

Computing Repairs from Active Integrity Constraints

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The Problem

Databases typically pose conditions on data (“integrity constraints”). . .

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Question

How can we repair a database that no longer satisfies its integrity constraints?

Outline

1 Integrity constraints

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- 1 Integrity constraints
- 2 Active integrity constraints

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- 2 Active integrity constraints
- 3 Founded and justified repairs

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- 4 Future directions

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- 2 Active integrity constraints
- 3 Founded and justified repairs
- 4 Future directions
- 5 Conclusions

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- 2 Active integrity constraints
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A database of family relations (I)

Consider a database with information on family relations.

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Fact

siblingOf(John, Mary)

A database of family relations (I)

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Fact

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This database should also contain

Missing fact

siblingOf(Mary, John)

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Integrity constraint (simple)

$$\forall x \forall y. ((\text{siblingOf}(x, y) \wedge \neg \text{siblingOf}(y, x)) \supset \perp)$$

A database of family relations (II)

Fact

Parent(John)

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(motherOf(John, ...) would fix this, but would cause other problems)

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Integrity constraint (existential)

$$\forall x. (\text{Parent}(x) \supset \exists y. (\text{fatherOf}(x, y) \vee \text{motherOf}(x, y)))$$

A database of family relations (III)

Fact

fatherOf(John, Paul)

A database of family relations (III)

Fact

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Fact

fatherOf(Jack, Paul)

A database of family relations (III)

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Something is wrong here. . .

A database of family relations (III)

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Something is wrong here. . .

Integrity constraint (cardinality)

$$\forall x \forall y \forall z. ((\text{fatherOf}(x, z) \wedge \text{fatherOf}(y, z)) \supset x = y)$$

Sometimes we can fix the problem automatically. . .

Inconsistency

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Add siblingOf(Mary, John)

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Solution

Add siblingOf(Mary, John)

... but is this so automatic?

Another solution

Remove siblingOf(John, Mary)

Sometimes we can fix the problem automatically...

Oops.

... sometimes not really...

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What should we substitute for y ?

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Another solution

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Ok, but...

... and computers do not like to make choices.

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fatherOf(John, Paul)

fatherOf(Jack, Paul)

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Another solution

Remove fatherOf(Jack, Paul)

But which?

To make matters worse. . .

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Exercise

Think up a scenario where the “bad” solution is actually the good one and the “good” solution is the bad one.

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Think up a scenario where the “bad” solution is actually the good one and the “good” solution is the bad one.

Solution

Imagine information is being removed from the database.

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- 2 Active integrity constraints**
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Active integrity constraints

Motivation

Specify a constraint **and** propose possible solutions.

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Works both ways:

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- may express preferences

Active integrity constraints

Motivation

Specify a constraint **and** propose possible solutions.

Works both ways:

- may express preferences
- may eliminate options

Family relations, revisited

Integrity constraint

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Active integrity constraint

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$$\forall x \forall y. ((\text{siblingOf}(x, y) \wedge \neg \text{siblingOf}(y, x)) \supset \\ + \text{siblingOf}(y, x) \mid - \text{siblingOf}(x, y))$$

Active integrity constraints

Definition (Caroprese et al., 2011)

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

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

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

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An invalid AIC

$$\text{siblingOf}(x, y) \wedge \neg \text{siblingOf}(y, x) \supset -\text{siblingOf}(x, y) \mid +\text{Parent}(x)$$

Intuitive semantics of AICs

A generic AIC

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- conjunction on the left (“body”)
- disjunction on the right (“head”)
- semantics of (normal) implication
- holds iff one of the L_i s fails (but...)
- $\{\alpha_1^D, \dots, \alpha_k^D\}$ are *updatable* literals

Repairs

Definition

Let I be a database and η be a set of (A)ICs. A *weak repair* for I and η is a consistent set \mathcal{U} of update actions such that:

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Let I be a database and η be a set of (A)ICs. A *weak repair* for I and η is a consistent set \mathcal{U} of update actions such that:

- \mathcal{U} consists of essential actions only
- $\mathcal{I} \circ \mathcal{U} \models \eta$

(Sorry for the notation.)

Definition

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

Family relations, yet again

Inconsistency

siblingOf(John, Mary)

$\text{siblingOf}(x, y) \wedge \neg \text{siblingOf}(y, x) \supset +\text{siblingOf}(y, x)$

Family relations, yet again

A repair

+siblingOf(Mary, John)

Family relations, yet again

A repair

+siblingOf(Mary, John)

Another repair

−siblingOf(John, Mary)

Family relations, yet again

A repair

+siblingOf(Mary, John)

Another repair

−siblingOf(John, Mary)

A weak repair

+siblingOf(Mary, John), +Parent(John)

Family relations, yet again

A repair

+siblingOf(Mary, John)

Another repair

−siblingOf(John, Mary)

A weak repair

+siblingOf(Mary, John), +Parent(John)

Not a weak repair

+siblingOf(Mary, John), −siblingOf(John, Mary)

Where does the “active” part come in?

The notion of (weak) repair ignores the head of the AIC.

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At this stage, how can we find repairs?

Finding weak repairs is NP-complete

Algorithm

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- 1 Choose a set \mathcal{U} of update actions (based on \mathcal{I})

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- 1 Choose a set \mathcal{U} of update actions (based on \mathcal{I})
- 2 Compute $\mathcal{I} \circ \mathcal{U}$

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- 3 Check if all AICs in η hold

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- 2 Compute $\mathcal{I} \circ \mathcal{U}$
- 3 Check if all AICs in η hold

Each step can be done in polynomial time on \mathcal{I} and η .

Finding weak repairs is NP-complete, our version

Tree algorithm

Build a tree (the *repair tree for \mathcal{I} and η*) as follows.

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Lemma

- *This tree is finite.*

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Lemma

- *This tree is finite.*
- *Every consistent leaf is a weak repair for I and η .*

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Lemma

- *This tree is finite.*
- *Every consistent leaf is a weak repair for I and η .*
- *Every repair for I and η corresponds to a leaf in the tree.*

Repair trees find all repairs

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Proof.

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Let \mathcal{U} be a repair. If \mathcal{U} is a node in the tree, then \mathcal{U} is a leaf.

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Every repair for I and η corresponds to a leaf in the tree.

Proof.

Let \mathcal{U} be a repair. If \mathcal{U} is a node in the tree, then \mathcal{U} is a leaf.

We show that we can find a branch $\mathcal{U}_0 = \emptyset, \mathcal{U}_1, \dots, \mathcal{U}_n$ in the tree such that $\mathcal{U}_i \subseteq \mathcal{U}$ and $\mathcal{U}_n = \mathcal{U}$.

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If \mathcal{U}_i is a weak repair, then $\mathcal{U}_i = \mathcal{U}$, otherwise \mathcal{U} is not a repair.

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Assume that is not the case.

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Assume that is not the case. Then $\mathcal{I} \circ \mathcal{U}_i \not\models r$ for some rule r .

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Since \mathcal{U} is finite, this construction must end at \mathcal{U} . □

Optimizations

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The repair tree can be significantly pruned, e.g. by identifying nodes that correspond to the same set of actions.

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The repair tree can be significantly pruned, e.g. by identifying nodes that correspond to the same set of actions.

Inconsistent nodes may also be left out.

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Founded repairs I

The notion of repair ignores the head of the AIC.

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Definition

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Definition

A set \mathcal{U} is *founded* w.r.t. I and η if every update action in \mathcal{U} is founded w.r.t. I , η and \mathcal{U} .

Founded repairs II

In other words, if \mathcal{U} is founded, then removing an action from \mathcal{U} causes some AIC to be violated.

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Definition

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Catch

A founded repair is *not* a minimal founded weak repair.

Computing founded repairs

Example

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

$$r_1 : a, \text{not } b \supset -a$$

$$r_2 : \text{not } a, b \supset -b$$

$$r_3 : a, \text{not } c \supset +c$$

$$r_4 : b, \text{not } c \supset +c$$

Following the heads of the violated rules, we obtain:

Computing founded repairs

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Following the heads of the violated rules, we obtain:

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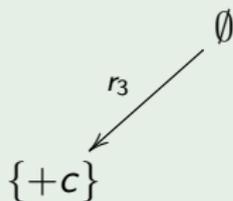
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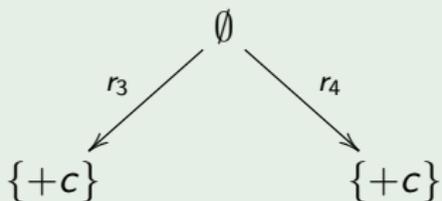
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With this in mind, the Caroprese et al. introduced *justified repairs*.

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Motivation

Keep track of the non-updatable atoms in the rules that were used.

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Checking that a repair is justified is again NP-complete, so our algorithm is (asymptotically) optimal.

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Outline

- 1 Integrity constraints
- 2 Active integrity constraints
- 3 Founded and justified repairs
- 4 Future directions**
- 5 Conclusions

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Next step

Implementing, testing and improving these algorithms

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Justified repairs make no sense in this setting...

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New notion of repair

This tree computes all justified repairs and some founded (weak) repairs, but eliminates true circularity of support.

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Next steps

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- 1 Formalize the notion of generalized AIC and study it in particular settings.
- 2 Characterize the (weak) repairs computed by the well-founded repair tree in this new setting.

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Thank you.