Unit 3 — ASP for the Semantic Web

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Unit Outline

1. DL-Programs
2. HEX-Programs
3. Other Linguistic Extension of ASP in the Direction of Semantic Web
4. Other Semantic Web Enabled Systems Based on ASP
5. Future Directions of ASP

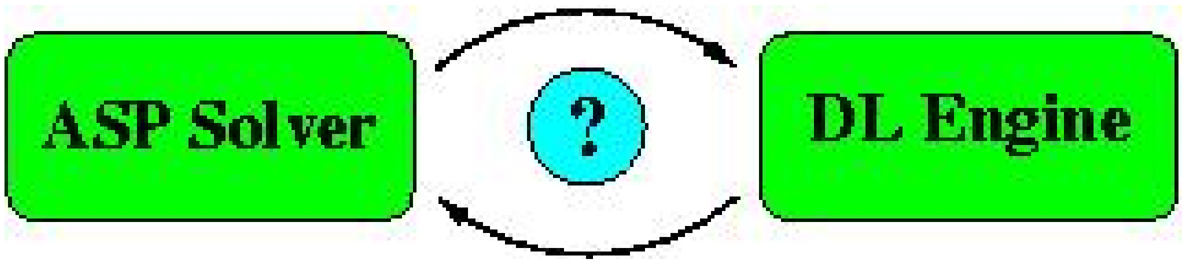
ASP vs DL: the realm of DL-Programs

Two main approaches

- Translate DLs to ASP programs
- Integrate ASP with DLs

A knowledge base KB formed by two sides:

- a logic program P
- a description logic knowledge base L.
- L is accessible from P by means of *dl-atoms*



DL-program example - I

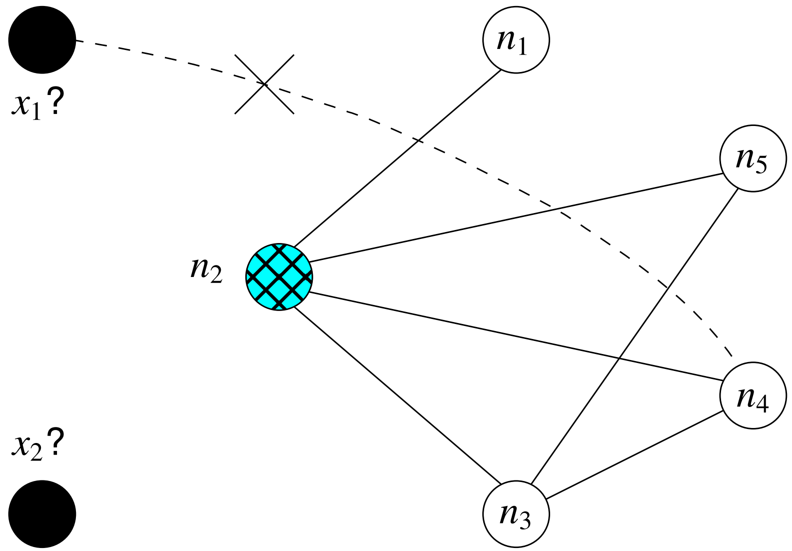


Figure: Hightraffic network

Example

Input: a DL ontology representing a network of nodes, possibly containing *high traffic nodes* (e.g. n_2), some new nodes to be added (e.g. x_1, x_2)

Output: A new connection for each of the new nodes, not causing new high traffic nodes.

DL-program example - II

L, describing the given network

$$
\begin{aligned}
&\geq 1\ wired \sqsubseteq Node; \quad \top \sqsubseteq \forall wired.Node; \quad wired = wired^{-};\\
&\geq 4\ wired \sqsubseteq HighTrafficNode; \quad n_1 \neq n_2 \neq n_3 \neq n_4 \neq n_5;\\
&Node(n_1); \quad Node(n_2); \quad Node(n_3); \quad Node(n_4); \quad Node(n_5);\\
&wired(n_1, n_2); \quad wired(n_2, n_3); \quad wired(n_2, n_4);\\
&wired(n_2, n_5); \quad wired(n_3, n_4); \quad wired(n_3, n_5).
\end{aligned}
$$

- Defines high traffic nodes
- Enforces unique name assumption on nodes

DL-program example - III

P, describing how to add nodes

$$
\begin{aligned}
newnode(x_1).& \\
newnode(x_2).excl(x_1, n_4).& \\
overloaded(X) &\leftarrow \mathrm{DL}[wired \uplus connect; HighTrafficNode](X). \\
connect(X,Y) &\leftarrow newnode(X), \mathrm{DL}[Node](Y), \\
&\quad\; not\ overloaded(Y), not\ excl(X,Y). \\
excl(X,Y) &\leftarrow connect(X,Z), \mathrm{DL}[Node](Y), Y \neq Z. \\
excl(X,Y) &\leftarrow connect(Z,Y), newnode(Z), newnode(X), Z \neq X.
\end{aligned}
$$

- $newnode(x) \Rightarrow x$ should be added to the network
- $overload(x) \Rightarrow x$ turns out to be overloaded in the current interpretation
- $connect(x,y) \Rightarrow x$ should be connected to y
- $excl(x,y) \Rightarrow x$ should *not* be connected to y

dl-atoms

The dl-atom device

- Can specify a query to L:

$$\mathrm{DL}[\mathit{Node}](Y)$$

$\mathrm{DL}[\mathit{Node}](y)$ true for y s.t. $L \models \mathit{Node}(y)$.

- Can push knowledge to L before querying:

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

$\mathrm{DL}[\mathit{wired} \uplus \mathit{connect}; \mathit{HighTrafficNode}](x)$ true in an interpretation I of P for x s.t. $L \cup C \models \mathit{HighTrafficNode}(x)$ for $C = \{\mathit{wired}(x,y) \mid \mathit{connect}(x,y) \in I\}$.

also $\cup\!\!\!\!-$, $\cap\!\!\!\!-$ available.

Answer Sets of our example

Encoding of P

$$
\begin{aligned}
&newnode(x_1).\\
newnode(x_2).excl(x_1, n_4).&\\
overloaded(X) &\leftarrow \mathrm{DL}[wired \uplus connect; HighTrafficNode](X).\\
connect(X, Y) &\leftarrow newnode(X), \mathrm{DL}[Node](Y),\\
&\quad\; not\ overloaded(Y), not\ excl(X, Y).\\
excl(X, Y) &\leftarrow connect(X, Z), \mathrm{DL}[Node](Y), Y \neq Z.\\
excl(X, Y) &\leftarrow connect(Z, Y), newnode(Z), newnode(X), Z \neq X.
\end{aligned}
$$

- We get $M_1 = \{connect(x_1, n_1), connect(x_2, n_3), \ldots\}, M_2 = \{\ldots$

DL-programs properties

- Bidirectional: can push knowledge from P to L and pull knowledge from L to P;
- Clear separation between L and P: allows devising an integrated system based on existing ASP and DL reasoners.
- Two semantics available: strong/weak answer set & well-founded semantics.
- Can introduce on top of L most nonmonotonic features (e.g. (E)CWA [Reiter, 1978], Default Reasoning [Reiter, 1980])

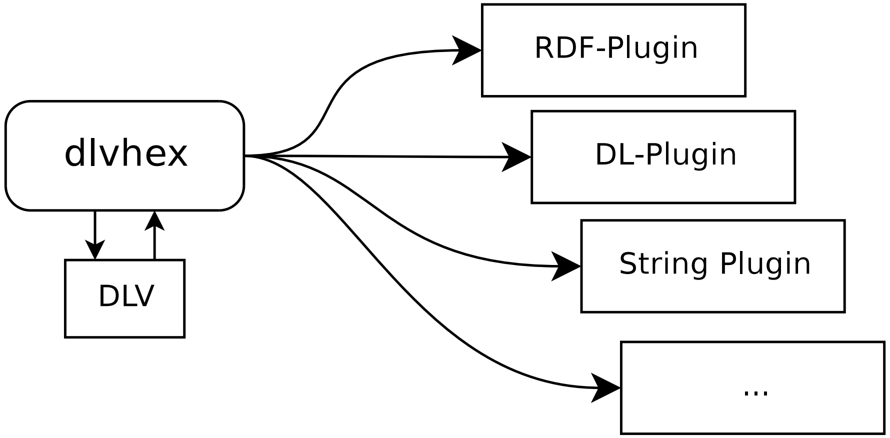
More information on [Eiter *et al.*, 2008b] and in previous Reasoning Web School lectures [Eiter *et al.*, 2006], [Eiter *et al.*, 2008a]

Semantics

New generalized definitions

- Herbrand base *not* defined in terms of constants explicitly mentioned in P
- For the answer set semantics case,
  - Least model of positive DL-program
  - Iterative least model of stratified DL-program
  - Answer sets of general DL-program
- For the well-founded semantics case, notion of unfoundedness lifted to dl-atoms.

The realm of HEX-programs



- Extends dl-programs from one-to-one coupling to many-one.
  - Outer Knowledge sources are not constrained to DL knowledge bases only.
- P can interface multiple external sources of knowledge of any sort via so called *external atoms*
- P has *higher order* atoms

An example

$$
\begin{aligned}
subRelation(brotherOf, relativeOf).\\
brotherOf(john, al).\\
relativeOf(john, joe).\\
brotherOf(al, mick).\\
invites(john, X) \vee skip(X) \leftarrow X \neq john, \&reach[relativeOf, john](X).\\
R(X, Y) \leftarrow subRelation(P, R), P(X, Y).\\
someInvited \leftarrow invites(john, X).\\
\leftarrow not\ someInvited.\\
\leftarrow \&degs[invites](Min, Max), Max > 2.
\end{aligned}
$$

Example

Input: Some data about *John*'s neighborhood

Output: Possible picks for persons John might want to invite, according to some constraints

Higher order atoms

$$\begin{aligned}
subRelation(brotherOf, relativeOf).\\
R(X,Y) \leftarrow subRelation(P,R), P(X,Y).\\
brotherOf(john, al).\\
relativeOf(john, joe).\\
brotherOf(al, mick).
\end{aligned}$$

The device of higher order atoms

- Predicate names can be variables
- Constants can appear both as terms values or as predicate values
- Allows (comfortable) meta-reasoning

$$\begin{aligned}
subRelation(brotherOf, relativeOf). \quad &\Rightarrow \quad relativeOf(X,Y) \leftarrow brotherOf(X,Y).\\
R(X,Y) \leftarrow subRelation(P,R), P(X,Y).
\end{aligned}$$

External atoms

$$\&reach[relativeOf, john](X) \tag{1}$$

$$\&degs[invites](Min, Max) \tag{2}$$

The device of external atoms

- Each external predicate is tied to a corresponding evaluation function
- E.g. $\&reach$ corresponds to $f_{\&reach}$.

For a given interpretation I, $I \models \&reach[relativeOf, john](x)$ if $f_{\&reach}(I, relativeOf, john) = 1$

Semantics

Higher order atoms

Generalized Herbrand base: an higher order atom $T_0(T_1, \ldots, T_n)$ can be grounded to $t_0(t_1, \ldots, t_n)$.

External atoms

Given a = $\&g[y_1, \ldots, y_n](x_1, \ldots, x_m)$, then $I \models a$, if and only if $f_{\&g}(I, y_1, \ldots, y_n, x_1, \ldots, x_m) = 1$.

Notion of answer sets

Similar to strong answer sets of dl-programs, but based on the FLP [Faber *et al.*, 2004] reduct.

- For interpretation I and program P, $fP^I = \{r \in P \mid$ the body of P is satisfied in $I\}$

Features and Applications of HEX-programs

- System available [1]
- Features a powerful SDK for developing own external atoms
- SW knowledge can be accessed via the $\&rdf$ atom. Access to reasoners via the $\&dlC$ and $\&dlR$ atom (similar to dl-atoms).
- Many other plugins available (string manipulation, aggregates etc.)

Applications

- ASP reasoning (possibly nonmonotonic) on ontologies [Hoehndorf *et al.*, 2007], [Bodenreider *et al.*, 2008]
- Planning [Nieuwenborgh *et al.*, 2007]

[1] `http://www.kr.tuwien.ac.at/research/systems/dlvhex/`

Loose vs Tight coupling

- HEX-programs take the loose coupling approach
  - L appears as a reasoning service for P.
- Knowledge bases of different semantics can be however integrated on different levels, e.g. on a *tight* coupling approach

Tight coupling

Tight coupling (e.g. $\mathcal{D}L+$log [Rosati, 2006]), features a single interpretative structure embracing both P and L.

Tight Coupling vs Loose Coupling - II

Example

$$p(X) \leftarrow \mathrm{DL}[Person](X)$$

Single answer set $M_1 = \{p(alice), p(bob), \ldots\}$, containing all the $p(x)$ s.t. $L \models Person(x)$

$$p(X) \leftarrow Person(X)$$

Has infinitely many stable models. A stable model M_I for each consistent interpretation I of L.

Other coupling methods exists. A thorough comparison can be found in [Eiter *et al.*, 2008a], [de Bruijn *et al.*, 2006].

Other SW Related ASP systems

OntoDLV

An extension of DLV with ontology modelling features living under native ASP semantics [Ricca *et al.*, 2008]

GiaBATA

A SPARQL enabled RDF store, based on dlvhex and DLV^{DB}
[_ et al. 2009a; _ et al. 2009b]

DLT

An ASP frontend allowing contexts, higher order, and frame syntax
[Calimeri and _ 2006; Alviano et al. 2008]

Current state-of-the-art

Semantics

- **Introduction of Function Symbols** [Syrjänen, 2001],[Bonatti, 2004],[Calimeri *et al.*, 2008],[Šimkus and Eiter, 2007],[Eiter and Šimkus, 2009]
- **Modularity** [Dao-Tran *et al.*, 2009],[Janhunen *et al.*, 2007],[Oikarinen and Janhunen, 2008],[Tari *et al.*, 2005],[Balduccini, 2007],[Baral *et al.*, 2006],[Calimeri and Ianni, 2006],[Polleres *et al.*, 2006],[Analyti *et al.*, 2008]
- **Study of equivalence** [Lifschitz *et al.*, 2001],[Gelfond, 2008],[Eiter *et al.*, 2007],[Eiter *et al.*, 2004],[Woltran, 2008]

Engineering

- **Debuggers** [El-Khatib *et al.*, 2005],[Brain and Vos, 2005] **and in-database evaluation** [Terracina *et al.*, 2008]
- **See the SEA workshop series** `http://sea07.cs.bath.ac.uk/`

Current state-of-the-art II

Scalability

- **Intelligent and lazy grounders** [Calimeri *et al.*, 2008],[Gebser *et al.*, 2008],[Palù *et al.*, 2008], [Lefévre and Nicolas, 2008]
- **See the Answer Set Programming competition**
  `http://www.cs.kuleuven.be/ dtai/events/ASP-competition/`

Session is over

Thanks!

You can play with ASP solver on this nice web interface
`http://asptut.gibbi.com`

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