LSC Seminar Lyon - France
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User-guided Repairing of Inconsistent Knowledge Bases

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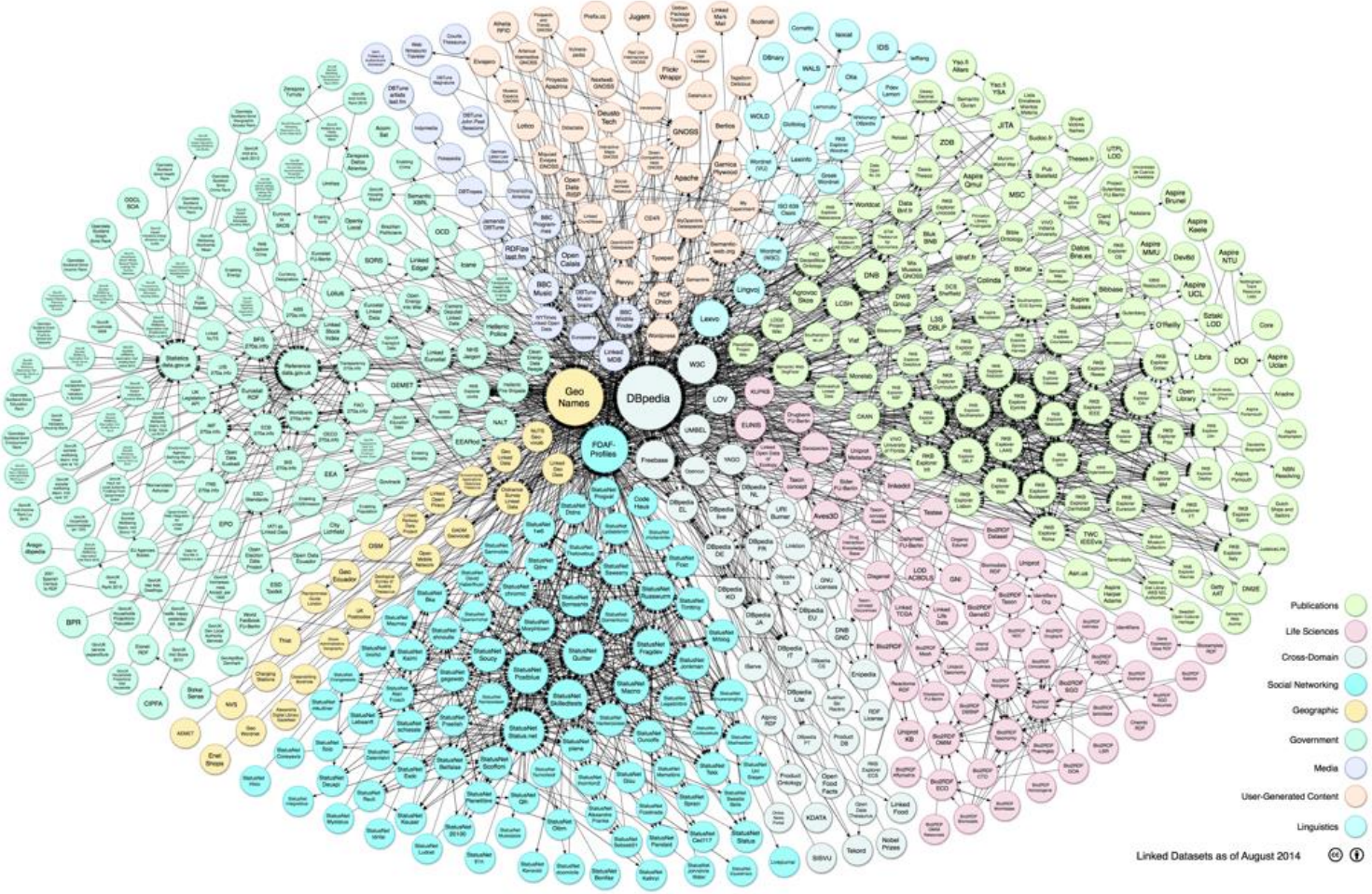
- 2013 - 2016: PhD Computer Science (Montpellier, INRIA GraphIK team) on *Explanation and Argumentation in Inconsistent Knowledge Bases.*
- 2016 - present: Postdoc & ATER with Angela Bonifati (Lyon, LIRIS, DB team) on *Graph Databases, Cleaning and Data Integration.*
- Research interest: *Data Quality and Cleaning, Knowledge Representation, Graph Databases and Data Integration.*

1 Motivation

Interactive repairing of knowledge bases

- Knowledge Bases are **ubiquitous** (Semantic Web, ontology-based reasoning and data access, LOD, Big data integration and fusion, Knowledge and concept graphs in industry)



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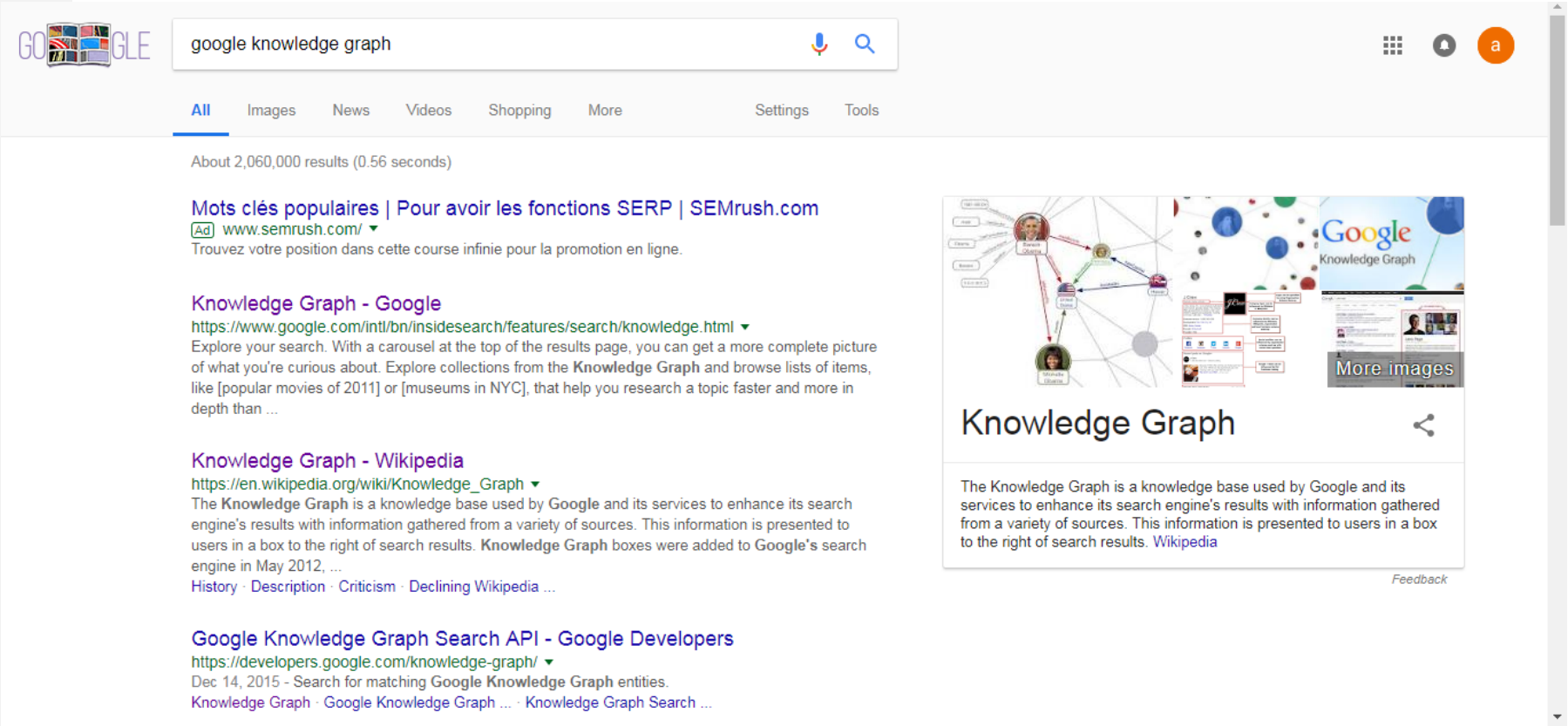

Motivation

Interactive repairing of knowledge bases

- Errors can be introduced from mappings, typos, knowledge fusion, etc.
- Automatic repairing is ***costly*** and ***lossy***.
- Bring human to the loop for a ***better quality***.

Preliminaries

Logical language and knowledge bases

- A knowledge base K is a set of facts, TGDs (rules) and CDDs (constraints).

$$\mathcal{F} = \{prescribed(Aspirin, John), hasAllergy(John, Aspirin), hasAllergy(Mike, Penicillin), hasPain(John, Migraine), isPainKillerFor(Nsaids, Migraine), incompatible(Aspirin, Nsaids)\}$$

$$\Sigma_T = \{isPainKillerFor(X, Y), hasPain(Z, Y) \rightarrow prescribed(X, Z)\}$$

$$\Sigma_C = \{prescribed(X, Y), hasAllergy(Y, X) \rightarrow \bot, prescribed(X, Z), prescribed(X, Y), incompatible(Y, Z) \rightarrow \bot\}$$

Formalism

Tuple-generating dependency (TGD)

$$\forall \mathbf{x} \forall \mathbf{y} B(\mathbf{x}, \mathbf{y}) \rightarrow \exists \mathbf{z} H(\mathbf{y}, \mathbf{z})$$

Weakly-acyclic

Contradiction-detecting dependency (CDD)

$$\forall \mathbf{x} B(\mathbf{x}) \rightarrow \bot$$

Correspond to Denial Constraints with equality

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Reasoning

Chase $C\ell_{\Sigma_T}(\mathcal{F}) \models \mathcal{Q}$.

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$$\forall \mathbf{x} B(\mathbf{x}) \rightarrow \bot$$

Reasoning

Chase $C\ell_{\Sigma_T}(\mathcal{F}) \models \mathcal{Q}$.

Example:

$$\mathcal{Q}(X) = isPainKillerFor(X, Migraine), prescribed(X, Y)$$

$$\texttt{Ans}(\mathcal{Q}) = \{Nsaids\}$$

Preliminaries

Inconsistency handling

- A knowledge base K is inconsistent iff: $\exists N \in \Sigma_C, C\ell_{\Sigma_T}(\mathcal{F}) \models body(N)$.

Conflicts discovery

$\mathcal{F} = \{prescribed(Aspirin, John), hasAllergy(John, Aspirin), hasAllergy(Mike, Penicillin), hasPain(John, Migraine), isPainKillerFor(Nsaids, Migraine), incompatible(Aspirin, Nsaids), prescribed(Nsaids, John)\}$

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- K is inconsistent: $prescribed(X, Y), hasAllergy(Y, X) \rightarrow \bot$
  $prescribed(X, Z), prescribed(X, Y), incompatible(Y, Z) \rightarrow \bot$

- Repairing K using Deletions:
  - Remove facts that are involved in conflicts.
  - *Lossy approach.*

Preliminaries

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- K is inconsistent: $prescribed(X, Y), hasAllergy(Y, X) \rightarrow \bot$
  $prescribed(X, Z), prescribed(X, Y), incompatible(Y, Z) \rightarrow \bot$

- Repairing K using Updates:
  - E.g. John has an allergy against *Penicillin* rather than *Aspirin*
  - *Penicillin* is prescribed to John rather than *Aspirin*
  - ...

User interaction

Problem Statement

Given a KB equipped with a set of TGDs and CDDs, produce an error-free KB:

(i) Accounting for the interplay of TGDs and CDDs.

(ii) Minimizing user interaction.

OUTLINE

- Update-based repairing
- User intervention
- Questioning strategies
- Experimental study
- Conclusion

Update-based repairing

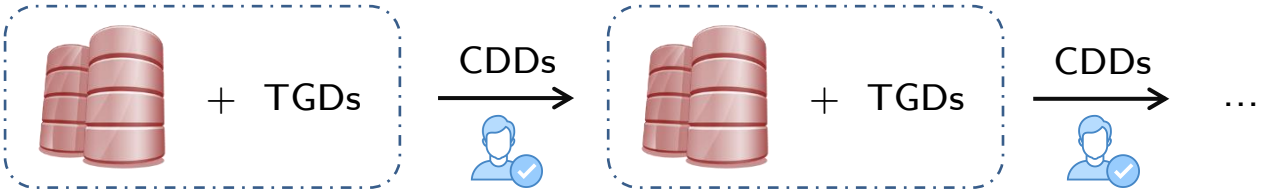
Introduction

- Repairing using updates in RDBs[1]
  - Functional Dependencies (FDs), Conditional FDs, Denial Constraints (DCs).

- Repairing using updates in KBs:
  - TGDs are natural in KB reasoning but they may introduce new conflicts.

$$\mathcal{F} = \{prescribed(Aspirin, John), hasAllergy(John, Aspirin), hasAllergy(Mike, Penicillin), hasPain(John, Migraine), isPainKillerFor(Nsaids, Migraine), incompatible(Aspirin, Nsaids), prescribed(Nsaids, John)\}$$

  - Typical user interaction workflow.



1 Philip Bohannon et al. 2005, Kolahi and Lakshmanan 2009, Yakout et al. 2011, Xu Chu et al. 2013, Farid et al. 2016

Update-based repairing

Basic concepts

Position and fix

- A position is a tuple (A, i) such that $A \in \mathcal{F}$.
- A *fix* is triple (A, i, t) such that (A, i) is a position and t is a term.

Fix

Position

$prescribed(Aspirin, \underset{2}{John})$

$t : X_1$

- A set of fixes P is called *consistent fix* if it produces a consistent KB.
- P is a *repair fix* if KB is consistent and minimally changed (w.r.t set inclusion).
- Example:

$$\mathcal{F} = \{prescribed(Aspirin, John), hasAllergy(\overset{t:X_1}{John}, Aspirin), hasAllergy(Mike, Penicillin), hasPain(\underset{t:Mike}{John}, Migraine), isPainKillerFor(Nsaids, Migraine), incompatible(Aspirin, Nsaids)\}$$

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Update-based repairing

Π-Repairability

- Repairing with immutable set of positions Π.
- Trusted positions or previously fixed positions.
- Some KBs cannot be fixed when some positions are immutable.
- Example:
  - Consider:

    $\Pi = \{(p(a,b),2),(q(b,d),1)\}$

    $\mathcal{F} = \{p(a,b), q(b,d)\} \quad \Sigma_C = \{p(X,Y), q(Y,Z) \rightarrow \bot\}$ Not p-repairable

- Checking Π-repairability:
  - Change all non-immutable positions to unique labelled nulls.
  - Check consistency.

    $\mathcal{F} = \{p(X_1,b), q(b,X_2)\} \quad \Sigma_C = \{p(X,Y), q(Y,Z) \rightarrow \bot\}$ Inconsistent

- The procedure is sound, complete and computed in linear time (data complexity).

User intervention

Basic definitions

- A question Φ is a finite set of fixes.
- If all the fixes in Φ yield a Π-repairable KB then Φ is sound.
- The user choses a fix from Φ as an answer.
- A sequence of sound questions and answers is called an inquiry over K.
- Example:

$$\mathcal{F} = \{prescribed(Aspirin, John), hasAllergy(John, Aspirin), hasAllergy(Mike, Penicillin), hasPain(John, Migraine), isPainKillerFor(Nsaids, Migraine), incompatible(Aspirin, Nsaids)\}$$

Φ: *which fix is true from the following set?*

$$\{(prescribed(Aspirin, John), 1, t) \mid t \in \{X_1, Nsaids\}\} \cup \{(hasAllergy(John, Aspirin), 1, t) \mid t \in \{X_3, Mike\}\}$$

$$\{(prescribed(Aspirin, John), 2, t) \mid t \in \{X_2, Mike\}\} \cup \{(hasAllergy(John, Aspirin), 2, t) \mid t \in \{X_4, Penicillin\}\}$$

User intervention

Generating sound questions and inquiries

- *Procedure:*
  1. Generate a sound question by filtering values.
  2. Ask the user and update, continue until no conflict is left.

User intervention

Generating sound questions and inquiries

- *Procedure:*
  1. Generate a sound question by filtering values.
     1. Get all positions from the conflict
     2. Generate the proposed fixes
     3. Filter out invalid fixes using Π-Repairability check.
     4. Return the question
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     1. Phase 1 (non-interleaving):
        1. Compute initial conflicts
        2. Generate a sound question for a given conflict
        3. Ask the user and apply the chosen fix
     2. Phase 2 (interleaving):

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     1. Phase 1 (non-interleaving):
        1. Compute initial conflicts
        2. Generate a sound question for a given conflict
        3. Ask the user and apply the chosen fix
     2. Phase 2 (interleaving):
        1. Generate sound questions when using TGDs (reasoning)
        2. Ask then apply the chosen fix

User intervention

Results

- Proposition 1: questions are sound and polynomial.
- Proposition 2: the procedure runs in finite time and produces a consistent knowledge base K.
- When the procedure produces a repair of K?
  - If the user is an oracle then K is minimally repaired.
  - An oracle is a user who knows everything about K (a domain and knowledge expert).
- Proposition 3: delay time between questions is polynomial.

Questioning strategies

Intuition by examples

- Consider the following knowledge base:

$$\mathcal{F} = \{p(a,b,c), r(b,d), q(c,e), s(d,e), v(c), p(f,f,f)\}$$

$$\Sigma_C = \{p(X,Y,Z), r(Y,W), q(Z,D) \rightarrow \bot, r(X,Y), s(Y,Z) \rightarrow \bot, q(X,Y), v(X) \rightarrow \bot\}$$

Conflicts

$$\{p(a,b,c), r(b,d), q(c,e)\}$$
$$\{r(b,d), s(d,e)\}$$
$$\{q(c,e), v(c)\}$$

Random strategy

1. Pick a conflict and generate all possible fixes.

$$\phi = \{(p(a,b,c),1,f), (p(a,b,c),1,X_1)(p(a,b,c),2,X_2), \ldots\}$$

- No resolution if the user chooses: $(p(a,b,c),1,X_1)$

- We ask more questions.

Join positions!

Questioning strategies

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Conflicts

$$\{p(a,b,c), r(b,d), q(c,e)\}$$
$$\{r(b,d), s(d,e)\}$$
$$\{q(c,e), v(c)\}$$

Join strategy

1. Pick a conflict and generate all possible fixes over join positions.

$$\phi = \{(p(a,b,c), 2, f), (p(a,b,c), 2, X_2), (p(a,b,c), 3, X_3), (r(b,d), 1, X_4), \ldots\}$$

- We ask less questions

Questioning strategies

Intuition by examples

- Consider the following knowledge base:

$$\mathcal{F} = \{p(a,b,c), r(b,d), q(c,e), s(d,e), v(c), p(f,f,f)\}$$

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Conflicts

$$\{p(a,b,c), r(b,d), q(\underline{c},e)\}$$

$$\{r(b,d), s(d,e)\}$$

$$\{q(\underline{c},e), v(c)\}$$

MCD strategy

1. Rank join positions w.r.t inclusion in conflicts and choose the top ranked.

$$\phi = \{(q(c,e), 1, X_8)\}$$

- 2 conflicts by one question in the example.

- **Observation:** more overlapping less questions

5 Experimental study

Experimental environment

Variables:

- **Effectiveness:** avg number of questions per strategy and average number of conflicts per question.
- **Delay time:** average delay time between asked question.

Environment:

- Java 8, 2.40GHz 4core, 16G RAM (windows 7).
- Multi trial experiments with a cold start.
- For each experimental variable we test our approach on synthetic and real-world datasets.

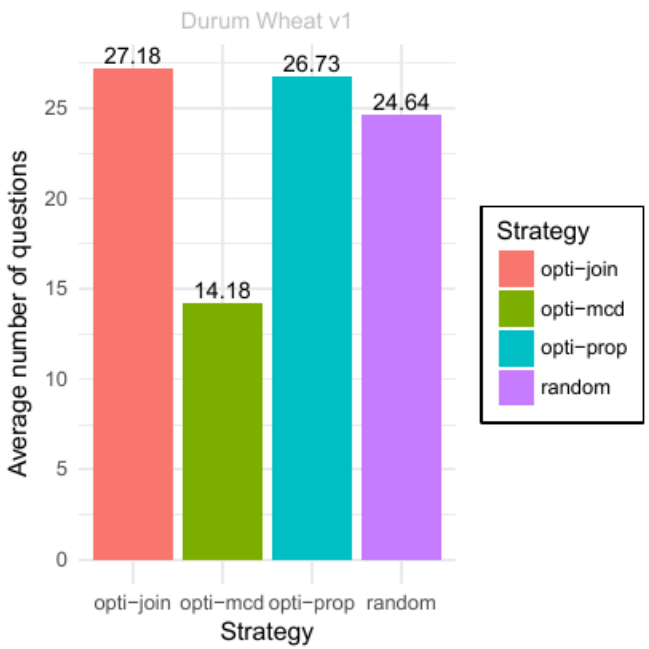
5 Experimental study

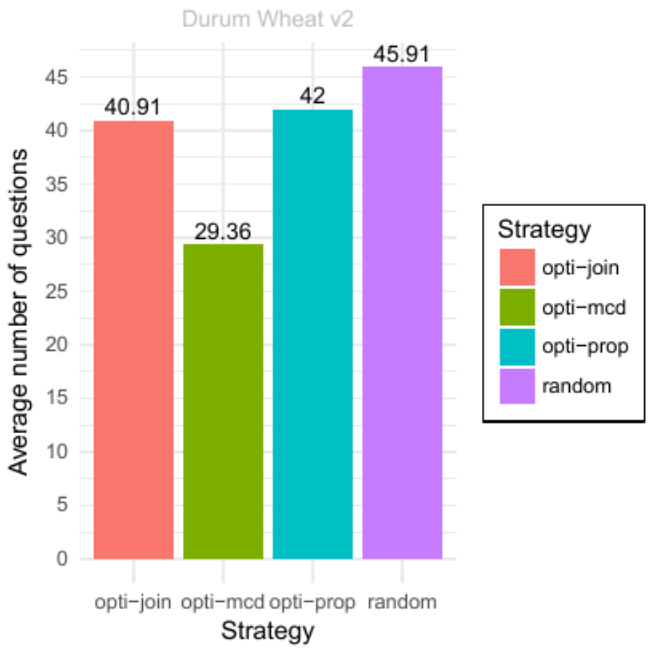
Effectiveness

KBs:

- **Durum Wheat Kb** v1: manually constructed. TGDs and CDDs have been validated by experts.
- **Summary v1:** 567 atoms, TGDs=269 , CDD=27, 185 conflicts.
- **Summary v2:** 567 atoms, TGDs=269, CDD=100, 212 conflicts.

Results:





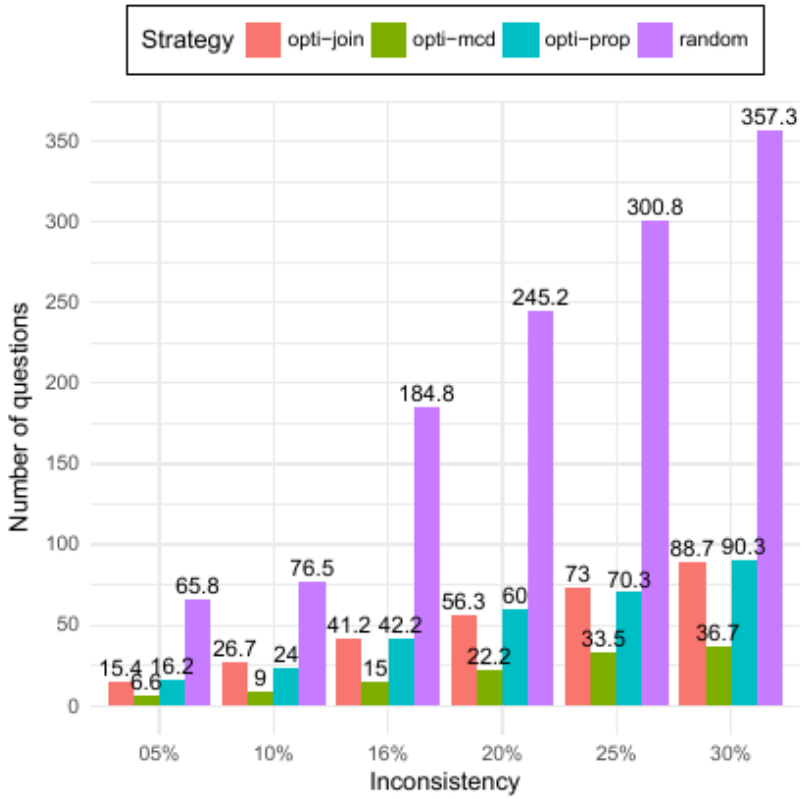
5

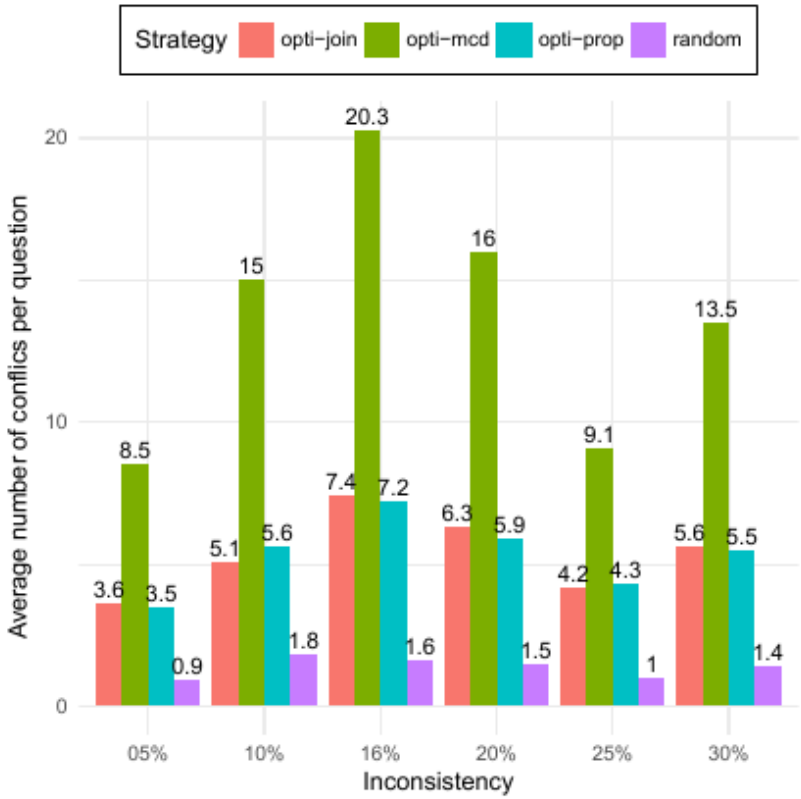
Experimental study

Effectiveness: synthetic KBs no TGDs

KB	Size (#atoms)	Conflicts
"05%"	1005	56
"10%"	1005	135
"16%"	1005	304
"20%"	1005	356
"25%"	1005	304
"30%"	1005	496

Results:





5 Experimental study

Effectiveness: synthetic KBs (convergence)

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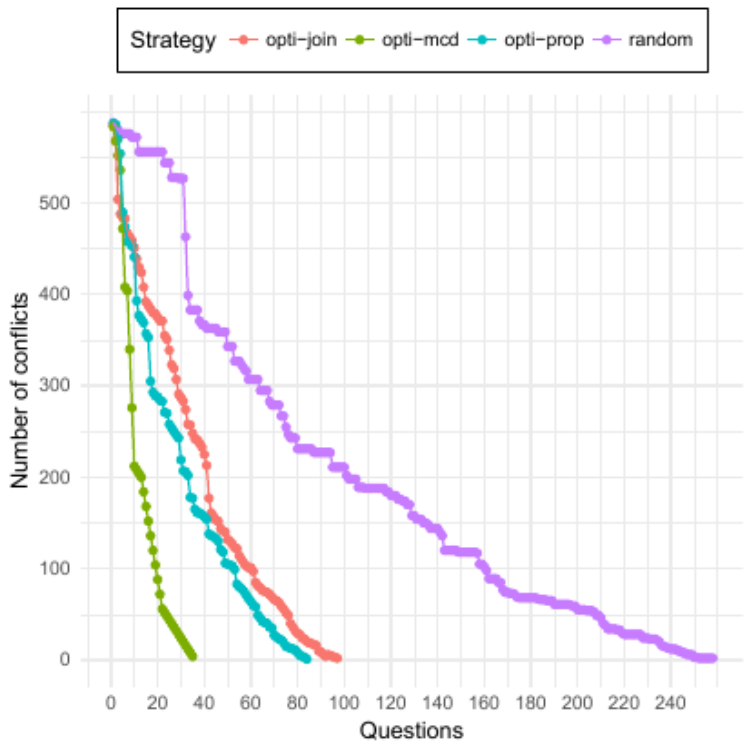
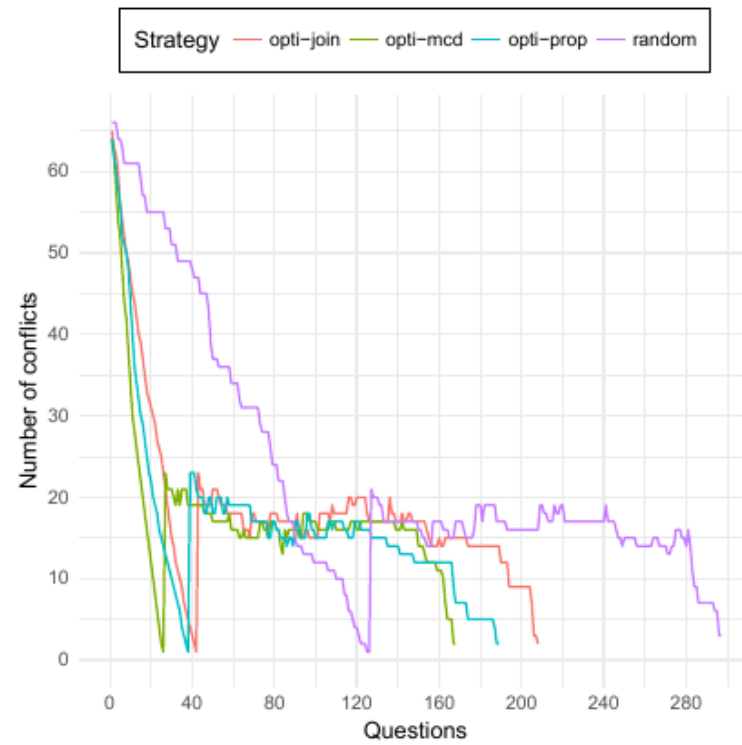


(a) Fixed size KB (3004 atoms) with constant inconsistency ratio 25%. With only CDDs and no TGDs.

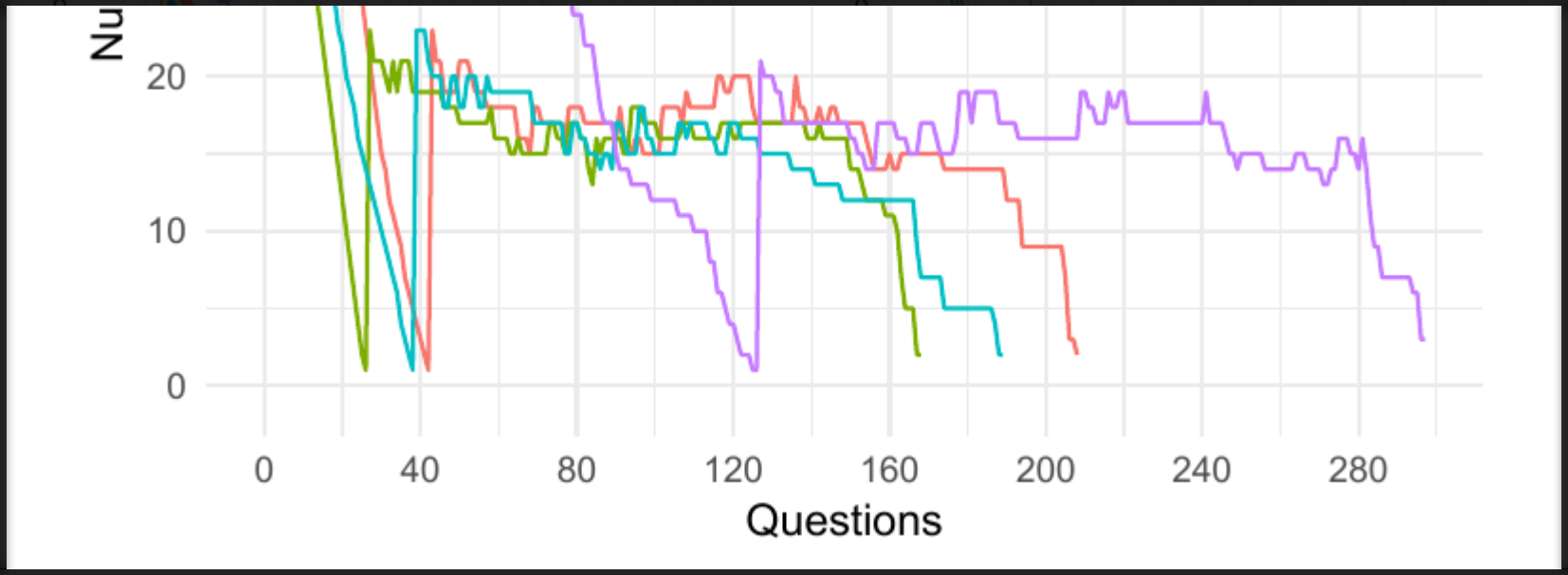


(b) Fixed size KB (800 atoms) with constant inconsistency ratio of 25%, 50 CDDs and 25 TGDs. Total number of conflicts after applying the chase is 136.

0 Experimental study

Effectiveness: synthetic KBs (convergence)

Results:

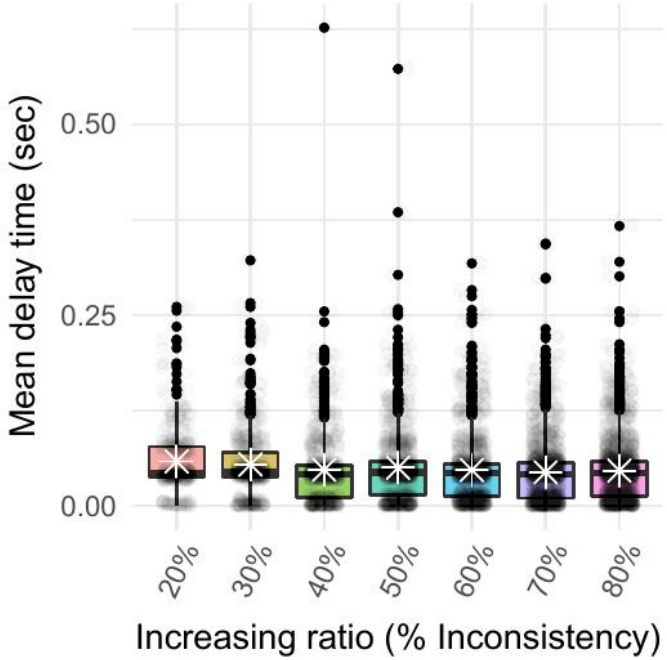


Experimental study

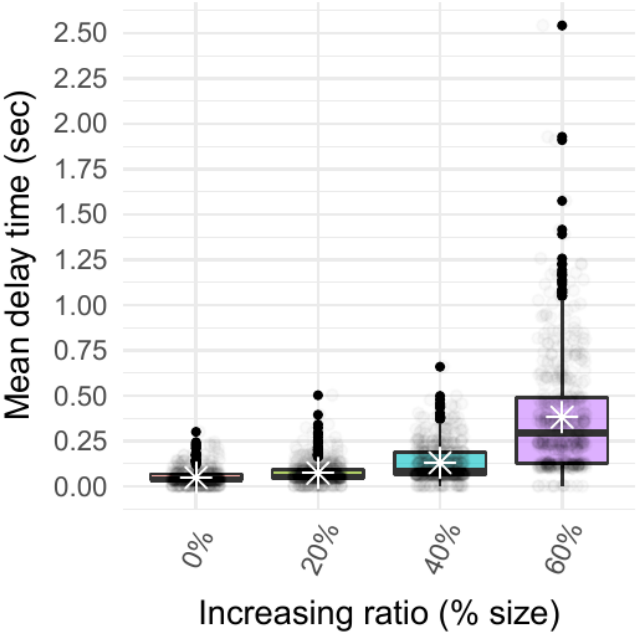
Delay time: synthetic KBs only CDDs

- **Reasonable** delay time: less than 1 to 2 seconds[1].
- MCD strategy is used.
- Drum wheat v1&2 less than *1 sec*.

Results:



(a) Fixed size KB (3000 atoms) with increasing inconsistency ratio.



(b) Increasing size KB starting at 0% with 3000 atoms, constant inconsistency ratio 30%.

1 Robert B Miller, Response time in man-computer conversational transactions, 1968.

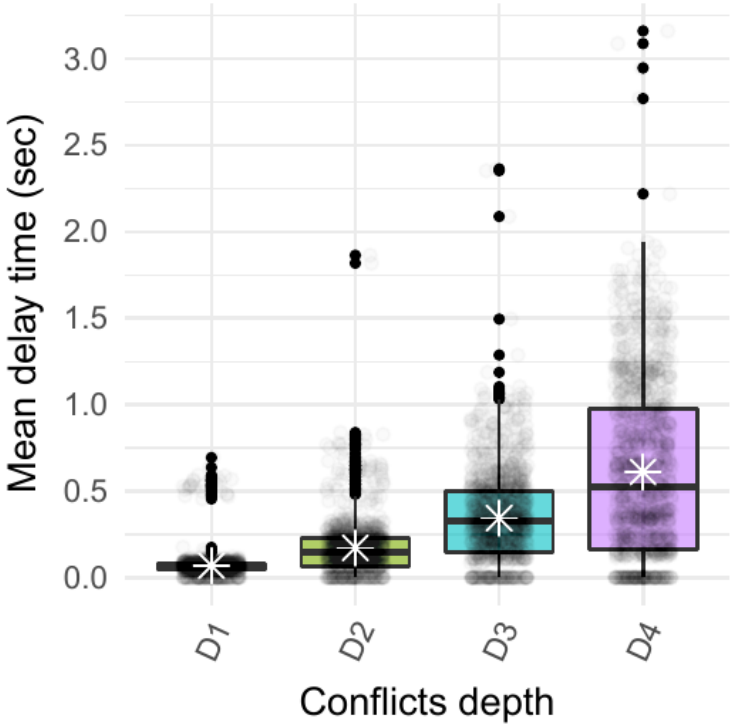
Experimental study

Delay time: synthetic KBs CDDs and TGDs

- **Reasonable** delay time: less than 1 to 2 seconds[1].
- MCD strategy is used.
- Drum wheat v1&2 less than *1 sec*.

Results:

	TGDs	CDDs
D1	50	150
D2	100	150
D3	150	150
D4	200	150
Size	400 atoms	
Inc ratio	100%	



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6 Conclusion

Summary:

- Update-based repairing of inconsistent knowledge bases.
- Interactive repairing in presence of interacting dependencies.
- Strategies for interaction minimization.
- Approach can be applied on portions of large knowledge bases.
- Delay time is reasonable.

Perspectives:

- Full Denial Constraints (but undecidability!).
- Other Data Cleaning constraints (CFDs, Metric FDs etc.).

End!

Thank you!
Questions

Abdallah Arioua and Angela Bonifati
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