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Data Repair of Inconsistent DL-programs

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1. Motivation

- Information exchange between rules and ontology can cause inconsistency.

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

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

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

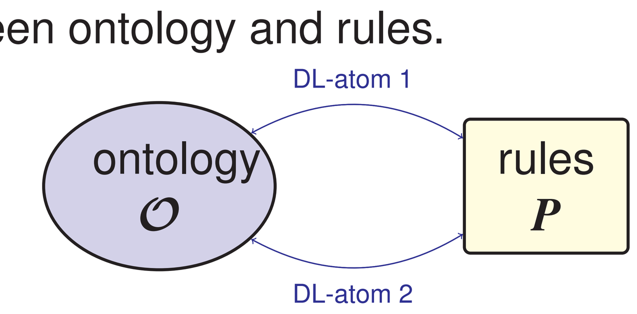
- **Aim of this work:** change ontology ABox to make DL-program consistent.
- $\mathcal{A}' = \{Male(john), hasParent(john, pat)\}$ is a possible repair of Π that yields *flp*-repair answer set $I = \{ischild(john, alex), boy(john)\}$.
- **Contributions:**
  - Notion of repair and repair answer set;
  - Preference selection function σ and its independence property;
  - Sound and complete algorithm for repair computation;
  - Tractable cases of special ontology repair problem for $DL\text{-}Lite_{\mathcal{A}}$.

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.

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



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

- 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, which are x-founded models;
- **Inconsistent** DL-program is the one that does not have any answer sets;
- *weak* and *flp* semantics are relevant in this work.

Consider ontologies in $DL\text{-}Lite_{\mathcal{A}}$ (CQ answering is tractable [Calvanese *et al.*, 2007]).

3. DL-program Evaluation

Given:

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

Construct:

- $\hat{\Pi} = \{r(c);\ q(c) \leftarrow e_{a_1};\ e_{a_1} \vee ne_{a_1}\}$ (ne_{a_1} corresponds to 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: $\hat{I}_1(e_{a_1}) = false \Leftrightarrow \hat{I}_1|_{\Pi} \not\models^{\mathcal{O}} a_1$? ✓
  It holds that $\neg C(c) \cup \mathcal{O} \not\models D(c)$ 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. ($\hat{I}_2$ is not compatible, hence $\hat{I}_2|_{\Pi}$ is not an answer set).

Reasons for Inconsistency:

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

4. Ontology Repair Problem (ORP)

Ontology repair problem (ORP) is a triple $\mathcal{P} = \langle \mathcal{O}, D_1, D_2 \rangle$, where

- $\mathcal{O} = \langle \mathcal{T}, \mathcal{A} \rangle$: ontology;
- $D_i = \{\langle U_j^i, Q_j^i \rangle | 1 \leq j \leq m_i\}$ is s.t. U_j^i: any ABox, Q_j^i: DL-query.

Related problems were studied in [Sakama, *et al.*, 2003; Calvanese *et al.*, 2012].

Repair (solution) for $\mathcal{P}$ is any ABox $\mathcal{A}'$ s.t.

- $\mathcal{O}' = \langle \mathcal{T}, \mathcal{A}' \rangle$ is consistent;
- $\tau(\langle \mathcal{T}, \mathcal{A}' \cup U_k^1 \rangle) \models Q_j^1$ holds for $1 \leq j \leq m_1$;
- $\tau(\langle \mathcal{T}, \mathcal{A}' \cup U_k^2 \rangle) \not\models Q_j^2$ holds for $1 \leq j \leq m_2$.

Given:

- $\Pi = \langle \mathcal{O}, P \rangle$, s.t. $P = \left\{ \begin{array}{l} p(c);\ \ r(c);\ \ q(c) \leftarrow \underbrace{DL[C \uplus r; D](c)}_{a_1}; \\ \bot \leftarrow \underbrace{DL[D \uplus p, E \uplus r; \neg C](c)}_{a_2} \end{array} \right\}$
- $\hat{I} = \{p(c),\ r(c),\ q(c),\ e_{a_1}\}$: a_1 is guessed *true*, a_2 is guessed *false*.

Construct: ORP $\mathcal{P} = \langle \mathcal{O}, D_1, D_2 \rangle$, where

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

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

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

> ORP is NP-complete even for $\mathcal{O} = \emptyset$!

ABox $\mathcal{A}' = \{A(c)\}$ is a possible repair for $\mathcal{P}$ if $\mathcal{O} = \{E \sqsubseteq D; A \sqsubseteq D; \neg C(c)\}$.

5. Selection Preferences and Tractable Cases of ORP

Selection function σ: given set of ABoxes S and ABox $\mathcal{A}$ selects σ-preferred $S' \subseteq S$.
Independent σ: given $\mathcal{A}$ one can immediately decide whether $\mathcal{A}' \in S$ is σ-selected.

- deletion repair is independent;
- set-minimal (cardinality minimal) change repair is not independent.

Tractable cases of ORP (C1-C4 are independent):

C1. bounded $\delta^{\pm}$-change: $\sigma_{\delta^{\pm},k}(S, \mathcal{A}) = \{\mathcal{A}' \mid |\mathcal{A}' \Delta \mathcal{A}| \leq k\}$, for some k;
C2. deletion repair: $\sigma_{del}(S, \mathcal{A}) = \{\mathcal{A}' \mid \mathcal{A}' \subseteq \mathcal{A}\}$;
C3. deletion δ^{+}: first apply σ_{del} and get $\mu(\mathcal{O})$ s.t. for all $1 \leq j \leq m_2$ $\tau(\langle \mathcal{T}, \mathcal{A}' \cup U_j^2 \rangle) \not\models Q_j^2$, then further compute $\sigma_{\delta^{+}}(S, \mu(\mathcal{O}))$;
C4. addition under bounded opposite polarity:
$\sigma_{bop}(S, \mathcal{A}) = \{\mathcal{A}' \supseteq \mu(\mathcal{O}) \mid |\mathcal{A}'^{+} \backslash \mathcal{A}| \leq k$ or $|\mathcal{A}'^{-} \backslash \mathcal{A}| \leq k\}$, for some k.

6. Repair Answer Set Computation

- ***RepAns*** extends DL-program evaluation to DL-program repair computation;
- ***RepAnsSet*** uses ***RepAns*** to compute answer sets of repaired program.

> ***RepAns*** and ***RepAnsSet*** are sound and complete for independent σ.

Complexity of deciding the existance of repair AS is the same as for normal AS.

Π	$RAS_{FLP}(\Pi) \neq \emptyset$	$RAS_{weak}(\Pi) \neq \emptyset$
normal	Σ_2^P-complete	NP-complete
disjunctive	Σ_2^P-complete	Σ_2^P-complete

7. References

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FWF Der Wissenschaftsfonds.