Computing Repairs for Inconsistent DL-programs over $\mathcal{EL}$ Ontologies

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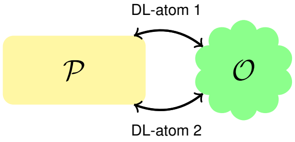
Motivation

- DL-program: rules $\mathcal{P}$ + consistent ontology $\mathcal{O}$ (loose coupling combination approach)
- DL-atoms serve as query interfaces to $\mathcal{O}$
- Possibility to add info from $\mathcal{P}$ to $\mathcal{O}$ prior to querying it: bidirectional data flow



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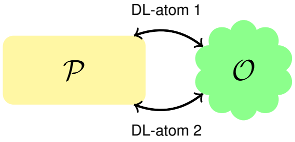

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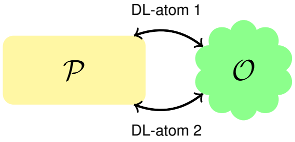

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✓ Repair answer sets [E_ *et* al, *IJCAI* 2013]

✓ Algorithm based on complete support families [E_ *et* al, *ECAI* 2014]

Effective for *DL-Lite*$_\mathcal{A}$ (few small support sets per DL-atom)
Not well suited for $\mathcal{EL}$ (might be many / large support sets . . .)

In this work: algorithm for repairing DL-programs over $\mathcal{EL}$ ontologies

Overview

$\mathcal{EL}$ Description Logic

- Lightweight DL, widely used in biology, medicine and other domains
- Concepts and roles model sets of objects and their relationships
- $\mathcal{EL}$-concept is formed according to the rule

$$C ::= A \mid \top \mid C \sqcap C \mid \exists R.C$$

- An $\mathcal{EL}$ ontology $\mathcal{O} = \langle \mathcal{T}, \mathcal{A} \rangle$ consists of
  - TBox $\mathcal{T}$ specifying inclusions/equivalence between $\mathcal{EL}$-concepts
    $$C \sqsubseteq D \quad C \equiv D$$
  - ABox $\mathcal{A}$ specifying facts that hold in the domain
    $$A(b) \qquad R(a,b)$$

Example

$$\mathcal{T} = \left\{ \begin{array}{l} Blacklisted \sqsubseteq Staff \\ BLStaffRequest \equiv StaffRequest \sqcap \exists hasSubject.Blacklisted \end{array} \right\}$$

$$\mathcal{A} = \{\ StaffRequest(r1) \quad hasSubject(r1, john) \quad Blacklisted(john) \}$$

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- Normalized TBox $\mathcal{T}_{norm}$ contains only inclusions of the form

$$A_1 \sqsubseteq A_2 \quad A_1 \sqcap A_2 \sqsubseteq A_3 \quad \exists R.A_1 \sqsubseteq A_2 \quad A_1 \sqsubseteq R.A_2$$ [1]

[1] A_i is an atomic concept

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

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$$\mathcal{P} = \left\{ \begin{array}{l} (7)\ \mathit{projfile}(\mathit{p1});\quad (8)\ \mathit{hasowner}(\mathit{p1}, \mathit{john}); \\ (9)\ \mathit{grant}(\mathit{r1}) \leftarrow \mathrm{DL}[\mathit{Proj} \uplus \mathit{projfile}; \mathit{StaffRequest}](\mathit{r1}), \mathit{not\ deny}(\mathit{r1}) \\ (10)\ \mathit{deny}(\mathit{r1}) \leftarrow \mathrm{DL}[; \mathit{BLStaffRequest}](\mathit{r1}) \end{array} \right\}$$

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Further repair for I: e.g. remove $\mathit{Blacklisted}(john)$

Support Sets for DL-atoms

$$\mathcal{O} = \Big\{ \overbrace{(1)\ StaffRequest \equiv \exists hasTarg.Proj}^{\mathcal{T}} \quad \overbrace{(2)\ hasTarg(r1, p1)}^{\mathcal{A}} \Big\}$$

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- Nonground Support Set for $d(\mathbf{X})$ is $S = \langle N, \gamma \rangle$, where
  N: set of nonground literals over input predicates of $d(\mathbf{X})$

  γ : "guard" function, selects from groundings of N support sets for $d(c)$

Support Sets for DL-atoms

$$\mathcal{O} = \Bigg\{ \overbrace{(1)\ \mathit{StaffRequest} \equiv \exists \mathit{hasTarg}.\mathit{Proj}}^{\mathcal{T}} \quad \overbrace{(2)\ \mathit{hasTarg}(r1, p1)}^{\mathcal{A}} \Bigg\}$$

$$d = \text{DL}[\mathit{Proj} \uplus \mathit{projfile}; \mathit{StaffRequest}](\mathbf{X})$$

- Support Sets encode partial info about $\mathcal{O}$, relevant for value of d
- Ground Support Set for d is set S of atoms over *projfile* such that for all interpretations $I \supseteq S$, it holds that $I \models d$ ("*implicant*")

  E.g., $S = \{\mathit{projfile}(p1)\}$

- Complete Support Family $\mathcal{S}$ for d consists of S's s.t. whenever $I \models d$, some $S \in \mathcal{S}$ with $I \supseteq S$ exists
- Nonground Support Set for $d(\mathbf{X})$ is $S = \langle \overbrace{\mathit{projfile}(Y)}^{N}, \gamma \rangle$, where
  N: set of nonground literals over input predicates of $d(\mathbf{X})$

  $\gamma : \mathcal{C} \times \mathit{grnd}_{\mathcal{C}}(\mathit{projfile}(Y)) \rightarrow \{0, 1\}$ where $\gamma(c, \mathit{projfile}(c')) = 1$ if $\mathit{hasTarg}(c, c') \in \mathcal{A}$

Nonground Support Set Computation

$\mathcal{T} = \{StaffRequest \equiv \exists hasSubj.Staff \sqcap \exists hasTarg.Proj\}$
$d = \text{DL}[Proj \uplus projfile; StaffRequest](X)$

Nonground Support Set Computation

$\mathcal{T} = \{StaffRequest \equiv \exists hasSubj.Staff \sqcap \exists hasTarg.Proj\}$
$d = \mathrm{DL}[Proj \uplus projfile; StaffRequest](X)$

- Construct $\mathcal{T}_d$ by compiling info about input predicates of d into $\mathcal{T}$:
  $\mathcal{T}_d = \mathcal{T} \cup \{Proj_{projfile} \sqsubseteq Proj\}$

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- Rewrite DL-query over normalized $\mathcal{T}_d$ into a datalog program:

$$\mathcal{T}_{d_{norm}} = \left\{ \begin{array}{ll} (1)\ StaffRequest \sqsubseteq \exists hasSubj.Staff & (2)\ Proj_{projfile} \sqsubseteq Proj \\ (3)\ StaffRequest \sqsubseteq hasTarg.Proj & (4)\ \exists hasSubj.Staff \sqsubseteq C_1 \\ (5)\ \exists hasTarg.Proj \sqsubseteq C_2 & (6)\ C_1 \sqcap C_2 \sqsubseteq StaffRequest \end{array} \right\}$$

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$d = \mathrm{DL}[Proj \uplus projfile; StaffRequest](X)$

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- Rewrite DL-query over normalized $\mathcal{T}_d$ into a datalog program:

$$\mathcal{P}_{\mathcal{T}_{d_{norm}}} = \left\{ \begin{array}{l} (1^*)\ StaffRequest(X) \leftarrow C_1(X), C_2(X) \\ (2^*)\ C_1(X) \leftarrow hasSubj(X,Y), Staff(Y) \\ (3^*)\ C_2(X) \leftarrow hasTarg(X,Y), Proj(Y) \\ (4^*)\ Proj(X) \leftarrow Proj_{projfile}(X) \end{array} \right\}$$

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- Unfold the DL-query and extract support sets:

$StaffRequest(X) \leftarrow hasSubj(X,Y), Staff(Y), hasTarg(X,Z), Proj(Z)$
$StaffRequest(X) \leftarrow hasSubj(X,Y), Staff(Y), hasTarg(X,Z), Proj_{projfile}(Z)$

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- Unfold the DL-query and extract support sets:

  $S_1 = \langle \emptyset, \gamma \rangle$ (i.e., $N = \emptyset$) and $\gamma(c, \emptyset) = 1$ if for some c', c'', we have $hasSubj(c, c'), Staff(c'), hasTarg(c, c''), Proj(c'') \in \mathcal{A}$

  $S_2 = \langle projfile(X), \gamma \rangle$ (i.e., $N = \{projfile(X)\}$), and $\gamma(c, projfile(c')) = 1$ if for some c'', we have $hasSubj(c, c''), Staff(c''), hasTarg(c, c') \in \mathcal{A}$

Nonground Support Set Computation

$\mathcal{T} = \{StaffRequest \equiv \exists hasSubj.Staff \sqcap \exists hasTarg.Proj\}$
$d = \text{DL}[Proj \uplus projfile; StaffRequest](X)$

- Construct $\mathcal{T}_d$ by compiling info about input predicates of d into $\mathcal{T}$:
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- Unfold the DL-query and extract support sets:

$S_1 = \{hasSubj(X, Y), Staff(X), hasTarg(X, Z), Proj(Z)\}$
$S_2 = \{hasSubj(X, Y), Staff(X), hasTarg(X, Z), Proj_{projfile}(Z)\}$

Nonground Support Set Computation

$\mathcal{T} = \{StaffRequest \equiv \exists hasSubj.Staff \sqcap \exists hasTarg.Proj\}$
$d = \text{DL}[Proj \uplus projfile; StaffRequest](X)$

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- Unfold the DL-query and extract support sets:

  – infinitely many support sets (axioms $\exists R.A \sqsubseteq A$)
  – exponentially many for acyclic $\mathcal{T}$

- Completeness is costly!
- Compute partial support families: bound size/number

Repair Answer Set Computation

✓ Compute partial support families **S** for all DL-atoms of Π

Repair Answer Set Computation

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  - Add guessing rules on values of a: $e_a \vee ne_a$

Repair Answer Set Computation

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- For all $\hat{I} \in AS(\hat{\Pi})$: $D_p = \{a \mid e_a \in \hat{I}\}$; $D_n = \{a \mid ne_a \in \hat{I}\}$
- ✓ Ground support sets in **S** wrt. $\hat{I}$ and $\mathcal{A}$: $S_{gr}^{\hat{I}} \leftarrow Gr(\mathbf{S}, \hat{I}, \mathcal{A})$

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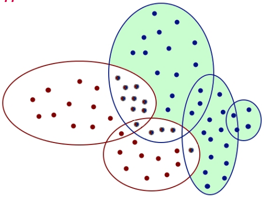
- ✓ Ground support sets in **S** wrt. $\hat{I}$ and $\mathcal{A}$: $S^{\hat{I}}_{gr} \leftarrow Gr(\mathbf{S}, \hat{I}, \mathcal{A})$
- ✓ For all HS $H \subseteq \mathcal{A}$ of support families for all $a \in D_n$:
  - ✓ If all $a \in D_p$ have at least one $S \in S^{\hat{I}}_{gr}$, s.t. $S \cap H = \emptyset$, then do eval. postcheck on D_n (evaluate atoms from D_n over I and $\mathcal{A} \backslash H$)
  - ✓ Else do eval. postcheck on D_n and D_p
- ✓ Check minimality of $\hat{I}|_{\Pi}$ wrt. $\Pi' = \langle \mathcal{T}, \mathcal{A} \backslash H, \mathcal{P} \rangle$



Repair Answer Set Computation

- ✓ Compute partial support families **S** for all DL-atoms of Π
- • Construct $\hat{\Pi}$ from $\Pi = \langle \mathcal{O}, \mathcal{P} \rangle$:
  - • Replace all DL-atoms a with normal atoms e_a
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Sound wrt. deletion repair answer sets,
complete if all support families are complete!

- ✓ For all HS $H \subseteq \mathcal{A}$ of support families for all $a \in D_n$:
  - ✓ If all $a \in D_p$ have at least one $S \in S^{\hat{I}}_{gr}$, s.t. $S \cap H = \emptyset$, then do eval. postcheck on D_n (evaluate atoms from D_n over I and $\mathcal{A} \backslash H$)
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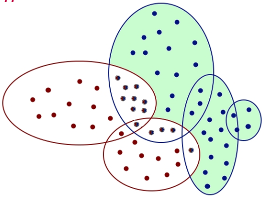
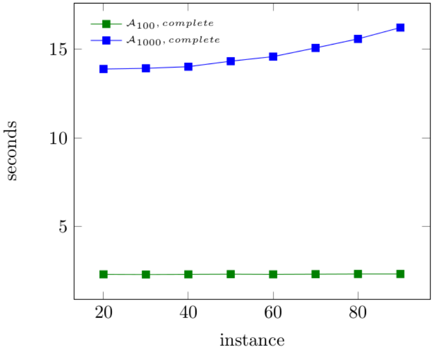


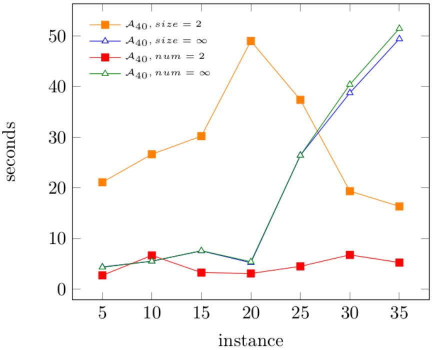
Declarative Implementation

- Implementation within DLVHEX
- Requiem tool is used for support set computation
- Repair is computed in a declarative manner using ASP techniques:

$$
\begin{array}{ll}
(1) & S_a(\mathbf{X}) \leftarrow S_a^{\mathcal{P}}(\mathbf{Y}) \\
(2) & S_a(\mathbf{X}) \leftarrow S_a^{\mathcal{A},\mathcal{P}}(\mathbf{Y}) \\
(3) & S_a^{\mathcal{P}}(\mathbf{Y}) \leftarrow rb(S_a^{p}(\mathbf{Y})) \\
(4) & S_a^{\mathcal{A},\mathcal{P}}(\mathbf{Y}) \leftarrow rb(S_a^{\mathcal{A},\mathcal{P}}(\mathbf{Y})), nd(S^{\mathcal{A},\mathcal{P}}(\mathbf{Y})) \\
(5) & \perp \leftarrow ne_a(\mathbf{X}), S_a^{\mathcal{P}}(\mathbf{Y}) \\
(6) & \bar{P}_{1a}(\mathbf{Y}) \vee \ldots \vee \bar{P}_{na}(\mathbf{Y}) \leftarrow ne_a(\mathbf{X}), S_a^{\mathcal{A},\mathcal{P}}(\mathbf{Y}) \\
(7) & eval_a(\mathbf{X}) \leftarrow e_a(\mathbf{X}), not\ C_a(\mathbf{X}), not\ S_a(\mathbf{X}) \\
(8) & eval_a(\mathbf{X}) \leftarrow ne_a(\mathbf{X}), not\ C_a(\mathbf{X})
\end{array}
$$

Benchmarks-Policy





- Add axiom *Blacklisted* $\sqsubseteq$ *Unauthorized*
- ABoxes $\mathcal{A}$: staff size n, 30% unauthorized 20% blacklisted
- $hasowner(p_i, s_i)$ with probability p (x-axis)
- Complete vs partial support families, with bounded/unbounded number/size of supports (2, ∞)
- Few support sets, but size > 2

Benchmarks-Open Street Map

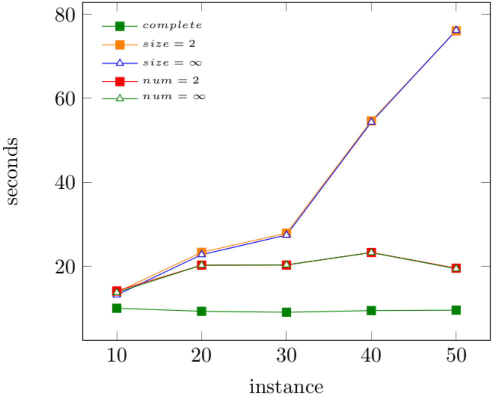
$$\mathcal{O} = \left\{ \begin{array}{l} (1)\ \mathit{BuildingFeature} \sqcap \exists \mathit{isLocatedInside}.\mathit{Private} \sqsubseteq \mathit{NoPublicAccess} \\ (2)\ \mathit{BusStop} \sqcap \mathit{Roofed} \sqsubseteq \mathit{CoveredBusStop} \end{array} \right\}$$

$$\mathcal{P} = \left\{ \begin{array}{l} (9)\ \mathit{publicstation}(X) \leftarrow \mathrm{DL}[\mathit{BusStop} \uplus \mathit{busstop}; \mathit{CoveredBusStop}](X); \\ \qquad\qquad\qquad\qquad \mathit{not}\ \mathrm{DL}[; \mathit{Private}](X); \\ (10)\ \bot \leftarrow \mathrm{DL}[\mathit{BuildingFeature} \uplus \mathit{publicstation}; \mathit{NoPublicAccess}](X), \\ \qquad\qquad \mathit{publicstation}(X). \end{array} \right\}$$

- Rules on top of the MyITS ontology:[2]
  - personalized route planning with semantic information
  - TBox with 406 axioms
- $\mathcal{O}$ (part): building features located inside private areas are not publicly accessible, covered bus stops are those with roof.
- *P* checks that public stations don't lack public access, using CWA on private areas.

[2] http://www.kr.tuwien.ac.at/research/projects/myits/

Benchmarks-Open Street Map



- ABox $\mathcal{A}$ with bus stops (285) and leisure areas (682) of Cork, plus role *isLocatedInside* on them (9)
- Randomly made 80% bus stops roofed, 60% leisure areas private
- For *isLocatedInside*(*bs*, *la*) make *bs* a bus stop with *p* chance (*x*-axis)
- Many support sets have size $\leq$ 2

Conclusion and Future Work

Conclusions:

- Generalization of repair answer set computation for $\mathcal{EL}$
  - Partial support families: restricting support sets size/number
- Formal definition of support sets for $\mathcal{EL}$ and their computation
- Declarative realization within DLVHEX
- Evaluation on a set of benchmarks

Further and future work:

- Computing preferred repairs
- Syntactic conditions ensuring support families completeness
- Repair by bounded addition..