LinCQA: Faster Consistent Query Answering with Linear Time Guarantees

Zhiwei Fan[†], Paraschos Koutris[†], Xiating Ouyang[†], Jef Wijsen[‡] *(alphabetical authorship)*

[†]University of Wisconsin – Madison, [‡]University of Mons

Consistent Query Answering (CQA)

While data cleaning is widely adopted to repair the inconsistent/dirty data, finding the "right repair" remains a challenge. Alternatively, the idea of CQA is to compute the answers that are guaranteed to be returned in **all** repairs.

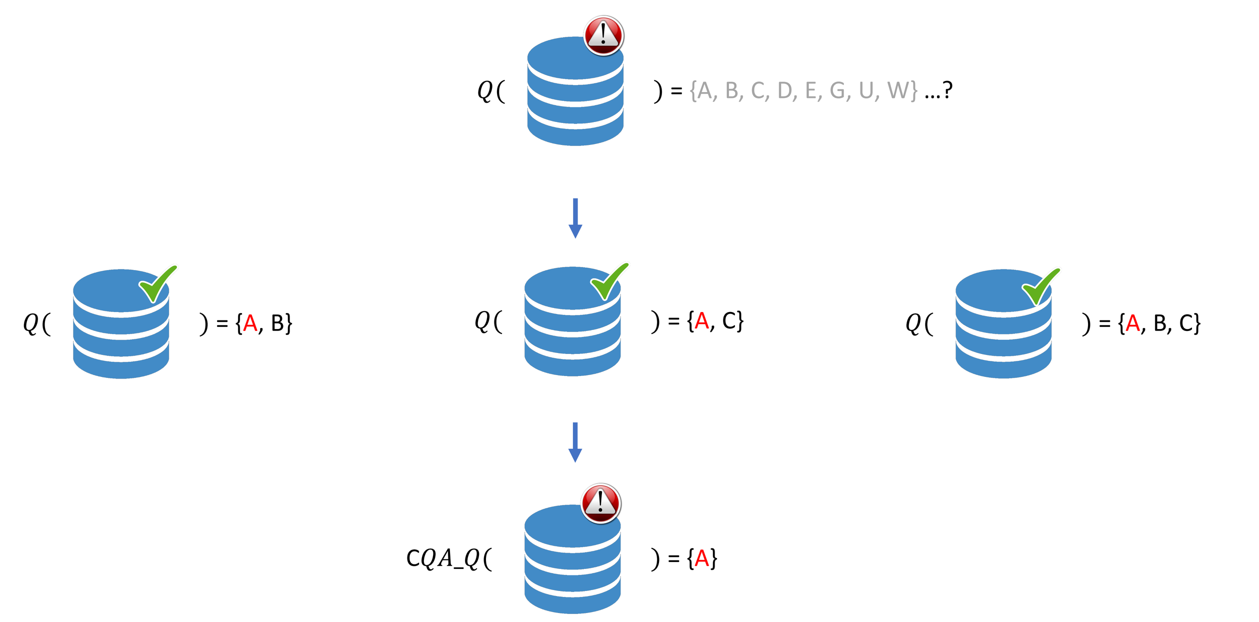


Fig. 1: An example of CQA. The middle layer shows the different sets of answers returned for each possible repair, and the bottom layer explains that the answer "A" is returned in **all** repairs.

$$\mathrm{CQA}_Q(\mathbf{db}^{!}) := \bigcap_{\mathbf{db}^{\checkmark} \text{ is a repair of } \mathbf{db}^{!}} Q(\mathbf{db}^{\checkmark}).$$

We study inconsistent databases that could violate the primary key constraint: every primary key could correspond to multiple distinct tuples in the database.

Problem: CQA(Q), where Q is a SPJ query

Input: a database $\mathbf{db}$ that violates the primary key constraint

Output: the answers **guaranteed** to be returned by Q on all repairs of $\mathbf{db}$

Course

course_id	faculty_id
CS 703	2
CS 703	5
MATH 770	3
MATH 770	7
CS 787	8
CS 787	9

Faculty

faculty_id	name	area
2	Adam	DB
2	Alice	ML
5	Bob	PL
9	Cathy	DB
9	Carrol	DB

Executing the following blue SQL query on the database returns the inconsistent answers **CS 703** and **CS 787**. The rewritten query Q' by adding the red segments would find the consistent answers (i.e., **CS 703**) that are returned in every repair of the database.

```
SELECT DISTINCT Course.c_id
FROM Course, Faculty
WHERE Course.f_id = Faculty.f_id
AND (all f_id's for the same c_id
     appear in Faculty)
```

Fig. 2: An example of first-order (FO) rewriting Q'.

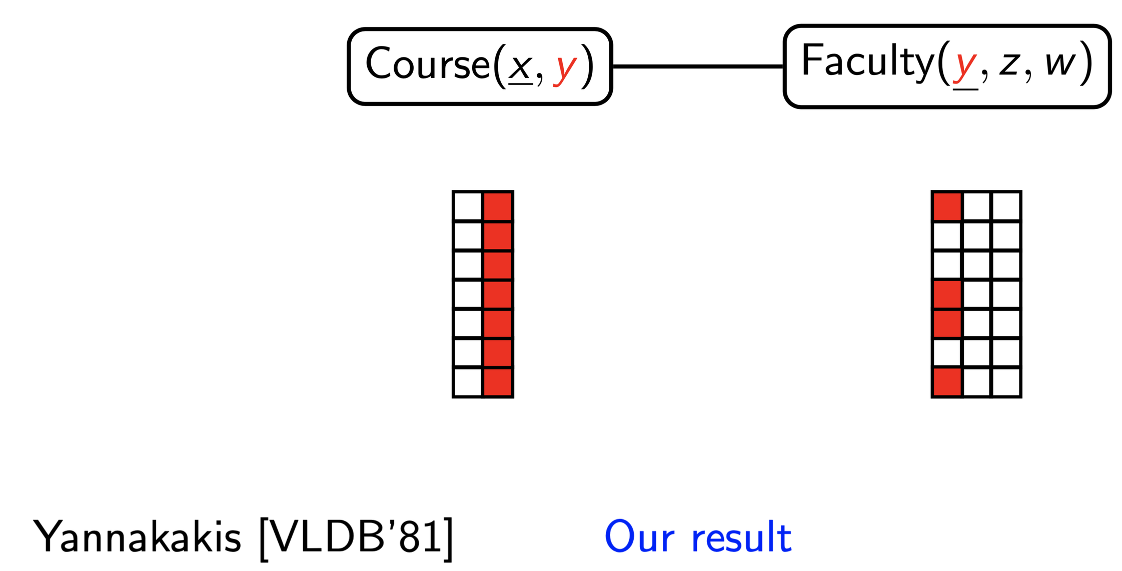
$$Q'(\mathbf{db}^{!}) = \bigcap_{\mathbf{db}^{\checkmark} \text{ is a repair of } \mathbf{db}^{!}} Q(\mathbf{db}^{\checkmark}) = \mathrm{CQA}_Q(\mathbf{db}^{!}).$$

Not all queries admit a first-order rewriting! And the classification on the rewritability remains an open problem.

Acyclic Queries in Linear Time

Evaluating an acyclic query is a well-studied problem by using hash joins on the join tree. For example, the **Boolean** blue SQL query is acyclic:

$$q() \text{:-} \mathrm{Course}(\underline{x}, y), \mathrm{Faculty}(\underline{y}, z, w).$$



The ~~answer~~ consistent answer to every **Boolean** acyclic query can be computed in $O(|\mathbf{db}|)$.

$\wedge$ with a pair-pruning join tree (PPJT)

Queries with projection can be reduced to **Boolean** queries $\Longrightarrow$

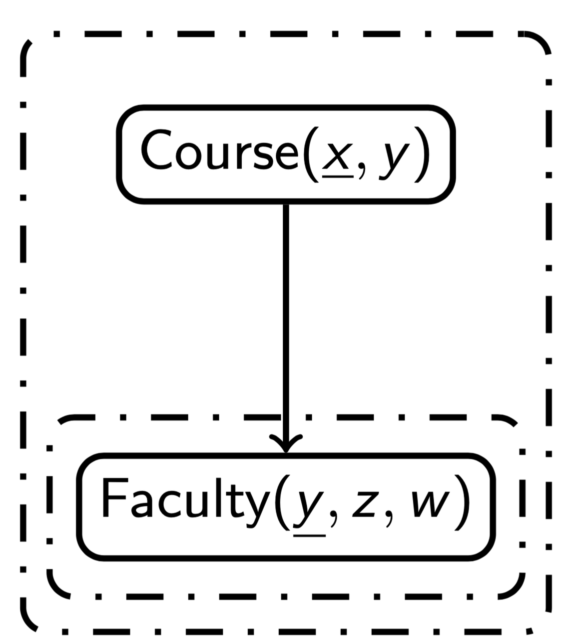
Pair-pruning Join Tree (PPJT)

We consider acyclic self-join-free SPJ queries (each table name occurs once).

Definition: A join tree rooted at some atom is a PPJT if

the root of every subtree is unattacked in the subtree.

For example, q has a PPJT:



- Queries on star/snowflake schema (e.g. TPC-H, TPC-DS)
- Two tables
- acyclic queries in $\mathcal{C}_{\text{forest}}$ [Fuxman and Miller, SIGMOD'05]

Proposition: If a **Boolean** query q have a pair-pruning join tree (PPJT), then CQA(q) has a first-order rewriting that runs in linear time.

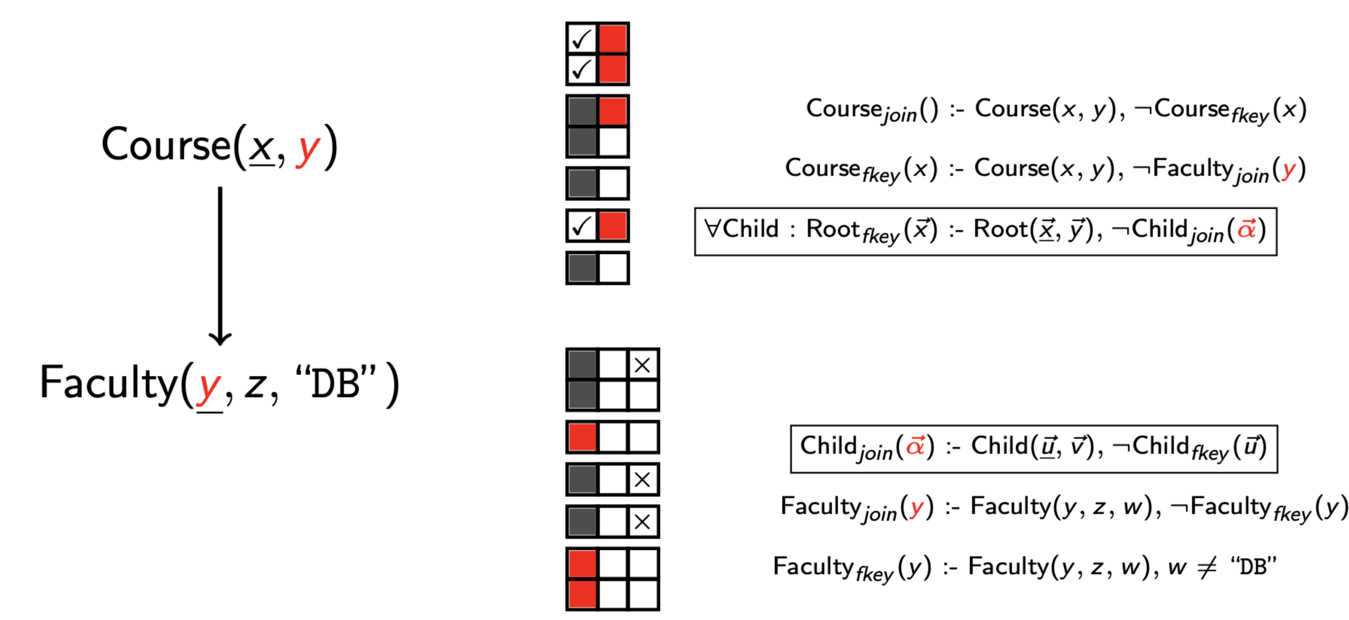
LinCQA and the Rewriting

LinCQA is a query rewriter that takes as input a SQL query, output its first-order rewriting.

```
python3 lincqa.py -i <input.sql/dlog> -o <output.sql/dlog>
```

Using PPJT, the consistent answers can be computed in a bottom-up fashion.

$$q() \text{:-} \mathrm{Course}(\underline{x}, y), \mathrm{Faculty}(\underline{y}, z, \text{"DB"}).$$



For queries **with projection**:

```
SELECT DISTINCT A1, A2 FROM T WHERE A3 = 42
```

we use PPJT to check for each potential answer $(a, b)\dots$ in **one** program:

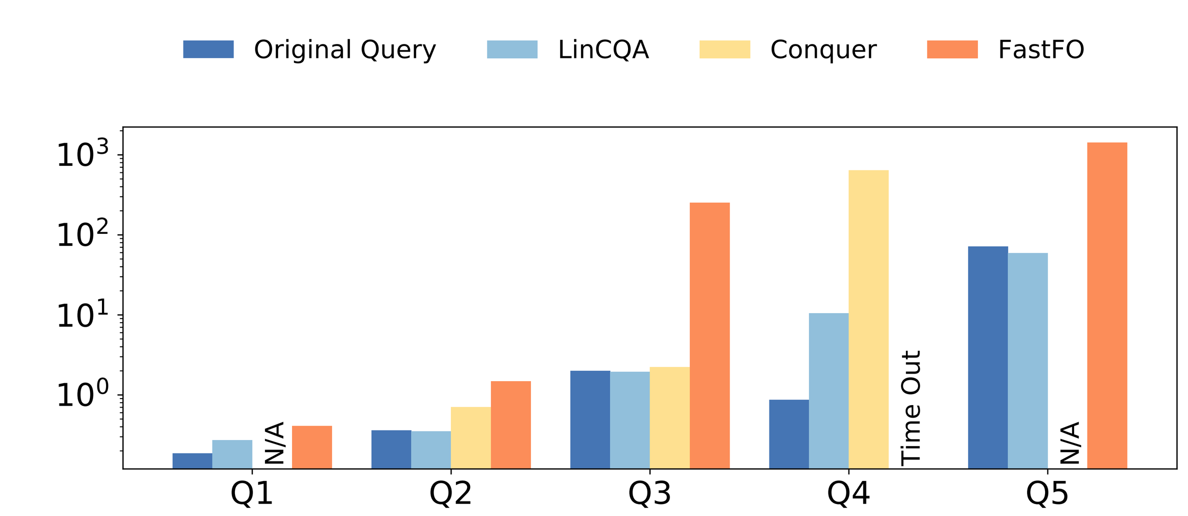
```
SELECT DISTINCT 1 FROM T WHERE A3 = 42 AND A1 = a AND A2 = b
```

if **yes**, then (a, b) is a consistent answer.

Experiments

We used a 400GB StackOverflow dataset (among others) on SQL Server.

Table	# of rows	inconsistencyRatio	blockSize	# of Attributes
Users	14M	0%	1	14
Posts	53M	0%	1	20
PostHistory	141M	0.001%	4	9
Badges	40M	0.58%	941	4
Votes	213M	30.9%	1441	6



	Q1	Q2	Q3	Q4	Q5
$\lvert Q(\mathbf{db}^{!})\rvert$	27578	145	38320	3925	1250
$\lvert \mathrm{CQA}_Q(\mathbf{db}^{!})\rvert$	27578	145	38320	3925	1245

Acyclic q	LinCQA [SIGMOD'23]	Yannakakis [VLDB'81]
Boolean q	$O(\lvert\mathbf{db}\rvert)$	$O(\lvert\mathbf{db}\rvert)$
Projection q	$O(\lvert\mathbf{db}\rvert \cdot \lvert\mathrm{OUT}_{\text{inconsistent}}\rvert)$	$O(\lvert\mathbf{db}\rvert \cdot \lvert\mathrm{OUT}\rvert)$
full q (SELECT *)	$O(\lvert\mathbf{db}\rvert + \lvert\mathrm{OUT}_{\text{consistent}}\rvert)$	$O(\lvert\mathbf{db}\rvert + \lvert\mathrm{OUT}\rvert)$

Consistent answers can be computed with no asymptotic overhead