Inconsistencies in Hybrid Knowledge Bases

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1. Motivation

- Hybrid Knowledge Bases: combination of different logical formalisms

Loose coupling (DL-programs, F-Logic#..)	Tight coupling (SWRL, ELP..)	Embedding (MKNF, Open ASP..)

- Inconsistencies easily emerge in HKBs

DL-program $\Pi = \langle \mathcal{O}, P \rangle$ is inconsistent

$$\mathcal{O} = \left\{ \begin{array}{ll} (1)\ Child \sqsubseteq \exists hasParent & (4)\ Male(pat) \\ (2)\ Adopted \sqsubseteq Child & (5)\ Male(john) \\ (3)\ Female \sqsubseteq \neg Male & (6)\ hasParent(john, pat) \end{array} \right\}$$

$$P = \left\{ \begin{array}{l} (7)\ ischildof(john, alex); \quad (8)\ boy(john); \\ (9)\ hasfather(john, pat) \leftarrow DL[Male \uplus boy; Male](pat), \\ \qquad DL[; hasParent](john, pat); \\ (10)\ \perp \leftarrow \textit{not } DL[; Adopted](john), pat \neq alex, \\ \qquad hasfather(john, pat), ischildof(john, alex), \\ \qquad \textit{not } DL[Child \uplus boy; \neg Male](alex) \end{array} \right\}$$

$\mathcal{A}' = \{Male(john), hasParent(john, pat)\}$ is a possible repair of Π yielding repair answer set $I = \{ischild(john, alex), boy(john)\}$

- **Aim of this work:** methodology for repairing Hybrid KBs (at $\mathcal{O}$ side)
- **Contributions:**
  - Framework for repair computation and its complexity
  - Implementation and evaluation of developed framework

3. DL-program Evaluation

Given:

- $\Pi = \langle \mathcal{O}, P \rangle$, $P = \left\{ r(c);\ q(c) \leftarrow \underbrace{DL[C \cup r; D](c)}_{a_1} \right\}$, $\mathcal{O} = \{C \sqsubseteq D;\ A(c)\}$

Construct:

- $\hat{\Pi} = \{r(c);\ q(c) \leftarrow e_{a_1};\ e_{a_1} \vee ne_{a_1}\}$ (ne_{a_1}: negation of e_{a_1})

Compute:

- Answer sets of $\hat{\Pi}$: $AS(\hat{\Pi}) = \{\overbrace{\{r(c), ne_{a_1}\}}^{\hat{I}_1}, \overbrace{\{r(c), e_{a_1}, q(c)\}}^{\hat{I}_2}\}$

Check:

- Compatibility: $\hat{I}_1(e_{a_1}) = \textit{false} \Leftrightarrow \hat{I}_1|_{\Pi} \not\models^{\mathcal{O}} a_1$? ✓
  $\neg C(c) \cup \mathcal{O} \not\models D(c)$ thus $\hat{I}_1$ is compatible!
- Minimality: Is $\hat{I}_1|_{\Pi} = \{r(c)\}$ minimal model of Π? ✓
  A smaller model does not exist, thus $\hat{I}_1|_{\Pi}$ is minimal!

$\hat{I}_1|_{\Pi}$ is an ***flp***-answer set of Π. ($\hat{I}_2|_{\Pi}$ is not, compatibility fails)

Reasons for Inconsistency:

- $AS(\hat{\Pi}) = \emptyset$
- for all $\hat{I} \in AS(\hat{\Pi})$: compatibility or minimality check failed

2. DL-programs

- **DL-program**: ontology + rules (loose-coupling approach)
- **DL-atoms** serve as query interfaces to ontology
- Bidirectional information flow between ontology and rules

$\Pi = \langle \mathcal{O}, P \rangle$ is a DL-program

$\mathcal{O} = \{ (1)\ C \sqsubseteq D \quad (2)\ A(c) \}$

DL-atom 1
ontology $\mathcal{O}$
rules P
DL-atom 2

$$P = \left\{ (3)\ r(c); \quad (4)\ q(c) \leftarrow \overbrace{DL[C \uplus r; D](c),\ DL[; A](c)}^{\text{DL-atoms}} \right\}$$

- Interpretation: $I = \{r(c), q(c)\}$
- Satisfaction relation: $I \models^{\mathcal{O}} q(c);\ I \models^{\mathcal{O}} DL[; A](c)$
- Semantics is given in terms of answer sets
- **Inconsistent** DL-program is the one without any answer sets

4. Repair Approach

Given:

- $\Pi = \langle \mathcal{O}, P \rangle$, s.t. $P = \left\{ \begin{array}{l} p(c);\ \ r(c);\ \ q(c) \leftarrow \underbrace{DL[C \cup r; D](c)}_{a_1}; \\ \perp \leftarrow \underbrace{DL[D \uplus p, E \cup r; \neg C](c)}_{a_2} \end{array} \right\}$

$$\mathcal{O} = \{E \sqsubseteq D; A \sqsubseteq D; A(c); \neg C(c); E(c)\}$$

Compute support sets for $a_1(X)$, $a_2(X)$:

- $\mathcal{S}_{a_1} = \{\{D(X)\}, \{A(X)\}, \{E(X)\}, \{\neg C_r(Y), C(Y)\}\}$
- $\mathcal{S}_{a_2} = \{\{\neg C(X)\}, \{D_p(Y), \neg D(Y)\}, \{\neg E_r(Y), E(Y)\}\}$

For each $\hat{I} \in AS(\hat{\Pi})$:

- $\hat{I} = \{p(c),\ r(c),\ q(c),\ e_{a_1}\}$: a_1 is guessed ***true***, a_2 is guessed ***false***

Construct Ontology Repair Problem (ORP) $\mathcal{P} = \langle \mathcal{O}, D_1, D_2 \rangle$, where

- $D_1 = \{\langle \{\neg C(c)\}; D(c) \rangle\}$, $D_2 = \{\langle \{D(c), \neg E(c)\}; \neg C(c) \rangle\}$

Ground support sets $\mathcal{S}_{a_i}$:

- $Grnd(\mathcal{S}_{a_1}, \hat{I}, \mathcal{A}) = \{\{A(c)\}, \{E(c)\}\}$
- $Grnd(\mathcal{S}_{a_2}, \hat{I}, \mathcal{A}) = \{\{\neg C(c)\}, \{\neg E_r(c), E(c)\}\}$

Compute Repair $\mathcal{A}'$ for $\mathcal{P}$ s.t.

- $\mathcal{O}' = \langle \mathcal{T}, \mathcal{A}' \rangle$ is consistent, $\mathcal{O}' \cup \{\neg C(c)\} \models D(c)$,
  $\mathcal{O}' \cup \{D(c), \neg E(c)\} \not\models \neg C(c)$

$\mathcal{A}'$ = $\{A(c), \neg C(c), E(c)\}$ is a deletion repair!

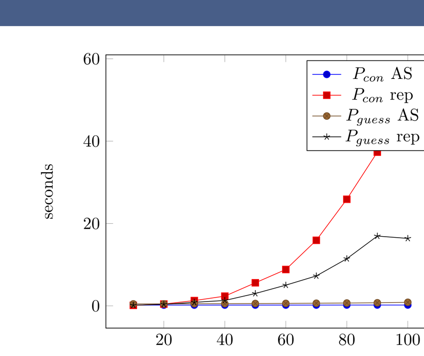
5. Results

- Repair semantics for DL-programs and its complexity (*IJCAI'13*)
  - Independent repair selection functions
  - Sound and complete deletion repair algorithm

- Support sets as optimization means (*AAAI'14*)
- Usage of complete support families for $DL\text{-}Lite_{\mathcal{A}}$ (*ECAI'14, DL'14*)
- Usage of incomplete support families for $\mathcal{EL}$ (*JELIA'14*)
- Implementation within dlvhex framework, evaluation
- Independent DL-atoms, calculus for their derivation (*RR'12*)

6. Future Work

- Further benchmark construction and evaluation
- Size bounded and other preferred repairs (implementation)
- Completeness conditions on support families for $\mathcal{EL}$
- Wrapping up..



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FWF Der Wissenschaftsfonds.