Rules with Contextually Scoped Negation for the Web

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Overview

- The Semantic Web
- Where to add Rules in the "Layer Cake"?
- A lightweight approach: Logic Programs with Context and Scoped Negation
  - Contextually Bounded Semantics
  - Contextually Closed Semantics
  - Summary/Open Issues
- Other approaches . . . time allowed.
  - SWRL – Rules on top of OWL
  - DLP – Intersection of LP and DL
  - dl-programs – a query interface between LP and OWL

Motivation - Semantic Web

http://imdb.com http://badmovies.org

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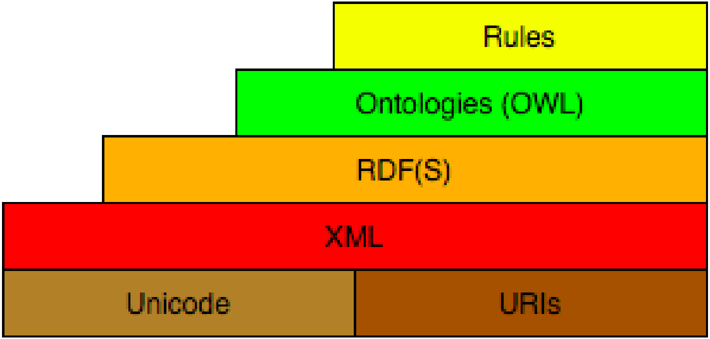
- I want to express **taxonomies** such as *"Science-fiction movies are movies."*
- Besides **facts** in RDF, I want to express more complex **rules** such as for instance: *"All movies listed on* `badmovies.org` *are rated bad."*

The W3C's Semantic Web "layer cake"



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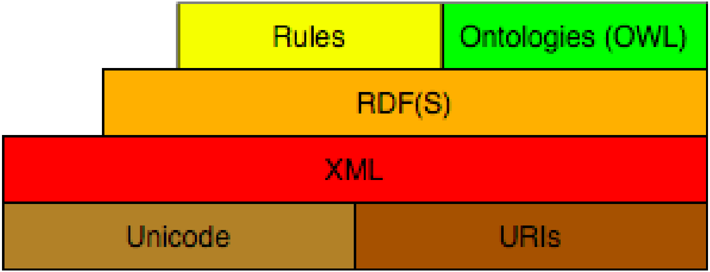

Can LP style rules really be layered ON TOP of OWL?

I. Horrocks , B. Parsia , P. Patel-Schneider , J. Hendler. *Semantic Web Architecture: Stack or Two Towers?* PPSWR, 2005.

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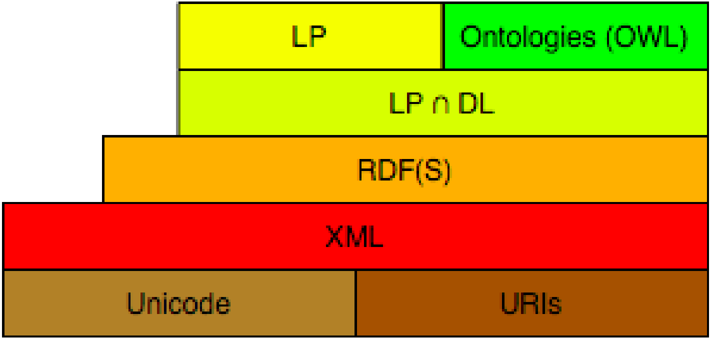

What is the common interoperability layer?

B. Grosof, I. Horrocks , R. Volz , S. Decker. *Description Logic Programs: Combining Logic Programs with Description Logic.* WWW, 2003.

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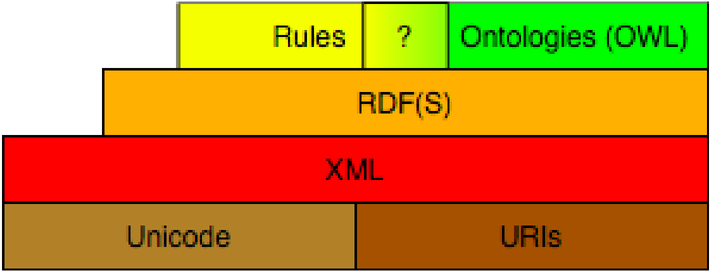

Can we define a "safe" interface between LP and OWL?

T. Eiter, T. Lukasiewicz, R. Schindlauer, H. Tompits *Combining Answer Set Programming with Description Logics for the Semantic Web.* KR, 2004.

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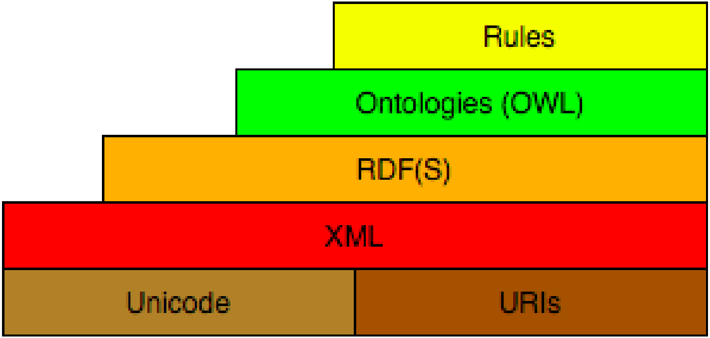

What is the "right" way to go?

RDF - A standard for metadata

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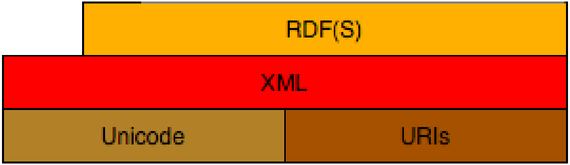

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$$\langle Subject, Predicate, Object \rangle$$

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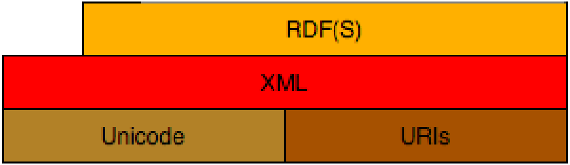

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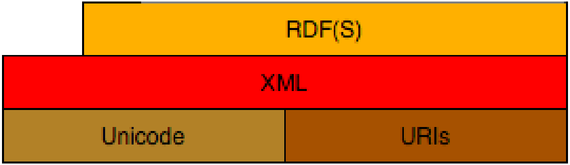

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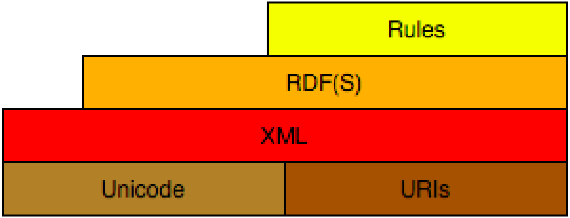

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- Some subtleties in RDF semantics (blank nodes, XML literals, RDF keywords treated as normal resources, reification, etc.)
- The presented approach discuss rules on top of RDF(S) only.

Metadata on the Web as RDF facts.

http://moviereviews.com/
`triple(ex:m1,ex:rate,ex:bad).`
	http://polleres.net/myreviews
	`triple(ex:m2,ex:rate,ex:bad).`
	`triple(ex:m2,rdf:type,movie).`

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triple(ex:m1,rdf:type,ex:sciFiMovie).
triple(ex:m1,ex:title,"Plan 9 from Outer Space").
triple(ex:m1,ex:directedBy,"Ed Wood").
triple(ex:m2,rdf:type,ex:sciFiMovie).
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triple(ex:m2,ex:directedBy,"Larry Wachowski").
triple(ex:m3,rfd:type,ex:sciFiMovie).
triple(ex:m3,ex:title,"Bride of the Monster").
triple(ex:m3,ex:directedBy,"Ed Wood").
triple(ex:sciFiMovie,rdf:subClassOf,ex:movie).
...
```

Figure: RDF triples for some movie information sites

RDFS semantics

RDFS semantics can (to a large extent) be captured by LP style rules:

```
http://www.example.org/rdfs-semantics :
 triple(P,rdf:type,rdf:Property) :- triple(S,P,O).
 triple(S,rdf:type,rdfs:Resource) :- triple(S,P,O).
 triple(O,rdf:type,rdfs:Resource) :- triple(S,P,O).
 triple(S,rdf:type,C) :- triple(S,P,O), triple(P,rdfs:domain,C).
 triple(O,rdf:type,C) :- triple(S,P,O), triple(P,rdfs:range,C).
 triple(C,rdfs:subClassOf,rdfs:Resource) :- triple(C,rdf:type,rdfs:Class).
 triple(C1,rdfs:subClassOf,C3) :- triple(C1,rdfs:subClassOf,C2),
                                  triple(C2,rdfs:subClassOf,C3).
 triple(S,rdf:type,C2)          :- triple(S,rdf:type,C1),
                                  triple(C1,rdfs:subClassOf,C2).
 triple(C,rdf:type,rdfs:Class) :- triple(S,rdf:type,C).
 triple(C,rdfs:subClassOf,C)    :- triple(C,rdf:type,rdfs:Class).
 triple(P1,rdfs:subPropertyOf,P3) :- triple(P1,rdfs:subPropertyOf,P2),
                                     triple(P2,rdfs:subPropertyOf,P3).
 triple(S,P2,O)                   :- triple(S,P1,O),
                                     triple(P1,rdfs:subPropertyOf,P2).
 triple(P,rdfs:subPropertyOf,P)   :- triple(P,rdf:type,rdf:Property).
```

plus the respective axiomatic triples in RDF/RDFS, cf. Sections 3.1 and 4.1 of

http://www.w3.org/TR/rdf-mt/.

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Adding normal logic programs on top of RDF(S)

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- We want to add arbitrary LP style rules on top of RDF(S)
- We want to allow negation as failure (normal logic programs)
- We want to base our semantics on the stable model semantics for logic programs
- But: There are some problems when allowing negation as failure on the Web

The stable model semantics for logic programs (1/2)

Syntax:
A normal logic programs P is a set of rules of the form:

$$h :- l_1, \ldots, l_n.$$

- $l_1, \ldots, l_n$ are literals, i.e. atoms $p(t_1, \ldots, t_m)$ or negated atoms `not` $p(t_1, \ldots, t_m)$, such that $t_1, \ldots, t_m$ are either constants or variables.

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- h is an atom.

Semantics:

Herbrand models defined as usual:

- U_H consists of the the set of all constants appearing in P
- B_H is the set of all atoms constructible from predicate symbols in P and constants in U_H.
- Since there are no function symbols, B_H is finite.
- A Herbrand interpretation I is a subset of B_H.
- We denote by $ground(P)$ the set of all possible **ground instantiations** of rules in P where variables are substituted with the constants in U_H.
- A Herbrand interpretation I is called Herbrand model of P if all rules in $ground(P)$ are satisfied wrt. I.
- Each positive (`not`-free) program P has a unique minimal Herbrand model M.

The stable model semantics for logic programs (2/2)

The stable models for programs with negation is defined via the *Gelfond-Lifschitz-reduct*:
Let I be a Herbrand interpretation of P. Then the reduct P^I denotes the set of rules obtained from $ground(P)$ by

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There are efficient solvers to compute stable models: `dlv`, smodels, cmodels, assat, etc.

Incomplete knowledge on the Web

Problems:

- Incompleteness: The knowledge of a search engine about the Web is notoriously incomplete, i.e. it does not know about all available Websites.

  "Search for **all** *movies by Ed Wood"*

  Cannot be answered, without e.g. local completeness assumptions. Usually, this is not a problem as long as query results are good enough (sound, at least).

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Solution: Enforce to make the scope for negation as failure always explicit!

Metadata on the Web as distributed rule sets

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`rated(m1,bad).`
`rated(X,bad) :-`
`    directedBy(X,"Ed Wood").`
	http://polleres.net/myreviews
	`rated(m2,bad).  movie(m2).`
	`rated(X,bad) :- movie(X),`
	`    not movie(X)@http://imdb.com.`
	
	http://badmovies.org/
	`movie(m1).`
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sciFiMovie(m1).  hasTitle(m1,"Plan 9 from Outer Space").
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sciFiMovie(m2).  hasTitle(m2,"Matrix Revolutions").
directedBy(m2,"Andy Wachowski").  directedBy(m2,"Larry
Wachowski").
sciFiMovie(m3).  hasTitle(m3,"Bride of the Monster").
directedBy(m3,"Ed Wood").
movie(X) :- sciFiMovie(X).
...
```

Figure: We use a more LP notation than before . . . and add rules

Syntax: Logic Programs with scoped literals

Assumption: A *program* is a set of rules associated with a URI u, where it is accessible:

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Examples of open and scoped rules:

```
http://moviereviews.com :
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http://badmovies.org :
    movie(m1).
    ...
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Requirements for a reasonable semantics for such rules

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R2 The chosen semantics should be **closed under context closure, i.e.**

$$Cn_{\mathcal{S}}(\mathcal{P}) = Cn_{\mathcal{S}}(Cl(\mathcal{P}))$$

where $Cl(\mathcal{P})$ is the set of all programs in $\mathcal{P}$ plus the ones "linked" recursively via scoped literals.

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We define two semantics based on the stable model semantics, both fullfilling R1, one of them fullfilling R2.

Contextually Bounded semantics: Cn_{CB} (1/2)

Intuitively, scoping negative literals alone is not enough, since scoped literals can again depend on open rules, e.g.

```
interestingmovie(X) :- movie(X),
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depends on whether the agent evaluating this rule knows `http://imdb.com` or not.

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> *We call a (set of) rules contextually bounded if no negative literal recursively depends on unscoped (open) literals.*

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Attention: This rule is NOT contextually bounded:

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$\Rightarrow$

$$h@p \texttt{ :- } l_1, \ \ldots, \ l_n.$$
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Contextually Bounded semantics: Cn_{CB} (2/2)

Semantics is based on usual stable model semantics, plus "linking" open and closed literals by the following rewriting p_{CB} for each rule in program p:

h `:-` l_1`,` ... `,` l_n`.`

$\Rightarrow$

$h@p$ `:-` l_1`,` ... `,` l_n`.`
h `:-` $h@p$`.`

Let $\mathcal{P}_{CB} = \bigcup_{p \in Cl(\mathcal{P})} p_{CB}$, then

$$Cn_{CB}(\mathcal{P}) = \bigcap \mathcal{M}(\mathcal{P}_{CB})$$

where $\mathcal{M}(p)$ is defined as the set of all stable models of program p

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Contextually Closed semantics Cn_{CC} (1/2)

Alternative approach: Intuitively "close off", all open rules if referenced via a scoped literal.
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- $Cn_{CC}(\mathcal{P}) \subseteq Cn_{CB}(\mathcal{P})$ (proof in [Polleres, et al. 2006]).
- It does not "traverse" closure concerning open literals, i.e. **R2** does not hold:

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  Here, $a \in Cn_{CB}(p)$, but $a \notin Cn_{CC}(p)$ which one might consider more intuitive, i.e. cross-effects of open literals only within the query context.

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- Can be used on top of RDF (modulo blank nodes)
- Clear definition of “scoped” negation
- First attempt to
  - issue context-monotonicity
  - make dinstinction between open and closed rules
- The two solution proposed are simple/cautious on purpose, trying to start discussion about the “right” semantics of scoped negation for the Semantic Web.

Related works

- FLORA-2 (Kifer): an engine for F-Logic programs, allows modules, i.e. contexts, open literals/rules supported by allowing variables in place of modules, e.g.

  $$a : -b@X.$$

  No requirement for context-monotonicity though, well-founded semantics
- TRIPLE (Decker, et al.) allows parametrized contexts, union, intersection, set difference of contexts, also parameters allowed. Negation unsupported in current implementation, AFAIK.
- C-OWL extension of OWL by contexts and bridge rules, *local model semantics*, i.e. local inconsistencies do not spread over to the whole.

Sideremark: The approach is orthogonal to LCWA (Local closed world assumption) approaches allowing local completeness statements.

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- Classical Negation, integration with the Ontology Layer (OWL)

Time allowed... How to integrate OWL with Rules?

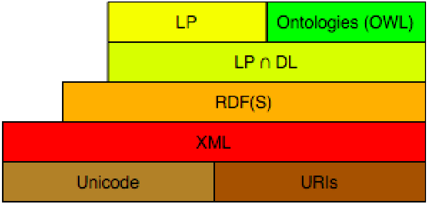
OWL (Web Ontology Language) adds more expressivity on top of RDF, allows to define taxonomies based on intersection, complement, cardinality restrictions, etc.

Axiom	DL Syntax
subClassOf	$C_1 \sqsubseteq C_2$
equivalentClass	$C_1 \equiv C_2$
disjointWith	$C_1 \sqsubseteq \neg C_2$
sameIndividualAs	$\{x_1\} \equiv \{x_2\}$
differentFrom	$\{x_1\} \sqsubseteq \neg\{x_2\}$
subPropertyOf	$P_1 \sqsubseteq P_2$
equivalentProperty	$P_1 \equiv P_2$
inverseOf	$P_1 \equiv P_2^-$
transitiveProperty	$P^+ \sqsubseteq P$
functionalProperty	$\top \sqsubseteq \leqslant 1P$
inverseFunctionalProperty	$\top \sqsubseteq \leqslant 1P^-$

Constructor	DL Syntax
intersectionOf	$C_1 \sqcap \ldots \sqcap C_n$
unionOf	$C_1 \sqcup \ldots \sqcup C_n$
complementOf	$\neg C$
oneOf	$\{x_1\} \sqcup \ldots \sqcup \{x_n\}$
allValuesFrom	$\forall P.C$
someValuesFrom	$\exists P.C$
maxCardinality	$\leqslant nP$
minCardinality	$\geqslant nP$

Expressivity in principle based on the description logic $\mathcal{SHOIN}(D)$.
(OWL DL, this is not not completely true for OWL Full)

Interoperability on the common (Horn) intersection only



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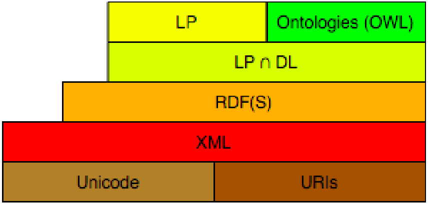


DLP:

The Horn fragment of SHOIN(D) can be understood as a rule set. So, you can understand a small part of OWL as rules.

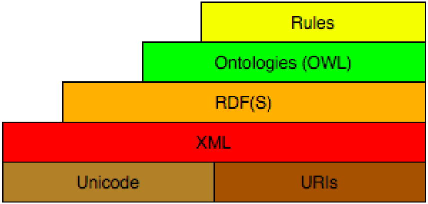
e.g. `father(X)` $\leftarrow$ `parent(X,Y),person(Y),male(X).`

$\Leftrightarrow \quad Father \sqsubseteq \exists Parent^{-1}.Human \sqcap Male$

BUT: cannot cover much either on the rules part, nor on the DL part.

Only a basis for extensions in either direction.

Rules on top of OWL – SWRL



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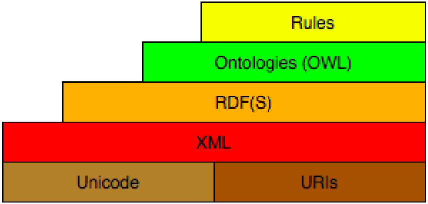

SWRL:

Add Horn rules to OWL syntax, allows you to express e.g.

`uncle(X,Y)` $\leftarrow$ `male(X), sibling(X,Z),parent(Z,Y).`

But, also:

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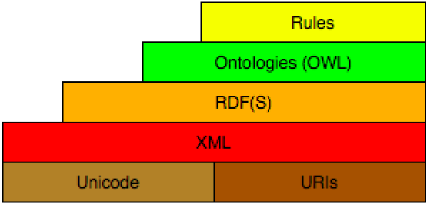

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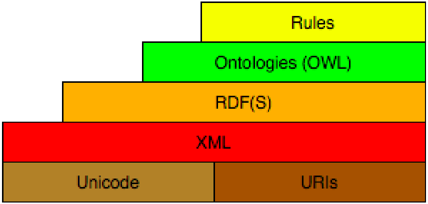

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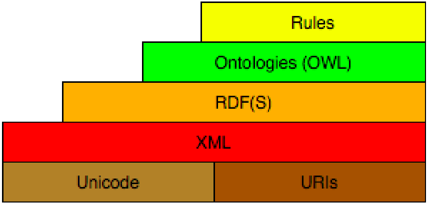

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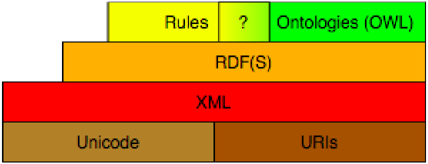
- On the one hand naive combination of Horn + DL destroys decidability of either.
- On the other hand SWRL does not even allow arbitrary HORN but only binary/unary predicates.
- Issues like open vs. closed rules, negation as failure untouched.

Interface between LP and DL – dl-programs



T. Eiter, T. Lukasiewicz, R. Schindlauer, H. Tompits *Combining Answer Set Programming with Description Logics for the Semantic Web.* KR, 2004.

Define an extension of LP under the stable model semantics by so-called dl-atoms in the body, which allow to query a DL Knowledge base, but also interchange facts in the other direction. Authors define minimal Herbrand models and stable models for dl-programs.

- pro: Decidability remains.
- con: DL KB and LP program talk about different things, exchange only via "import/export".

Generalization of this technique available, HEX-programs.
Extension to scoped literals? Not straightforward.

Thank you for your attention!