Answer Set Programming for the Semantic Web

Tutorial

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Unit 6 – Another ASP Extension: HEX-Programs

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Unit Outline

Motivation

- dl-programs: interfacing external source of knowledge
- Limited flexibility:
  - only one external KB possible
  - only one formalism allowed for KB (OWL)
- Spinning this idea further:
  - Access arbitrary external sources (solvers, services, different knowledge bases, etc.)
  - Standardized interface
  - Entire program: still ASP semantics
- Result: HEX-programs!

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Desirable Features for Rules in the Semantic Web:

- Software Interoperability
  - Importing external knowledge
  - Easily extendable reasoning framework
- Higher-Order Reasoning: rules that talk about predicates
  - Stating generic rules (e.g., general CWA rule)
  - Defining ontology semantics in a program

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Syntax

Def. A HEX-program is a finite set P of rules:

$$\alpha_1 \vee \cdots \vee \alpha_k \leftarrow \beta_1, \ldots, \beta_n, not\ \beta_{n+1}, \ldots, not\ \beta_m,$$

$m, k \geq 0$, where $\alpha_1, \ldots, \alpha_k$ are atoms, and $\beta_1, \ldots, \beta_m$ are either higher-order atoms or external atoms.

Higher-Order Atoms are expressions of the form

$$(t_0, t_1, \ldots, t_n) \text{ resp. } t_0(t_1, \ldots, t_n),$$

where $t_0, \ldots, t_n$ are (function-free) terms.

Examples: $(x, rdf{:}type, c)$, $node(X)$, $D(a, b)$.

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Examples: $(x, \mathit{rdf}{:}\mathit{type}, c)$, $\mathit{node}(X)$, $D(a, b)$.

Syntax /2

External Atoms are expressions of the form

$$\&g[t_1, \ldots, t_n](t'_1, \ldots, t'_m),$$

where
- $\&g$ is an external predicate name, and
- $t_1, \ldots, t_n$ and $t'_1, \ldots, t'_m$ are lists of terms (*input*/*output* lists).

Intuition: Decide membership of $(t'_1, \ldots, t'_m)$ in the output depending on an interpretation I and parameters $t_1, \ldots, t_n$.

Example:

$\&sum[p](X)$ $\Rightarrow$ $I : \{p(2), p(3), q(4)\}$ $\Rightarrow$ output list: 5
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$\&reach[edge, a](X)$ . . . reachable nodes from a in $edge$.

$\Rightarrow$ "Return 1 if $\langle a, X\rangle$ is in the extension of $edge$ in I."

$\&rdf[uri](X, Y, Z)$ . . . RDF-triples found under uri.

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Semantics

Define semantics of P in terms of its grounding $grnd(P)$.

⇒ *Herbrand base* HB_P of P: set of all groundings of atoms and external atoms in P (relative to set of constants $\mathcal{C}$).

- $I \subseteq HB_P$ models ground atom a, if $a \in I$
- $I \subseteq HB_P$ models ground $\&g[y_1, \ldots, y_n](x_1, \ldots, x_m)$ iff

  $$f_{\&g}(I, y_1 \ldots, y_n, x_1, \ldots, x_m) = 1,$$

  where $f_{\&g}$ is an $(n+m+1)$-ary Boolean function telling whether $(x_1, \ldots, x_m)$ is in the output for input $I, y_1 \ldots, y_n$.
- $I \subseteq HB_P$ models P iff it models $grnd(P)$
- $I \subseteq HB_P$ is an answer set of P iff I is a minimal model of fP^I, where fP^I is the FLP-reduct of P.

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Applications

- Importing external theories, stored in RDF:

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\begin{aligned}
triple(X,Y,Z) &\leftarrow \&rdf[<uri1>](X,Y,Z);\\
triple(X,Y,Z) &\leftarrow \&rdf[<uri2>](X,Y,Z);\\
proposition(P) &\leftarrow triple(P, rdfs{:}type, rdf{:}Statement).
\end{aligned}
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$\Rightarrow$ Avoid inconsistencies when merging ontologies O_1, O_2.

- Translating and manipulating reified assertions:

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\begin{aligned}
(X,Y,Z) \leftarrow\ & pick(P), triple(P, rdf{:}subject, X),\\
& triple(P, rdf{:}predicate, Y),\\
& triple(P, rdf{:}object, Z);\\
C(X) \leftarrow\ & (X, rdf{:}type, C).
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Applications /2

- Defining ontology semantics:

$$\begin{aligned} D(X) &\leftarrow subClassOf(D, C), C(X). \\ &\leftarrow maxCardinality(C, R, N), C(X), \\ &\quad \&count[R, X](M), M > N. \end{aligned}$$

- Closed World reasoning

$$\begin{aligned} cwa(faculty, project) &\leftarrow . \\ C'(X) &\leftarrow not\ \&DL[C](X), \\ &\quad concept(C), cwa(C, C'), \end{aligned}$$

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Safety

If new values are imported by external atoms, how can we guarantee a finite domain?

By imposing safety restrictions! (see also [28])

"Traditional" safety: Each variable in a rule must occur in a positive body literal.

Expansion safety: The input list of an external atom must be bounded:

$$triple(S, P, O) \leftarrow \&rdf[U](S, P, O), uri(U).$$

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dlvhex

We implemented a reasoner for HEX-programs, called dlvhex [29].
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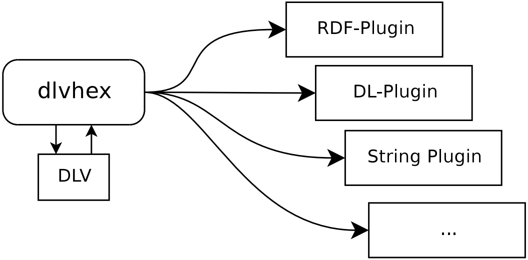
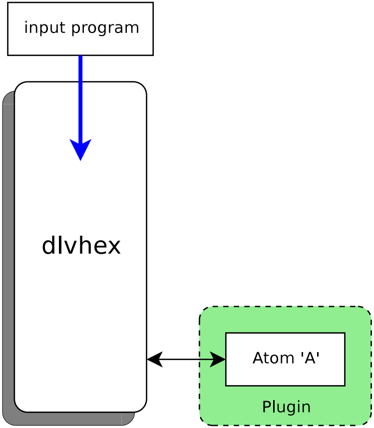


Plugin Mechanism

- A plugin is a shared library, dynamically linked at runtime
- A plugin can provide several Atoms
- A plugin can rewrite the program



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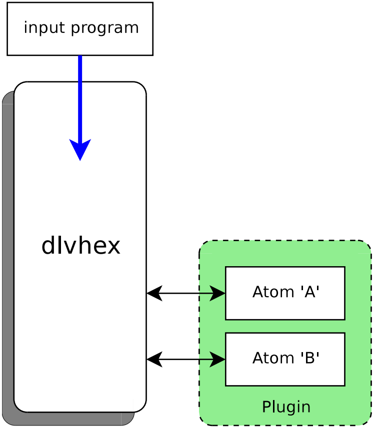

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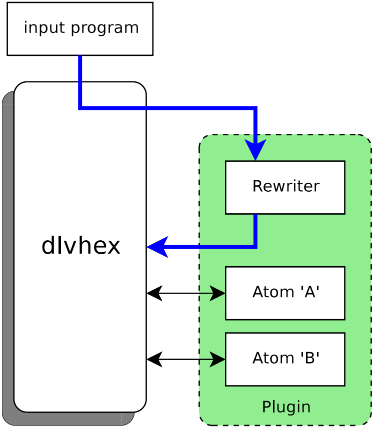

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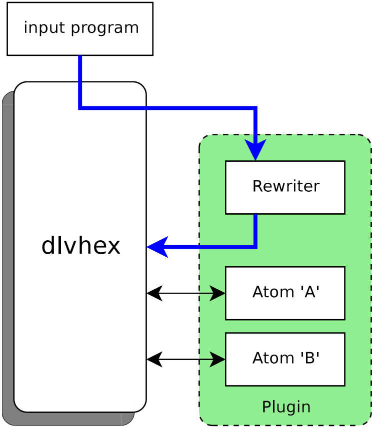

Plugin development toolkit available!

String Plugin

Purpose: String operations on names.

Available atoms:

`&concat`	Concatenates two strings.
`&cmp`	Compares two strings lexicographically or two numbers arithmetically.
`&strstr`	Tests two strings for substring inclusion.
`&split`	Splits a string along a specified delimiter.
`&sha1sum`	Computes SHA1 checksum from a string.

String Plugin Atoms

`&concat[A,B](C)` builds a string `C` from `A + B`.

Example:
```
fullURI(X) :- &concat["http://",P](X),
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`&sha1sum[A](B)`	returns B as SHA1 checksum of A.

Example:
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ownerID(X) :- &sha1sum[X](Y), mailbox(X).
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`&rdf[U](S,P,O)`	returns all triples `<S,P,O>` from `U`.

Example:
```
tr(X,Y,Z) :- &rdf[U](X,Y,Z), uri(U).
uri("http://www.example.org/foaf.rdf").
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RDF Plugin Example

Program `delicious_a.dlh` retrieves triples from a del.icio.us URI.

Del.icio.us is a social bookmarking service: Users store their bookmarks and tag them with keywords. It has an RDF/RSS-interface: adding a keyword to the URL `http://del.icio.us/rss/tag/` returns all bookmarks with this tag.

- The namespace directive abbreviates long strings, simple syntactic sugar.
- The single URL given returns all bookmarks with the tag `eswc`.

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Exercise

Task (1)

1. *Introduce a new predicate* `keyword` *and find a way to append its extension to the string* `"http://del.icio.us/rss/tag/"` *in order to build the URI in a more flexible way.*
2. *To get the actual bookmarks corresponding to a keyword, extract from the triples all resources that have* `"rdf:type"` *as property and* `"rss:item"` *as value.*

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tag("eswc").
url(X) :- &concat["http://del.icio.us/rss/tag/",W](X), tag(W).
```

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tag("eswc").

url(X) :- &concat["http://del.icio.us/rss/tag/",W](X), tag(W).
link(X) :- "rdf:type"(X,"rss:item").
```

Solution available as delicious_b.dlh

DL Plugin

Purpose: Query Description Logics knowledge bases.

Available atoms:

`&dlC`	Queries a DL concept.
`&dlR`	Queries a DL role.
`&dlDR`	Queries a DL datatype role.
`&dlConsistent`	Tests a DL KB for consistency.

These atoms descent from the corresponding dl-atoms of our dl-programs and also allow for extending the DL-KB.

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`&dlC`	Queries a DL concept.
`&dlR`	Queries a DL role.
`&dlDR`	Queries a DL datatype role.
`&dlConsistent`	Tests a DL KB for consistency.

These atoms descent from the corresponding dl-atoms of our dl-programs and also allow for extending the DL-KB.

DL Plugin Atoms

`&dlC[U,a,b,c,d,Q](C)`	Returns all members of `Q` in KB `U`.

`a,b,c,d`: Predicates from the HEX-program, specifying the DL update, in this order:

1. Add `p` to `P` for each tuple `<P,p>` in the extension of `a`.
2. Add `p` to ¬`P` for each tuple `<P,p>` in the extension of `b`.
3. Add `<p,q>` to `R` for each tuple `<R,p,q>` in the extension of `c`.
4. Add `<p,q>` to ¬`R` for each tuple `<R,p,q>` in the extension of `d`.

Example:

```
student(X) :- &dlC[U,x,x,add,x,"PhdStudent"](X), url(U).
add("supervisorOf","Roman","Thomas").
```

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```
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add("supervisorOf","Roman","Thomas").
```

DL Plugin Atoms /2

`&dlR[U,a,b,c,d,Q](X,Y)`	Returns all pairs of `Q` in KB `U`.

`Q` has to be an ObjectProperty!

Example:

```
uncle(X,Y) :- &dlR[U,x,x,x,x,"brotherOf"](X,Z),
              &dlR[U,x,x,x,x,"parentOf"](Z,Y), url(U).
```

DL Plugin Atoms /2

`&dlR[U,a,b,c,d,Q](X,Y)`	Returns all pairs of `Q` in KB `U`.

`Q` has to be an ObjectProperty!

Example:

```
uncle(X,Y) :-  &dlR[U,x,x,x,x,"brotherOf"](X,Z),
               &dlR[U,x,x,x,x,"parentOf"](Z,Y), url(U).
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`&dlR[U,a,b,c,d,Q](X,Y)`	Returns all pairs of Q in KB U.

Q has to be an ObjectProperty!

Example:

```
uncle(X,Y) :-  &dlR[U,x,x,x,x,"brotherOf"](X,Z),
               &dlR[U,x,x,x,x,"parentOf"](Z,Y), url(U).
```

`&dlDR[U,a,b,c,d,Q](X,Y)`	Returns all pairs of Q in KB U.

Q has to be a DatatypeProperty!

Example:

```
name(X,Y) :- &dlDR[U,a,b,c,d,"name"](X,Y),
             member(X), url(U).
```

DL Plugin Atoms /2

`&dlR[U,a,b,c,d,Q](X,Y)`	Returns all pairs of `Q` in KB `U`.

`Q` has to be an ObjectProperty!

Example:

```
uncle(X,Y) :-  &dlR[U,x,x,x,x,"brotherOf"](X,Z),
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Exercise

Wine example: importing wine preferences from (RDF) foaf-descriptions!

RDF-graph: `X <"foaf:name"> Name`
`X <"foafplus:winePreference"> Wine`

Task (2)

Modify wineCover10a.dlht by creating a predicate `preferredWine` *that associates names to wines.*

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```
preferredWine(N,W) :- ?
```

Exercise

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```
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```

Task (2)

Modify wineCover10a.dlht by creating a predicate `preferredWine` *that associates names to wines.*

```
preferredWine(N,W) :- "foaf:name"(X,N),
                      "foafplus:winePreference"(X,W).
```

Solution at wineCover10b.dlht

Policy Specification

Recent project using dlvhex: Policy Specification

P. A. Bonatti, D. Olmedilla, and J. Peer.:
Advanced Policy Queries. For: European Commission, IST 2004-506779 (REWERSE), I2-D4, 2005.

Principle:

- Grant access to resources based on disclosed credentials.
- Various combinations of credentials might lead to the same goal.
- Credentials have specific disclosure sensitivities.
- Optimization Problem: Find least sensitive combination of credentials that grant access!

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Challenge: Computing the overall sensitivity of a set of credentials.

- Simple: sum, average, maximum
  $\Rightarrow$ Use aggregates
- Complicated: based on respective credentials, mutual effects
  $\Rightarrow$ Use external atom!

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`sens` is binary, associating a sensitivity value to a credential.

Example:
```
sens(ca,2).  sens(cb,3).
overall(S) :- &policy[sens](S).
```

Function inside the `&policy`-atom easily adaptable.

Policy Function Implementation: Sum

Simple version: Sum of all credential sensitivities—looking inside the plugin:

```
double
PolicySensFunction::eval(const std::vector<double>& values)
{
    double ret(0);

    for (vector<double>::const_iterator di = values.begin();
         di != values.end();
         ++di)
    {
        ret += *di;
    }

    return ret;
}
```

Exercise

Program policy_a.dlh creates a searchspace for all combinations of credentials → predicate `credential`

Task (3)

1. *remove models without granted access (strong constraint):* *For each* `availableFor(R,_)`, *we want* `allow(download,R)`*!*
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1 :- not allow(download,R), availableFor(R,_).
2 sensitivity(S) :- &policy[sens](S).
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Solution at policy_b.dlh

A larger Example: Reviewer Selection

Let us now take a closer look on the reviewer selection example from Unit 5:

- We have a number of submissions and a program committe
- We have an ontology about publications and researchers:
  - classes like paper, kw, senior researcher, publication, . . .
  - properties like hasAuthor, keyword, publishedIn, firstname, . . .
- We want to assign reviewers combining these knowledge bases with HEX-programs instead of dl-programs now!

Reviewer Selection – Variant 1

Take the original program at reviewers1.dlp as a starting point

Task

Now, reformulate the program as a HEX *program!*

Solution: reviewers1.dlh

We add namespaces:

```
#namespace("rev","http://localhost/asptut/sandbox/reviewers.rdf#")
url("http://localhost/asptut/sandbox/reviewers.rdf").
...
author(subm1,"jdbr"). author(subm1,"htom").
author(subm1,"rev:jdbr"). author(subm1,"rev:htom").
```

We replace dl-atoms by HEX' DL plugin atoms:

```
c1("rev:club100",X) :- pc(X).
cand(X,P) :-  url(U), paper(P), &dlC[U,c1,c2,r1,r2,"rev:senior"](X).
```

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Reviewer Selection – Variant 2

Now, let's have a closer look what happens in the DL ontology:

We add another PC member:

```
pc("rev:dknu").
```

File: reviewers2.dlh, filter the result by `cand`.

Task

Question: *Why has `"rev:dknu"` not been included in the candidate reviewers although we know he is in the Club100?*
Check the OWL ontology and find out why!

Solution:

$club100 \equiv person \geq 100 isAuthorOf$

$senior \equiv person \geq 3 isAuthorOf \sqcap \exists isAuthorOf.publication$

$publication \equiv paper \sqcap \geq 1 publishedIn$

There is no publication by dknu in the OWL KB!

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There is no publication by dknu in the OWL KB!

Reviewer Selection – Variant 3

Next variation:

We add information about the authors of submitted papers to the the OWL KB.:

```
r1("rev:hasAuthor",P,A) :- author(P,A).
```

File: reviewers3.dlh, filter the result by `cand`.

Task

Effect: *H. Tompits (htom) and R. Schindlauer (rsch) also become canditates!*
Again: *Check the OWL ontology and find out why!*

Reviewer Selection – Variant 3

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Effect: *H. Tompits (htom) and R. Schindlauer (rsch) also become canditates!*
Again: *Check the OWL ontology and find out why!*

Reviewer Selection – Variant 4/1

Last variation: Combines results of several queries.

Submissions as before but adding keyword information:

```
paper(subm1).
kw(subm1,"rev:Semantic_Web"). kw(subm1,"rev:OWL").
author(subm1,"rev:jdbr"). author(subm1,"rev:htom").

paper(subm2).
kw(subm2,"rev:Semantic_Web").
kw(subm2,"rev:Answer_Set_Programming").
author(subm2,"rev:teit"). author(subm2,"rev:gian").
author(subm2,"rev:rsch"). author(subm2,"rev:apol").
```

see reviewers4a.dlh

We now want to choose the review candidates candidates depending on keywords occurring in the submitted papers instead.

Reviewer Selection – Variant 4/2

Choose the review candidates candidates depending on keywords:

The OWL KB has properties defining

- keywords of papers "rev:keyword" and overlapping keywords "rev:overlapsWith"

Task

Modify the program reviewers4a.dlh as follows:

1. *A PC member who is author of a paper with the same keyword is a candidate.*
2. *A PC member who is author of a paper with an overlapping keyword as well.*

```
cand(X,P) :- ?
```

Reviewer Selection – Variant 4/2

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1. *A PC member who is author of a paper with the same keyword is a candidate.*
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```
cand(X,P) :- kw(P,K), pc(X), url(U),
             &dlC[U,c1,c2,r1,r2,"rev:person"](X),
             &dlR[U,c1,c2,r1,r2,"rev:isAuthorOf"](X,P1),
             &dlR[U,c1,c2,r1,r2,"rev:keyword"](P1,K).

cand(X,P) :- kw(P,K), pc(X), url(U),
             &dlR[U,c1,c2,r1,r2,"rev:overlapsWith"](K,K1),
             &dlR[U,c1,c2,r1,r2,"rev:isAuthorOf"](X,P1),
             &dlR[U,c1,c2,r1,r2,"rev:keyword"](P1,K1).
```

Solution: reviewers4b.dlh

Let's continue with the hands-on session!