

LinCQA: Faster Consistent Query Answering with Linear Time Guarantees

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joint work with Zhiwei Fan ^{1,2} Paris Koutris ¹ Jef Wijsen ³

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- 1 Consistent Query Answering for Primary Keys
- 2 Acyclic Queries Revisited
- 3 Pair-pruning join tree (PPJT) & LinCQA
- 4 Experiments

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Primary key constraint (violated)

- Metadata of `stackoverflow.com` as of 02/2021 from Stack Exchange Data Dump
- 551M rows, ~400 GB

Table	# of rows	inRatio	bSize	# 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

$\text{inconsistencyRatio} = \# \text{ facts violating PK constraint} / \# \text{ of rows}$

$\text{blockSize} = \max. \# \text{ facts with the same PK}$

Finding consistent answers

Course	
c_id	f_id
CS 703	2
CS 703	5
CS 787	3
CS 787	5

CS_Faculty	
f_id	f_name
2	Adam
2	Alice
5	Bob

```
SELECT DISTINCT c_id
FROM Course, CS_Faculty
WHERE Course.f_id
      = CS_Faculty.f_id
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Q :Return all classes taught by a CS faculty

$Q(\mathbf{db}) = \{\text{CS 703, CS 787}\} \dots$

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Data cleaning

$Q(\mathbf{rep})$

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$2 \times 2 \times 2 \times 1$ repairs

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$2 \times 2 \times 2 \times 1$ repairs

Which answers are guaranteed to be returned on <u>all</u> repairs?
--

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$\bigcap_{\text{rep is a repair of db}} Q(\text{rep})$

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Consistent Answer

Finding consistent answers without enumeration

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$$Q'(\text{db}) = \bigcap_{\text{rep is a repair of db}} Q(\text{rep})$$

The original query Q has a first-order rewriting Q'

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The original query Q has a *first-order rewriting* Q'

For which Q can the consistent answers be found efficiently?

Can we build a system to find the consistent answers?

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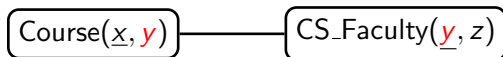
Acyclic query evaluation

$q() \text{ :- Course}(\underline{x}, y), \text{CS_Faculty}(\underline{y}, z)$



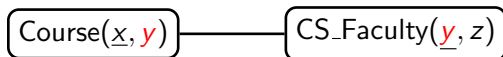
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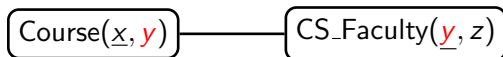
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Yannakakis [VLDB'81]

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

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Our result

consistent answer

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^
with a pair-pruning join tree (PPJT)

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Our result

consistent answer

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$$\text{non-Boolean} \leq_T^P \text{Boolean}$$

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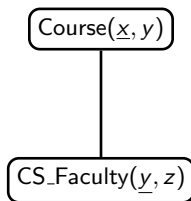
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Pair-pruning join tree (PPJT)

A join tree **rooted** at some atom is a PPJT if

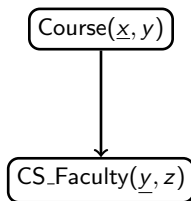
the root of every subtree is unattacked in the subtree



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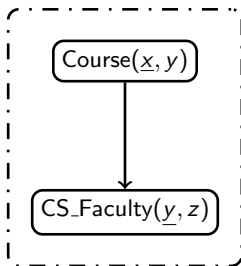
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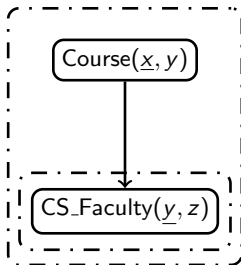
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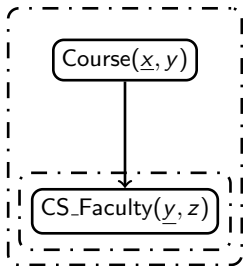
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Pair-pruning join tree (PPJT)

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the root of every subtree is unattacked in the subtree



Every acyclic query has a join tree, but not every acyclic query has a PPJT

PPJT is a wide class

- + star/snowflake schema (e.g. TPC-H)
- + Every acyclic query in $\mathcal{C}_{\text{forest}}$ [FM, ICDT'05] has a PPJT

From PPJT to **FO**-rewriting

Remove a primary key if some tuple with this primary key is “bad”

Course(x, y)
↓
Faculty(y, z, “DB”)

✓	✓	✓
✓	✓	✓
✓	✓	✓
✓	✓	✓
✓	✓	✓
✓	✓	✓

✓	✓	✓
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also expressible in SQL!
runs in $O(N)$

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✓	✓	red
✓	✓	red
grey	grey	red
grey	grey	white
grey	grey	white
✓	✓	red
grey	grey	white

grey	grey	white	×
grey	grey	white	×
red	red	white	×
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grey	grey	white	×
grey	grey	white	×
red	white	white	×
red	white	white	×
grey	white	white	×
grey	white	white	×
red	white	white	×

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$\text{Course}_{fkey}(x) \text{ :- } \text{Course}(x, y), \neg \text{Faculty}_{\text{join}}(y)$

$\forall \text{Child} : \text{Root}_{fkey}(\vec{x}) \text{ :- } \text{Root}(\vec{x}, \vec{y}), \neg \text{Child}_{\text{join}}(\vec{\alpha})$

$\text{Child}_{\text{join}}(\vec{\alpha}) \text{ :- } \text{Child}(\vec{u}, \vec{v}), \neg \text{Child}_{fkey}(\vec{u})$

$\text{Faculty}_{\text{join}}(y) \text{ :- } \text{Faculty}(y, z, w), \neg \text{Faculty}_{fkey}(y)$

$\text{Faculty}_{fkey}(y) \text{ :- } \text{Faculty}(y, z, w), w \neq \text{“DB”}$

also expressible in SQL!

runs in $O(N)$

From PPJT to **FO**-rewriting

Remove a primary key if some tuple with this primary key is “bad”

Course(x, y)
 \downarrow
 Faculty(y, z, “DB”)

✓	✓	red
✓	✓	red
gray	gray	red
gray	gray	white
gray	gray	white
✓	✓	red
gray	gray	white

gray	gray	white	×
gray	gray	white	×
red	red	white	×
red	red	white	×
gray	gray	white	×
gray	gray	white	×
red	red	white	×
red	red	white	×

$\text{Course}_{\text{join}}() \text{ :- Course}(x, y), \neg \text{Course}_{fkey}(x)$

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 runs in $O(N)$

From Boolean to non-Boolean

SELECT DISTINCT A1, A2 FROM T WHERE A3 = 42

Step 1 Evaluate directly

A1	A2
a	b
x	y
...	...

Step 2 Reduce to **Boolean** (using PPJT)

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

if yes, then output (a, b), otherwise continue

SELECT DISTINCT 1 FROM T WHERE A3 = 42 AND A1 = x AND A2 = y

...

$\xrightarrow{\text{LinCQA}}$ a single SQL/Datalog query

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$\xrightarrow{\text{LinCQA}}$ a single SQL/Datalog query

Acyclic q	PPJT	Yannakakis [VLDB'81]
Boolean q	$O(N)$	$O(N)$
non-Boolean q	$O(N \cdot \text{OUT}_{\text{inconsistent}})$	$O(N \cdot \text{OUT})$
full q (SELECT *)	$O(N + \text{OUT}_{\text{consistent}})$	$O(N + \text{OUT})$

Consistent answers of common join queries can be computed with no asymptotic overhead

Acyclic q	PPJT	Yannakakis [VLDB'81]
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Consistent answers of common join queries can be computed with no asymptotic overhead

1 Consistent Query Answering for Primary Keys

2 Acyclic Queries Revisited

3 Pair-pruning join tree (PPJT) & LinCQA

4 Experiments

Setup & Baselines

System	Target class	Interm. output	Backend
CAvSAT	*	SAT formula	SQL Server & MaxHS
Conquer	$\mathcal{C}_{\text{forest}}$	SQL	SQL Server
Improved Conquesto	SJF FO	SQL	SQL Server
LinCQA	PPJT	SQL	SQL Server



Stackoverflow data

- Metadata of `stackoverflow.com` as of 02/2021 from Stack Exchange Data Dump
- 551M rows, 400 GB

Table	# of rows	inRatio	bSize	# 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

Experiments on Stackoverflow

Q_1 : Posts \bowtie Votes Q_2 : Users \bowtie Badges Q_3 : Users \bowtie Posts

Q_4 : Users \bowtie Posts \bowtie Comments

Q_5 : Posts \bowtie PostHistory \bowtie Votes \bowtie Comments

```
1 SELECT DISTINCT Posts.Title
2 FROM Posts, PostHistory, Votes, Comments
3 WHERE Posts.Tags LIKE "%SQL%"
4 AND Posts.id = PostHistory.PostId
5 AND Posts.id = Comments.PostId
6 AND Posts.id = Votes.PostId
7 AND Votes.BountyAmount > 100
8 AND PostHistory.PostHistoryTypeId = 2
9 AND Comments.score = 0
```

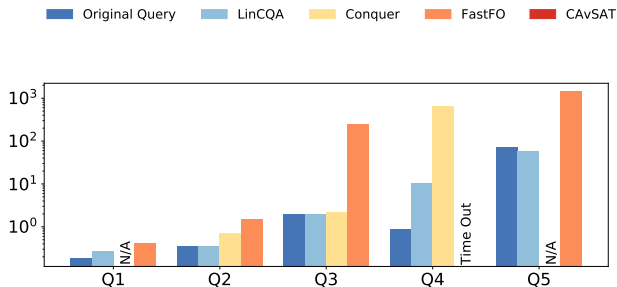
```
20
21
22
23 PostHistory_bad_key as (
24   select Ph.PostId, Ph.CreationDate, Ph.UserId, Ph.PostHistoryTypeId
25   from PostHistory Ph
26   where Ph.PostHistoryTypeId = 2
27 ),
28
29 PostHistory_good_join as (
30   select Ph.PostId
31   from PostHistory Ph
32   where not exists (
33     select
34       from PostHistory_bad_key
35     where Ph.PostId = PostHistory_bad_key.PostId and
36           Ph.CreationDate = PostHistory_bad_key.CreationDate and
37           Ph.UserId = PostHistory_bad_key.UserId and
38           Ph.PostHistoryTypeId = PostHistory_bad_key.PostHistoryTypeId
39   )
40 ),
41
42 Votes_bad_key as (
43   select V.PostId, V.UserId, V.CreationDate
44   from Votes V
45   where V.BountyAmount <= 100 or V.BountyAmount is null
46 ),
47
48 Votes_good_join as (
49   select V.PostId
50   from Votes V
51   where not exists (
52     select
53       from Votes_bad_key
54     where V.PostId = Votes_bad_key.PostId and
55           V.UserId = Votes_bad_key.UserId and
56           V.CreationDate = Votes_bad_key.CreationDate
57   )
58 ),
59
60 Comments_bad_key as (
61   select C.CreationDate, C.UserId, candidates.Title
62   from Comments C
63   join candidates on (C.CreationDate = candidates.CreationDate and C.UserId = candidates.UserId)
64   where C.score <= 0
65 ),
66
67 union all
68
69 select C.CreationDate, C.UserId, candidates.Title
70 from Comments C
71 join candidates on (C.CreationDate = candidates.CreationDate and C.UserId = candidates.UserId)
72 left outer join PostHistory_good_join as (C.PostId = PostHistory_good_join.PostId)
73 left outer join PostHistory_good_join as (C.PostId = PostHistory_good_join.PostId)
74 left outer join Votes_good_join as (C.PostId = Votes_good_join.PostId)
75 where (
76   PostHistory_good_join.Id is null or PostHistory_good_join.PostId is null or Votes_good_join.PostId is null
77   or PostHistory_good_join.Title is null
78 )
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Experiments on Stackoverflow

Q_1 : Posts \bowtie Votes Q_2 : Users \bowtie Badges Q_3 : Users \bowtie Posts

Q_4 : Users \bowtie Posts \bowtie Comments

Q_5 : Posts \bowtie PostHistory \bowtie Votes \bowtie Comments



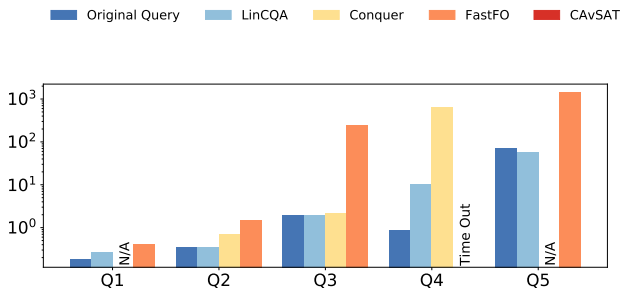
# poss.	27578	145	38320	3925	1250
# cons.	27578	145	38320	3925	1245

Concluding remarks

Acyclic q	PPJT	Yannakakis [VLDB'81]
Boolean q	$O(N)$	$O(N)$
non-Boolean q	$O(N \cdot \text{OUT}_{\text{inconsistent}})$	$O(N \cdot \text{OUT})$
full q (SELECT *)	$O(N + \text{OUT}_{\text{consistent}})$	$O(N + \text{OUT})$

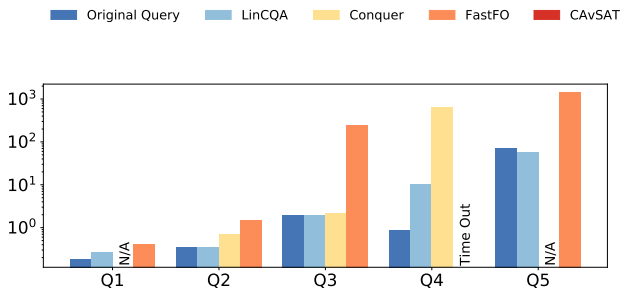
Concluding remarks

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Concluding remarks

Acyclic q	PPJT	Yannakakis [VLDB'81]
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Thank you!