Answer Set Programming for the Semantic Web

Tutorial

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Unit 5 – An ASP Extension: Nonmonotonic dl-Programs

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Unit Outline

Social Dinner Scenario (cont'd)

- Instead of a native, simple ontology inside the program, an external ontology should be used
- An ontology is available, formulated in OWL, which contains information about available wine bottles, as instances of a concept $Wine$.
- It has further concepts $SweetWine$, $DryWine$, $RedWine$ and $WhiteWine$ for different types of wine.

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- How to use this ontology from the logic program ?
- How to ascribe a semantics for this usage?

Nonmonotonic Description Logic Programs

- An extension of answer set programs with *queries to DL knowledge bases* (through dl-*atoms*)
- Formal semantics for emerging programs (*nonmonotonic* dl-*programs*), fostering the interfacing view
  $\Rightarrow$ Clean technical separation of DL engine and ASP solver
- New generalized definitions of answer sets of a general dl-program

Important: *bidirectional flow of information*

$\Rightarrow$ The logic program also may provide *input to DL knowledge base*

Prototype implementation, examples

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Approach to enable a call to a DL engine in ASP:

- Pose a query, Q, to a DL knowledge base, L
- Allow to modify the extensional part (ABox) of KB
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Examples: wine ontology

- $DL[Wine](\text{“}ChiantiClassico\text{”})$
- $DL[Wine](X)$
- $DL[DryWine \uplus my\_dry; Wine](W)$

  add all assertions $DryWine(c)$ to the ABox (extensional part) of L, such that $my\_dry(c)$ holds.

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dl-Atoms /2

A dl-*atom* has the form

$$DL[S_1\, op_1 p_1, \ldots, S_m\, op_m\; p_m; Q](\mathbf{t})\,, \qquad m \geq 0,$$

where

- each S_i is either a concept or a role
- $op_i \in \{\uplus, \uminus\}$,
- p_i is a unary resp. binary predicate (*input predicate*),
- $Q(\mathbf{t})$ is a *DL query*.

Intuitively:

$op_i = \uplus$ increases S_i by p_i.
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DL Queries

A *DL query* $Q(\mathbf{t})$ is one of

(a) a concept inclusion axiom $C \sqsubseteq D$, or its negation $\neg(C \sqsubseteq D)$,

(b) $C(t)$ or $\neg C(t)$, for a concept C and term t, or

(c) $R(t_1, t_2)$ or $\neg R(t_1, t_2)$, for a role R and terms t_1, t_2.

Remarks:

- Further queries are conceivable (e.g., conjunctive queries)
- The queries above are standard queries.

dl-Programs

A dl-*rule* r is of form

$$a \leftarrow b_1, \ldots, b_k, not\ b_{k+1}, \ldots, not\ b_m\,, \qquad m \geq k \geq 0,$$

where

- a is a classical first-order literal
- $b_1, \ldots, b_m$ are classical first-order literals or dl-atoms (no function symbols).

Definition

A *nonmonotonic description logic* $(\mathrm{dl}\text{-})$ *program* $KB = (L, P)$ consists of

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Social Dinner IX

Task

Modify wineCover09a.dlp by fetching the wines now from the ontology.

For instance:

```
wineBottle(X) :- DL["Wine"](X).
```

Fetches all the known instances of *Wine*.

Think at how the "`isA`" predicate could be redefined in terms of dl-atoms

```
isA(X,"SweetWine") :- ?
isA(X,"DessertWine") :- ?
isA(X,"ItalianWine") :- ?
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Solution at

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Solution at `wineCover9b.dlp`

Social Dinner X

- Suppose now that we learn that there is a bottle, *"SelaksIceWine"*, which is a white wine and not dry.
- We may add this information to the logic program by facts[1]:

```
white("SelaksIceWine"). not_dry("SelaksIceWine").
```

- In our program, we may pass this information to the ontology by adding in the dl-atoms the modification

$$WhiteWine \uplus white, DryWine \cupminus not\_dry.$$

E.g., `DL[Wine](X)` is changed to

```
DL[WhiteWine += white, DryWine -= not_dry; Wine](X).
```

[1] See wineCover09c.dlp

Semantics of $KB = (L, P)$

- HB_P^Φ: Set of all ground (classical) literals with predicate symbol in P and constants from finite relational alphabet Φ.
- Constants: those in P and (all) individuals in the ABox of L.
- Herbrand interpretation: consistent subset $I \subseteq HB_P^\Phi$
  - $I \models_L \ell$ for classical ground literal ℓ, iff $\ell \in I$;
  - $I \models_L DL[S_1\, op_1\, p_1 \ldots, S_m\, op_m\, p_m; Q](\mathbf{c})$ if and only if

$$L \cup A_1(I) \cup \cdots \cup A_m(I) \models Q(\mathbf{c}),$$

  where
    - $A_i(I) = \{S_i(\mathbf{e}) \mid p_i(\mathbf{e}) \in I\}$, for $op_i = \uplus$;
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Examples

- Suppose $L \models Wine(\text{“}TaylorPort\text{”})$, and I contains $wineBottle(\text{“}TaylorPort\text{”})$

  Then $I \models_L DL[\text{“}Wine\text{”}](\text{“}TaylorPort\text{”})$ and

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- Suppose $I = \{white(\text{“}siw\text{”}),\ not\_dry(\text{“}siw\text{”})\}$.

  Then $I \models_L DL[\text{“}WhiteWine\text{”} \uplus white, \text{“}DryWine\text{”} \uplus not\_dry; \text{“}Wine\text{”}](\text{“}siw\text{”})$

  Note that if “siw” does not occur in L, then $I \not\models_L DL[\text{“}WhiteWine\text{”} \uplus white, \text{“}DryWine\text{”} \uplus not\_dry; \text{“}Wine\text{”}](\text{“}siw\text{”})$

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- Suppose $L \not\models DL[\text{“}Wine\text{”}](\text{“}Milk\text{”})$. Then for every I,

$$I \models_L compliant(joe, \text{“}Milk\text{”}) \text{ :- } DL[\text{“}Wine\text{”}](\text{“}Milk\text{”})$$

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- Inconsistency of L is revealed with unsatisfiable DL queries:

$$inconsistent \text{ :- } DL[\text{“}Wine\text{”} \sqsubseteq \neg\text{“}Wine\text{”}]$$

Shorthand: $DL[\bot]$

- Consistency can be checked by

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Answer Sets

Answer Sets of positive $KB = (L, P)$ (no *not* in P):

- $KB = (L, P)$ has the least model $lm(KB)$ (if satisfiable)
- The single answer set of KB is $lm(KB)$

Answer Sets of general $KB = (L, P)$:

- Use a reduct KB^I akin to the Gelfond-Lifschitz (GL) reduct:

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Some Semantical Properties

- *Existence:* Positive dl-programs without "$\neg$" and constraints always have an answer set
- *Uniqueness:* Layered use of "not" (stratified dl-program) $\Rightarrow$ single answer set
- *Conservative extension:* For dl-program $KB = (L, P)$ without dl-atoms, the answer sets are the answer sets of P.
- *Minimality:* answer sets of KB are models, and moreover minimal models.
- *Fixpoint Semantics:* Positive and stratified dl-programs with monotone dl-atoms possess fixpoint characterizations of the answer set.

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- dl-atoms allow to query description knowledge base repeatedly
- We might use dl-programs as rule-based "glue" for inferences on a DL base.
- In this way, inferences can be combined
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- Here, we show some applications where non-monotonic and minimization features of dl-programs can be exploited

Closed World Assumption (CWA)

Reiter's Closed World Assumption (CWA)

For ground atom $p(c)$, infer $\neg p(c)$ if $KB \not\models p(c)$

- Express CWA for concepts $C_1, \ldots, C_k$ wrt. individuals in L:

$$\begin{array}{rcl} \neg c_1(X) & \leftarrow & not\ DL[C_1](X) \\ & \cdots & \\ \neg c_k(X) & \leftarrow & not\ DL[C_k](X) \end{array}$$

- CWA for roles R: easy extension

Query Answering under CWA

Example: $L = \{$ $SparklingWine(\text{``}VeuveCliquot\text{''})$,
$(Sparklingwine \sqcap \neg WhiteWine)(\text{``}Lambrusco\text{''})$ $\}$.

Query: $WhiteWine(\text{``}VeuveCliquot\text{''})$ (Y/N)?

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Query: $\mathit{WhiteWine}(\text{“}\mathit{VeuveCliquot}\text{”})$ (Y/N)?

Add CWA-literals to L:

$$\begin{array}{rcl} \overline{sp}(X) & \leftarrow & not\ \ DL[\mathit{SparklingWine}](X) \\ \overline{ww}(X) & \leftarrow & not\ \ DL[\mathit{WhiteWine}](X) \\ ww(X) & \leftarrow & DL[\mathit{SparklingWine} \uplus \overline{sp}, \\ & & \quad \mathit{WhiteWine} \uplus \overline{ww};\ \mathit{WhiteWine}](X) \end{array}$$

Ask whether $KB \models ww(\text{“}\mathit{VeuveCliquot}\text{”})$ or
$KB \models \neg ww(\text{“}\mathit{VeuveCliquot}\text{”})$

Extended CWA

- CWA can be inconsistent (disjunctive knowledge)
- **Example:**
  Knowledge base

$$L \;=\; \{\ Artist(\text{“}Jody\text{”}), Artist \equiv Painter \sqcup Singer\ \}$$

  - CWA for $Painter, Singer$ adds

$$\neg Painter(\text{“}Jody\text{”}), \neg Singer(\text{“}Jody\text{”}).$$

  - This implies $\neg Artist(\text{“}Jody\text{”})$

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Minimal Models

- ECWA singles out "minimal" models of L wrt $Painter$ and $Singer$ (UNA in L on ABox):

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\begin{aligned}
\overline{p}(X) &\leftarrow not\ p(X) \\
\overline{s}(X) &\leftarrow not\ s(X) \\
p(X) &\leftarrow DL[Painter \uplus \overline{p}, Singer \uplus \overline{s}; Painter](X) \\
s(X) &\leftarrow DL[Painter \uplus \overline{p}, Singer \uplus \overline{s}; Singer](X) \\
f &\leftarrow not\ f,\ DL[\bot] \quad \text{/* kill model if } L \text{ is inconsistent */}
\end{aligned}
$$

Answer sets:

$$
\begin{aligned}
M_1 &= \{p(\text{"}Jody\text{"}), \overline{s}(\text{"}Jody\text{"})\}, \\
M_2 &= \{s(\text{"}Jody\text{"}), \overline{p}(\text{"}Jody\text{"})\}
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- Extendible to keep concepts "fixed"
$\leadsto$ ECWA$(\phi; P; Q; Z)$

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Default Reasoning

Add simple default rules a la Poole (1988) on top of ontologies

Example: wine ontology

$$L = \{\ \mathit{SparklingWine}(\text{“}\mathit{VeuveCliquot}\text{”}),\ (\text{“}\mathit{SparklingWine}\text{”} \sqcap \neg \text{“}\mathit{WhiteWine}\text{”})(\text{“}\mathit{Lambrusco}\text{”})\ \},$$

Use default rule: Sparkling wines are white by default

$$\begin{array}{lrcl} r1: & \mathit{white}(W) & \leftarrow & DL[\mathit{SparklingWine}](W), \mathit{not}\, \neg \mathit{white}(W) \\ r2: & \neg \mathit{white}(W) & \leftarrow & DL[\mathit{WhiteWine} \uplus \mathit{white}; \neg \mathit{WhiteWine}](W) \\ r3: & f & \leftarrow & \mathit{not}\ \ f, DL[\bot] \quad \text{/* kill model if } L \text{ is inconsistent */} \end{array}$$

- In answer set semantics, $r2$ effects maximal application of $r1$.
- Answer Set: $M = \{\mathit{white}(\text{“}\mathit{VeuveCliquot}\text{”}),\ \neg \mathit{white}(\text{“}\mathit{Lambrusco}\text{”})\}$

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Further Aspects of dl-programs

- Stratified dl-programs: intuitively, composed of hierarchic layers of positive dl-programs linked via default negation.

  This generalization of the classic notion of stratification embodies a fragment of the language having single answer sets.

- Non-monotonic dl-atoms: Operator $\cap\!\!\!\!-$

$$DL[WhiteWine \cap\!\!\!\!- my\_WhiteWine](X)$$

  Constrain $WhiteWine$ to $my\_WhiteWine$

- *Weak answer-set semantics* (Here: Strong answer sets)

  Treat also positive dl-atoms like not-literals in the reduct

- *Well-founded semantics*

  Generalization of the traditional well-founded semantics for normal logic programs.

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Computational Complexity

Deciding strong answer set existence for dl-programs (completeness results)

$KB = (L, P)$	L in $\mathcal{SHIF}(\mathbf{D})$	L in $\mathcal{SHOIN}(\mathbf{D})$
positive	EXP	NEXP
stratified	EXP	$\mathrm{P}^{\mathrm{NEXP}}$
general	NEXP	$\mathrm{NP}^{\mathrm{NEXP}}$

Recall: Satisfiability problem in

- $\mathcal{SHIF}(\mathbf{D})$ / $\mathcal{SHOIN}(\mathbf{D})$ is EXP-/NEXP-complete (unary numbers).
- ASP is EXP-complete for positive/stratified programs P, and NEXP-complete for arbitrary P

- **Key observation:** The number of ground dl-atoms is polynomial
- $\mathrm{NP}^{\mathrm{NEXP}} = \mathrm{P}^{\mathrm{NEXP}}$ is less powerful than disjunctive ASP ($\equiv \mathrm{NEXP}^{\mathrm{NP}}$)
- Similar results for query answering

NLP-DL Prototype

- Fully operational prototype: NLP-DL

  `http://www.kr.tuwien.ac.at/staff/roman/semweblp/`.

- Accepts ontologies formulated in OWL-DL (as processed by RACER) and a set of dl-rules, where $\leftarrow$, $\uplus$, and $\cup\!\!\!\!-$, are written as `":-"`, `"+="`, and `"-="`, respectively.

- Model computation: compute
  - the answer sets
  - the well-founded model

  Preliminary computation of the well-founded model may be exploited for optimization.

- Reasoning: both *brave* and *cautious reasoning*; well-founded inferences

Example: Review Assignment

It is given an ontology about scientific publications

- Concept *Author* stores authors
- Concept *Senior* (senior author)
- Concept *Club100* (authors with more than 100 paper)
- ...

- Goal: Assign submitted papers to reviewers
- Note: Precise definitions are not so important (encapsulation)

Review Assignment /2

Facts:

```
paper(subm1). author(subm1,"jdbr"). author(subm1,"htom").
paper(subm2). author(subm2,"teit"). author(subm2,"gian").
              author(subm2,"rsch"). author(subm2,"apol").
```

The program committee:

```
pc("vlif"). pc("mgel"). pc("dfen"). pc("fley"). pc("smil").
pc("mkif"). pc("ptra"). pc("ggot"). pc("ihor").
```

All PC members are in the “Club100” with more than 100 papers:
Consider all senior researchers as candidate reviewers adding the club100 information to the OWL knowledge base:

```
cand(X,P) :- paper(P), DL["club100" += pc;"senior"](X).
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Review Assignment /3

Guess a reviewer assignment:

```
assign(X,P) :- not -assign(X,P), cand(X,P).
-assign(X,P) :- not assign(X,P), cand(X,P).
```

Check that each paper is assigned to at most one person:

```
:- assign(X,P), assign(X1,P), X1 != X.
```

A reviewer can't review a paper by him/herself:

```
:- assign(A,P), author(P,A).
```

Check whether all papers are correctly assigned (by projection)

```
a(P) :- assign(X,P).
error(P) :- paper(P), not a(P).
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Note: error(P) detects unassignable papers rather than a simple constraint.

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Task

Try out the complete reviewer example!

Run reviewer.dlp !