TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Computer Science ● Institute of Theoretical Computer Science ● Chair of Automata Theory

COMPUTING OPTIMAL REPAIRS OF QUANTIFIED ABOXES W.R.T. STATIC $\mathcal{EL}$ TBOXES

Franz Baader, Patrick Koopmann,
Francesco Kriegel, Adrian Nuradiansyah

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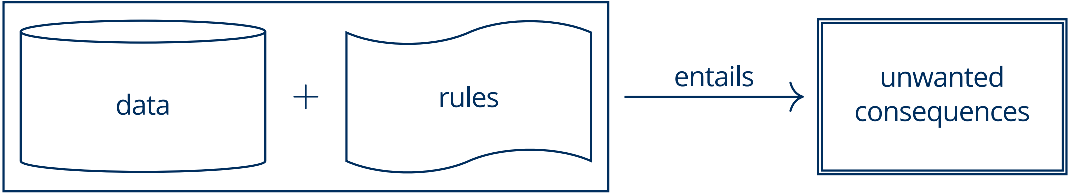
The 28th International Conference on Automated Deduction (CADE-28), 13 July 2021

Problem Setting



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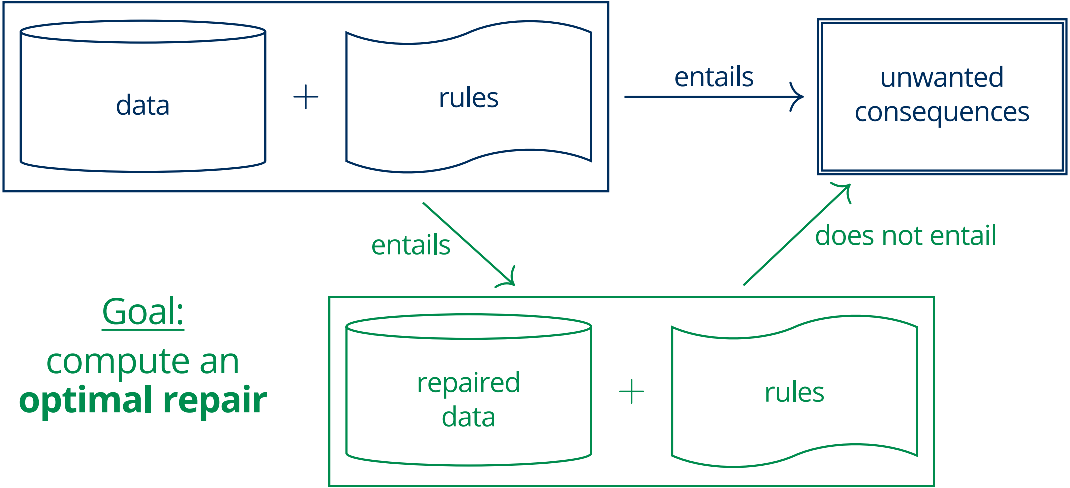

Goal:

compute an **optimal repair**

A Pizza with Parmesan and Salami

- **Data:** quantified ABox (qABox) $\exists X.\mathcal{A}$
  example: $\exists\{x\}.\{\text{hasTopping}(\text{myPizza}, x),\ \text{Parmesan}(x),\ \text{Salami}(x)\}$

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  example: $\{\mathsf{Parmesan} \sqsubseteq \mathsf{Cheese},\ \mathsf{Salami} \sqsubseteq \mathsf{Sausage}\}$

$\mathcal{EL}$ concepts:
$C ::= \top \mid A \mid C \sqcap C \mid \exists r.C$
where $A \in \Sigma_{\mathsf{C}}$ and $r \in \Sigma_{\mathsf{R}}$

$\mathcal{EL}$ concept inclusions:
$C_1 \sqsubseteq C_2$

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- A **repair** of $\exists X.\mathcal{A}$ for $\mathcal{R}$ w.r.t. $\mathcal{T}$ is a qABox $\exists Y.\mathcal{B}$ such that
  - $\exists X.\mathcal{A}$ and $\mathcal{T}$ entail $\exists Y.\mathcal{B}$, and
  - $\exists Y.\mathcal{B}$ and $\mathcal{T}$ do not entail $C(a)$ for each $C(a) \in \mathcal{R}$.

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- A repair is **optimal** if it is not strictly entailed by another repair.

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Related Work

Classical Repair Approach:

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- Removes axioms completely
- Syntax-dependent
- Unable to compute optimal repairs (in our sense)
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Novel, Gentle Repair Approach:

- Weakens axioms instead of removing them completely
- Produces better repairs than classical approach
- Syntax-dependent
- Unable to compute optimal repairs (in our sense)
- Applicable to every monotonic logic for which a weakening relation exists

Our Previous Work

Franz Baader, Francesco Kriegel, Adrian Nuradiansyah, Rafael Peñaloza:
Computing Compliant Anonymisations of Quantified ABoxes w.r.t. $\mathcal{EL}$ Policies.
19th International Semantic Web Conference (ISWC), Athens, Greece, November 2–6, 2020.

- Characterizes optimal repairs of qABoxes
- No TBox supported
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We expand on the above article and specifically address the last three points.

A Recipe for Removing an Unwanted Consequence

Two notions:

- An **atom** is either a concept name A or an existential restriction $\exists r.C$.
- Each $\mathcal{EL}$ concept is a conjunction of atoms (the **top-level conjunction**).
  $\mathsf{Conj}(C_1 \sqcap C_2 \sqcap \cdots \sqcap C_n) = \{C_1, C_2, \ldots, C_n\}$

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Repair Recipe: For each unwanted consequence $C(u)$:

- either choose a concept name $B \in \mathsf{Conj}(C)$ and remove $B(u)$ from $\mathcal{A}$,
- or choose an existential restriction $\exists r.D \in \mathsf{Conj}(C)$ and do the following for each $r(u, v) \in \mathcal{A}$:
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For each processed object u, we collect the chosen atoms in a set $\mathcal{K}$ (a **repair type**).

Note: We do not yet take the TBox into account.

A Pizza with Parmesan and Salami

$$\exists\,\{x\}.\,\{\ \text{hasTopping}(\text{myPizza}, x),\ \ \text{Parmesan}(x),\ \ \text{Salami}(x)\ \}$$

entails

$$(\exists\,\text{hasTopping}.\,(\text{Parmesan} \sqcap \text{Salami}))(\text{myPizza})$$

A Pizza with Parmesan and Salami

Applying the repair recipe

$$\exists\{x\}.\{\,\mathsf{hasTopping}(\mathsf{myPizza},x),\ \mathsf{Parmesan}(x),\ \cancel{\mathsf{Salami}(x)}\,\}$$

does not entail

$$(\exists\,\mathsf{hasTopping}.(\mathsf{Parmesan}\sqcap\mathsf{Salami}))(\mathsf{myPizza})$$

Object	*Repair Type*
myPizza	$\{\exists\,\mathsf{hasTopping}.(\mathsf{Parmesan}\sqcap\mathsf{Salami})\}$
x	$\{\mathsf{Salami}\}$

A Pizza with Parmesan and Salami

We can do even better

$$\exists\{x,\overline{x}\}.\{\,\text{hasTopping}(\text{myPizza},x),\ \text{Parmesan}(x),\ \sout{\text{Salami}(x)},\ \text{hasTopping}(\text{myPizza},\overline{x}),\ \sout{\text{Parmesan}(\overline{x})},\ \text{Salami}(\overline{x})\,\}$$

does not entail

$$(\exists\,\text{hasTopping}.(\text{Parmesan}\sqcap\text{Salami}))(\text{myPizza})$$

Object	*Copy of*	*Repair Type*
myPizza		$\{\exists\,\text{hasTopping}.(\text{Parmesan}\sqcap\text{Salami})\}$
x		{Salami}
$\overline{x}$	x	{Parmesan}

A Pizza with Parmesan and Salami

$$\exists\,\{x,\overline{x}\}.\,\{\ \mathsf{hasTopping}(\mathsf{myPizza},x),\ \mathsf{Parmesan}(x),\ \cancel{\mathsf{Salami}(x)},\ \mathsf{hasTopping}(\mathsf{myPizza},\overline{x}),\ \cancel{\mathsf{Parmesan}(\overline{x})},\ \mathsf{Salami}(\overline{x})\ \}$$

does not entail

$$(\exists\,\mathsf{hasTopping}.\,(\mathsf{Parmesan}\sqcap\mathsf{Salami}))(\mathsf{myPizza})$$

Object	*Copy of*	*Repair Type*	*Canonical Name* $y_{u,\mathcal{K}}$
myPizza		$\{\exists\,\mathsf{hasTopping}.\,(\mathsf{Parmesan}\sqcap\mathsf{Salami})\}$	$y_{\mathsf{myPizza},\{\exists\mathsf{hasTopping}.(\mathsf{Parmesan}\sqcap\mathsf{Salami})\}}$
x		$\{\mathsf{Salami}\}$	$y_{x,\{\mathsf{Salami}\}}$
$\overline{x}$	x	$\{\mathsf{Parmesan}\}$	$y_{x,\{\mathsf{Parmesan}\}}$

Taking the TBox into account

Example:

- qABox $\exists X.\mathcal{A} \coloneqq \exists\emptyset.\{\mathsf{Salami}(\mathsf{someThing}),\ \mathsf{Sausage}(\mathsf{someThing})\}$
- TBox $\mathcal{T} \coloneqq \{\mathsf{Salami} \sqsubseteq \mathsf{Sausage}\}$
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Repairing the qABox without taking $\mathcal{T}$ into account:

$\exists\emptyset.\{\text{Salami}(\text{someThing}),\ \cancel{\text{Sausage}(\text{someThing})}\}$

Repair type of someThing: $\{\text{Sausage}\}$

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$\exists\emptyset.\{\mathsf{Salami}(\mathsf{someThing}),\ \sout{\mathsf{Sausage}(\mathsf{someThing})}\} \models^{\mathcal{T}} \mathsf{Sausage}(\mathsf{someThing})$

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Thus, we need to **close the repair types under premises/implicants**:

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Example:

- qABox $\exists X.\mathcal{A} \coloneqq \exists\emptyset.\{\text{Parmesan}(\text{someThing})\}$
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Repairing the qABox without taking the TBox into account:

$\exists \emptyset.\{$~~Parmesan(someThing)~~$\}$

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Thus, we need to first **saturate the qABox** before repairing it:

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Saturations

Two entailment relations:

- **Classical entailment** compares qABoxes w.r.t. their models.
- **CQ-entailment** compares qABoxes w.r.t. which **C**onjunctive **Q**ueries they entail. It coincides with classical entailment and is NP-complete.
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Two saturations:

- The saturation of a qABox w.r.t. a TBox depends on the chosen entailment relation.
- To guarantee termination of saturation w.r.t. CQ-entailment, we require that the TBox is cycle-restricted.
- For cycle-restricted TBoxes, **CQ-saturations** can be computed in exponential time.
- In contrast, saturation w.r.t. IQ-entailment always terminates.
- For all TBoxes, **IQ-saturations** can be computed in polynomial time.

Canonical Repairs

Canonical repairs are built from the saturation and consist of all objects $y_{u,\mathcal{K}}$.

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CQ-Entailment:

1. **Up to equivalence, the set of all canonical repairs contains each optimal repair.**
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IQ-Entailment:

1. **Up to equivalence, the set of all canonical repairs contains each optimal repair.**
2. Given a qABox $\exists X.\mathcal{A}$, a TBox $\mathcal{T}$, and a repair request $\mathcal{R}$, **the set of all optimal repairs can be computed in exponential time.**

Optimized Repairs

- **Problem:** Each canonical repair has exponential size.
- Thus, it is expensive or even impossible to compute canonical repairs of large ontologies.
- There are examples where an optimal repair need not be exponentially large.
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- Thus, it is expensive or even impossible to compute canonical repairs of large ontologies.
- There are examples where an optimal repair need not be exponentially large.
- In these cases, the canonical repair is already equivalent to a small sub-qABox.
- We propose a rule-based way to compute **optimized repairs**, which contain only relevant parts of the canonical repairs.
  - CQ-repairs only need objects reachable either from the individuals or from the unmodified copies of all objects.
  - IQ-repairs only need objects reachable from the individuals.
  - In both cases, not all successors of an object are needed, but only those with the fewest modifications.

Implementation and Evaluation

Prototypical implementation:

`https://github.com/de-tu-dresden-inf-lat/abox-repairs-wrt-static-tbox`

Dependencies: OWL-API, ELK, VLOG, Rulewerk

Implementation and Evaluation

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Scenarios:

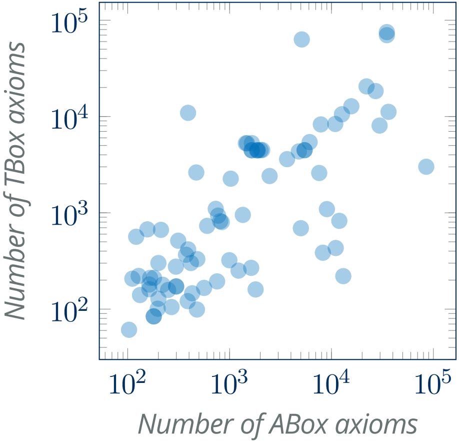
- **S1:** repairing a single unwanted consequence for a single individual
- **S2:** repairing a single unwanted consequence for $10\,\%$ of the individuals

Implementation and Evaluation

Evaluation corpus:

- 80 ontologies
- With up to 100,000 axioms
- Used in the 2015 OWL Reasoner Competition
- Track: OWL EL Realisation
- Cyclic ontologies ignored for CQ-experiments

Input Ontologies

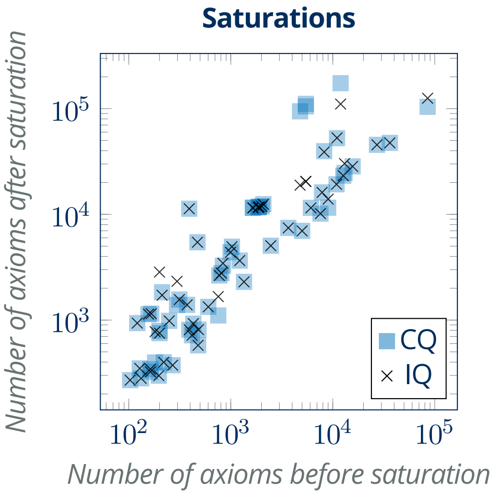


Implementation and Evaluation

Saturation timeout: 60 minutes

Success rates:

- CQ-saturations: $96.9\,\%$
- IQ-saturations: $100\,\%$



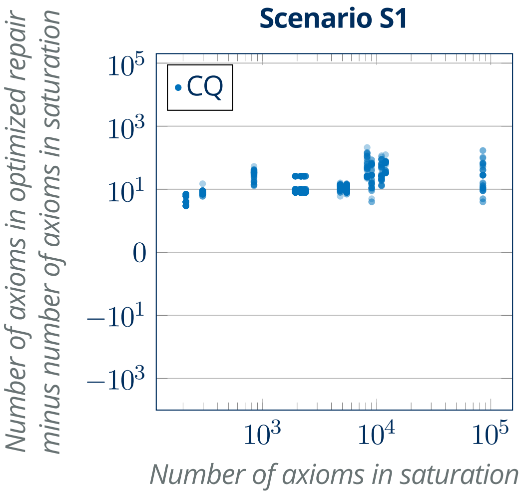
Implementation and Evaluation

Repair timeout: 10 minutes

Success rates:

- Canonical CQ-repairs: 62.1 %
- Optimized CQ-repairs, S1: 100 %
- Optimized CQ-repairs, S2: 99.9 %
- Canonical IQ-repairs: 52.9 %
- Optimized IQ-repairs, S1: 99.9 %
- Optimized IQ-repairs, S2: 98.9 %

Implementation and Evaluation



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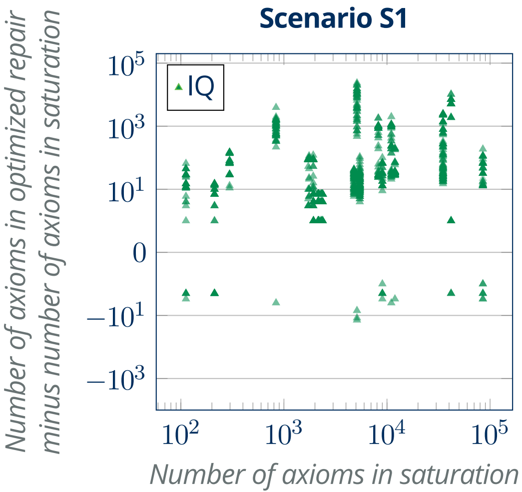

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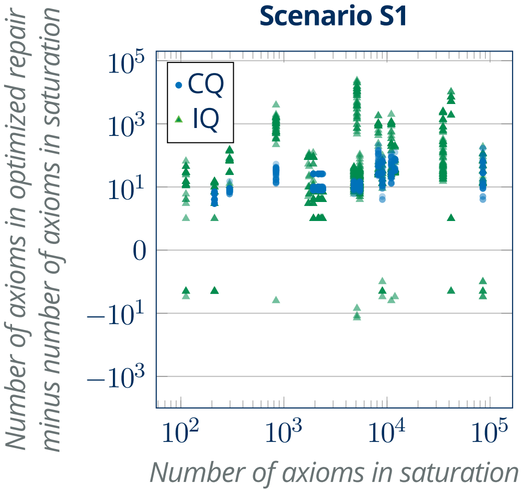
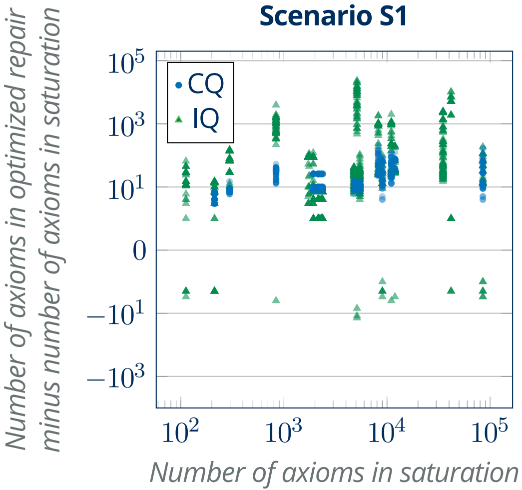
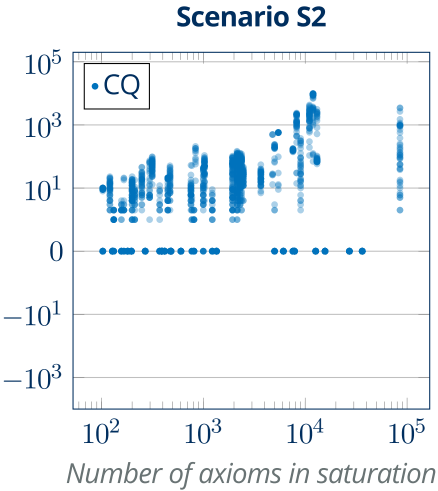


Implementation and Evaluation





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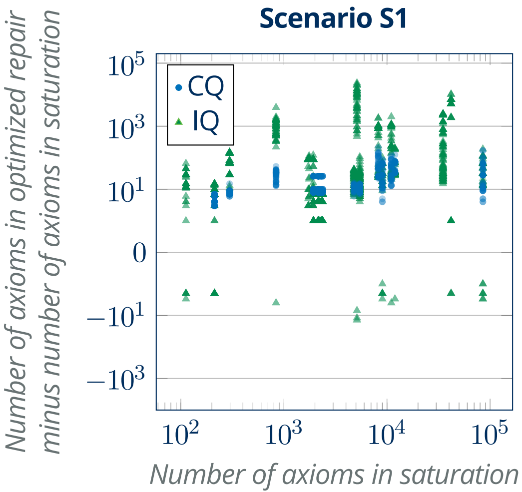

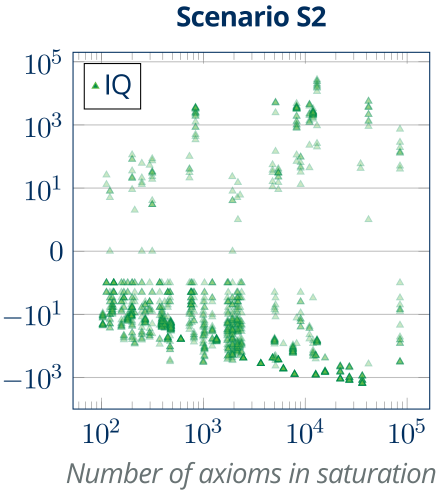

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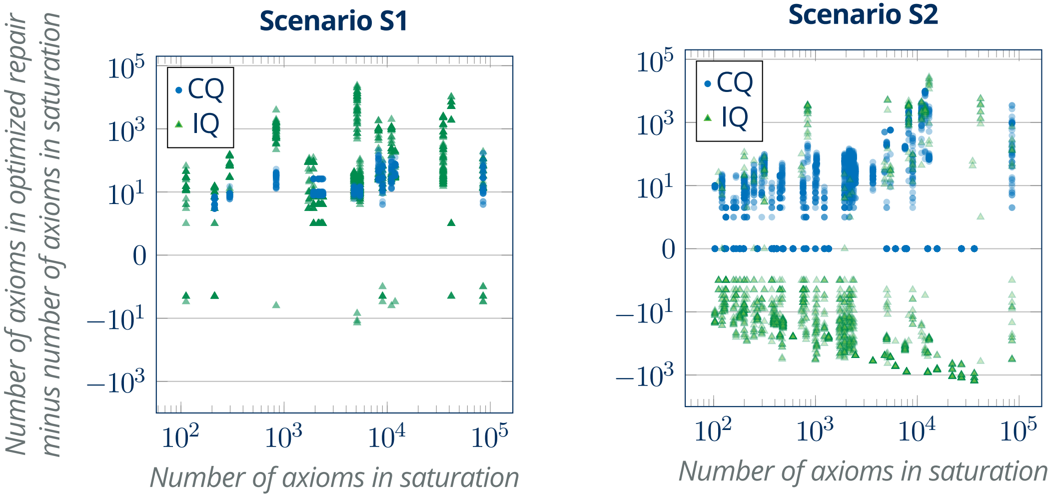

Conclusion and Outlook

Summary:

- We developed an approach to computing optimal repairs, i.e., which lose a minimal amount of consequences.
- As consequences to be preserved, we considered answers to conjunctive queries (CQ-entailment) as well as answers to $\mathcal{EL}$ instance queries (IQ-entailment).
- We support data in form of quantified ABoxes, sets of rules in form of $\mathcal{EL}$ TBoxes (that are assumed to be static), and $\mathcal{EL}$ concept assertions as unwanted consequences to be removed.
- We also devised an efficient construction of repairs that is only worst-case exponential.
- We implemented our methods and evaluated them on real-world ontologies.

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Future Work:

- Lifting the restriction to cycle-restricted TBoxes for CQ-entailment.
- Support for unwanted consequences in form of conjunctive queries.

That’s it for now!

Do you have questions or comments?