e.g. RDF)
  - Privacy, information hiding



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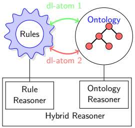
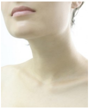
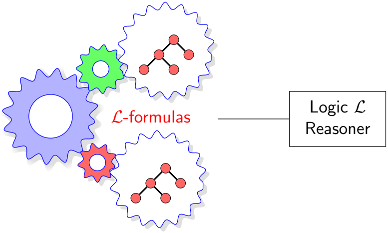


- **Drawback**: *impedance mismatch, performance*
  - Evaluation of DL-program needs multiple calls of a DL-reasoner
  - Calls are expensive
    - optimizations (caching, pruning ...)
  - In some case, exponentially many calls might be unavoidable
  - Even polynomially many calls might be too costly



Uniform Evaluation

Convert the evaluation problem into one for a single reasoning engine



- This means to transform a dl-program into an (equivalent) knowledge base in *one formalism* $\mathcal{L}$ for evaluation (*uniform evaluation*)
- In this talk, $\mathcal{L} = \text{Datalog}^{\neg}$

Reasoning with DL-Programs by Datalog$^\neg$ rewriting

1. Rewriting Ontology to Datalog
2. Duplicating rewritten ontologies according to the dl-inputs
3. Rewriting DL-rules to Datalog$^\neg$ rules
4. Rewriting DL-atoms to Datalog rules
5. Calling Datalog reasoner

DReW Reasoner

- DReW is a reasoner for DL-Programs over Datalog-rewritable Description Logics
- homepage: `http://www.kr.tuwien.ac.at/research/systems/drew/`
- open sourced: `https://github.com/ghxiao/drew`

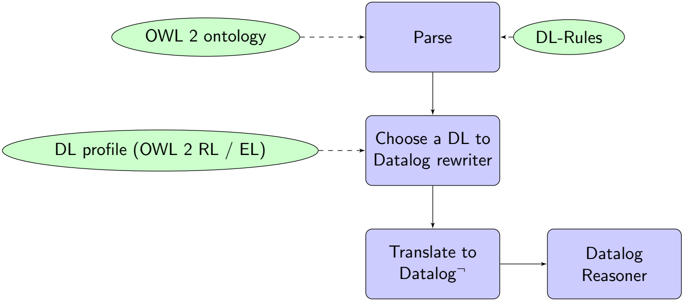


Figure : Control Flow of DReW with DL-programs

Features in DReW v0.3

- Ontology component
  - OWL 2 RL
  - OWL 2 EL
- Semantics
  - ASP semantics
  - Well-founded semantics
- Rule formalism
  - DL-Programs
  - Conjunctive Query under DL-safeness
  - Terminological default reasoning

Example Usage

Example with network DL-Programs under ASP semantics

```
$ ./drew -rl -ontology sample_data/network.owl \
  -dlp sample_data/network.dlp \
  -filter connect -dlv $HOME/bin/dlv

{ connect(x1, n1) connect(x2, n5) }

{ connect(x1, n5) connect(x2, n1) }

{ connect(x1, n5) connect(x2, n4) }

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```

Example Usage

Example with network dl-Programs under well-founded semantics

```
$ ./drew -rl -ontology sample_data/network.owl \
-dlp sample_data/network.dlp \
-filter overloaded -wf -dlv ./dlv-wf

{ overloaded(n2) }
```

Summary and Outlook

- Summary
  - DL-programs is a strong formalism for combining Ontology and Rules
  - Traditional engine for dl-Programs suffers from the overhead of calling external DL Reasoner
  - By exploiting Datalog-rewritablity, reasoning over dl-programs can be reduced to Datalog$^{\neg}$
  - Try DReW Reasoner!
- Outlook
  - More evaluation
  - More expressive DL component, e.g. Horn-SHIQ
  - More reasoning paradigm support, e.g. Closed World Assumption