Optimizing the Search for Repairs from Active Integrity Constraints

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Outline

1 Active integrity constraints

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2 Parallelization

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3. Stratification

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Active integrity constraints

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Specify a constraint and propose possible solutions.

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Works both ways:

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- may eliminate options

Example: family relations

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Active integrity constraints

Definition (Flesca2004)

An *Active integrity constraint* is a formula of the form

$$L_1, \ldots, L_m \supset \alpha_1 \mid \ldots \mid \alpha_k$$

where $\{\alpha_1^D, \ldots, \alpha_k^D\} \subseteq \{L_1, \ldots, L_m\}$.

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Intuitive semantics of AICs

A generic AIC

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- holds iff one of the L_is fails (but...)
- $\{\alpha_1^D, \ldots, \alpha_k^D\}$ are *updatable* literals

Repairs

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Definition

A *repair* is a weak repair that is minimal w.r.t. inclusion.

Family relations, yet again

Inconsistency

$$\mathrm{siblingOf}(\mathrm{John}, \mathrm{Mary})$$

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Another repair

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A weak repair

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Finding repairs

"Algorithm"

1. Choose a set $\mathcal{U}$ of update actions (based on $\mathcal{I}$)
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Finding weak repairs is NP-complete.

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- *founded* repairs take into account the actions in the head
- *justified* repairs avoid justification circles

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Intuitively: if $\mathcal{U}$ is founded, then removing an action from $\mathcal{U}$ causes some AIC with that action in the head to be violated.

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Definition

A (weak) repair that is founded is called a founded (weak) repair.

Founded repairs (II)

Example

Take $\mathcal{I} = \{a, b\}$ and

$$r_1 : a, \text{not } b \supset -a \qquad r_3 : a, \text{not } c \supset +c$$
$$r_2 : \text{not } a, b \supset -b \qquad r_4 : b, \text{not } c \supset +c$$

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Again $\{-a, -b\}$ is a founded repair that is not justified.

Complexity

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Deciding whether there is a justified (weak) repair for $\mathcal{I}$ and η is Σ_P^2-complete.

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Reduce the size of the problem by splitting the set of AICs into smaller sets.

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Two sets of AICs η_1 and η_2 are *independent*, $\eta_1 \perp\!\!\!\perp \eta_2$, if $r_1 \perp\!\!\!\perp r_2$ for every $r_1 \in \eta_1$ and $r_2 \in \eta_2$.

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- Not affected by the database.

Independence (II)

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Then $\{r_1, r_2\} \perp\!\!\!\perp \{r_3\}$.

Independence vs. parallelization (I)

Theorem

Let $\eta = \eta_1 \cup \eta_2$ with $\eta_1 \perp\!\!\!\perp \eta_2$; $\mathcal{I}$ be a database; and $\mathcal{U}$ be a weak repair for $\mathcal{I}$ and η.

Independence vs. parallelization (I)

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Define $\mathcal{U}_i$ as the set of actions in $\mathcal{U}$ affecting literals in the bodies of rules in η_i, for $i = 1, 2$.

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Furthermore, if every action in $\mathcal{U}$ affects a literal in the body of a rule in η, then $\mathcal{U} = \mathcal{U}_1 \cup \mathcal{U}_2$. This hypothesis is (very) reasonable in practice.

Independence vs. parallelization (II)

Proof (sketch).

Given $r_1 \in \eta_1$ and $r_2 \in \eta_2$, changing the logical values of literals in the body of r_1 cannot affect the semantics of r_2 and vice-versa.

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For foundedness, take $\alpha \in \mathcal{U}_1$. Since $\mathcal{U}$ is founded, there is a rule $r \in \eta$ such that $\mathcal{I} \circ (\mathcal{U} \setminus \{\alpha\}) \not\models r$. Necessarily $r \in \eta_1$ and $\mathcal{I} \circ (\mathcal{U}_1 \setminus \{\alpha\}) \not\models r$.

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For foundedness, take $\alpha \in \mathcal{U}_1$. Since $\mathcal{U}$ is founded, there is a rule $r \in \eta$ such that $\mathcal{I} \circ (\mathcal{U} \setminus \{\alpha\}) \not\models r$. Necessarily $r \in \eta_1$ and $\mathcal{I} \circ (\mathcal{U}_1 \setminus \{\alpha\}) \not\models r$. Therefore $\mathcal{U}_1$ is founded.

Independence vs. parallelization (II)

Proof (sketch).

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This means that we can parallelize the search for repairs without losing solutions.

Independence vs. parallelization (III)

Example

Let $\mathcal{I} = \{a, b, c, d\}$ and consider the following set of AICs η:

$$r_1 : a, \text{not } b \supset -a \qquad r_2 : b, c \supset -c \qquad r_3 : d \supset -d$$

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Since $\eta_1 = \{r_1, r_2\}$ and $\eta_2 = \{r_3\}$ are independent, the theorem guarantees that $\mathcal{U}_1 = \{-c\}$ and $\mathcal{U}_2 = \{-d\}$ are founded repairs for $\mathcal{I}$ and η_1 or η_2, respectively.

Independence vs. parallelization (IV)

Theorem

Let $\eta = \eta_1 \cup \eta_2$ *with* $\eta_1 \perp\!\!\!\perp \eta_2$; $\mathcal{I}$ *be a database; and* $\mathcal{U}_i$ *be weak repairs for* $\mathcal{I}$ *and* η_i, *for* $i = 1, 2$, *such that all actions in* $\mathcal{U}_i$ *affect a literal in the body of a rule in* η_i.

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Define $\mathcal{U} = \mathcal{U}_1 \cup \mathcal{U}_2$.

Then:

- *$\mathcal{U}$ is a weak repair for $\mathcal{I}$ and η;*
- *if each $\mathcal{U}_i$ is a repair, then so is $\mathcal{U}$;*
- *if each $\mathcal{U}_i$ is founded, then so is $\mathcal{U}$;*
- *if each $\mathcal{U}_i$ is justified, then so is $\mathcal{U}$.*

Independence vs. parallelization (V)

The proof is similar.

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This means that parallelization of the search does not add “new” (false) solutions.

Computing independent sets of AICs

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In order to split a set η into independent sets, consider the relation $\not\perp\!\!\!\perp$ of dependence. This relation is reflexive and symmetric. Therefore its transitive closure $\not\perp\!\!\!\perp^+$ is an equivalence relation. The quotient set ${}^{\eta}/_{\not\perp\!\!\!\perp^+}$ is the finest partition of η in independent sets, and can be computed efficiently.

Outline

1. Active integrity constraints
2. Parallelization
3. Stratification
4. Conclusions

Precedence (I)

Definition

AIC r_1 *precedes* AIC r_2, $r_1 \prec r_2$, if some action in the head of r_1 affects a literal in the body of r_2.

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(Similar to stratified negation in logic programming. . .)

Precedence (II)

Example

Consider the following set of AICs η.

$$r_1 : a, b \supset -a \qquad r_3 : \text{not } a, c, d \supset -c \mid -d$$

$$r_2 : a, \text{not } b, c \supset +b \qquad r_4 : b, d, e \supset -e$$

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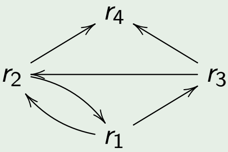

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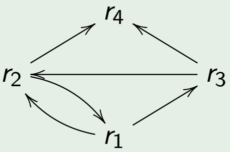

The equivalence classes are $\eta_1 = \{r_1, r_2, r_3\}$ and $\eta_2 = \{r_4\}$.

Precedence vs. stratification (I)

Theorem

Let $\eta_1, \eta_2 \in {}^{\eta}/_{\approx}$ with $\eta_1 \prec \eta_2$; $\mathcal{I}$ be a database; and $\mathcal{U}$ be a weak repair for $\mathcal{I}$ and $\eta_1 \cup \eta_2$.

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- *$\mathcal{U}_1$ is a weak repair for $\mathcal{I}$ and η_1 and $\mathcal{U}_2$ is a weak repair for $\mathcal{I} \circ \mathcal{U}_1$ and η_2;*

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This allows us to sequentialize the search for repairs.

However, some results do not hold:

- it may happen that $\mathcal{U}$ is a repair, but $\mathcal{U}_1$ and/or $\mathcal{U}_2$ are not;
- there may be a weak (founded, justified) repair $\mathcal{U}_1$ for $\mathcal{I}$ and η_1 that is not a subset of any weak repair for $\mathcal{I}$ and $\eta_1 \cup \eta_2$.

Precedence vs. stratification (III)

Example

Let $\mathcal{I} = \emptyset$ and consider the following active integrity constraints.

$$r_1 : \text{not } a \supset +a \quad r_2 : \text{not } b, c \supset +b \quad r_3 : b, \text{not } c \supset +c$$

$$r_4 : a, \text{not } b, \text{not } c, d \supset -d \quad r_5 : a, \text{not } b, \text{not } c, \text{not } d \supset +d$$

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Taking $\eta_1 = \{r_1, r_2, r_3\}$ and $\eta_2 = \{r_4, r_5\}$, one has $\eta_1 \prec \eta_2$.

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Taking $\eta_1 = \{r_1, r_2, r_3\}$ and $\eta_2 = \{r_4, r_5\}$, one has $\eta_1 \prec \eta_2$. Furthermore, $\{+a\}$ and $\{+a, +b, +c\}$ are weak repairs for $\mathcal{I}$ and η_1, the first of which is a repair. However, the only repair for $\mathcal{I}$ and $\eta_1 \cup \eta_2$ is $\{+a, +b, +c\}$.

Precedence vs. stratification (IV)

Theorem

Let η_1, η_2 and $\mathcal{I}$ be as before; $\mathcal{U}_1$ be a weak repair for $\mathcal{I}$ and η_1; $\mathcal{U}_2$ be a weak repair for $\mathcal{I} \circ \mathcal{U}_1$ and η_2; such that every action in $\mathcal{U}_i$ occurs in the head of a rule in η_i.

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1 Active integrity constraints

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- (More) practical evaluation
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- Generalizations of AICs outside the database world

Thank you.