CNRS interview

The Fine-Grained Complexity of Evaluating Database Queries

Nofar CARMELI

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The Fine-Grained Complexity of Evaluating Queries

- To use data: store & **query**
- Big data requires extremely efficient algorithms
  - **Fine-grained** complexity: ‘polynomial’ is not enough
- What is the **most efficient way** of answering a database query?

In the Slides

- Updates to CV
- One result: Enumeration Complexity of Unions of Conjunctive Queries
- Research project

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Enumeration Complexity of UCQs

- Goal
- Overview
- Explanations
  - Easy ∪ Hard
    - Why isn’t it always hard?
    - When is it easy?
  - Hard ∪ Hard
    - Sometimes it is easy
    - Dichotomy

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Goal

Which Unions of Conjunctive Queries can be answered with optimal time guarantees?

Studied Queries

tutorials:

Person	Title
Alan Fekete	Making Consistency…
Suresh Venkatasu…	Algorithmic Fairness…

schedule:

Title	Day
Making Consistency…	Tue
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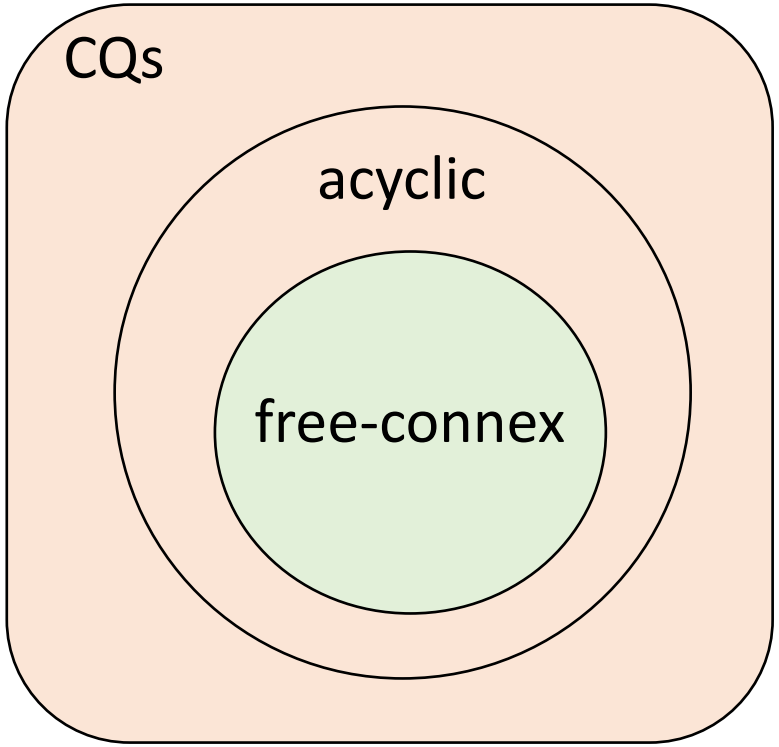
- $\mathbf{DelayC_{lin}}$: solvable in linear preprocessing and constant delay

Which queries are in $\mathrm{DelayC_{lin}}$?

Starting Point

[BaganDurandGrandjean CSL'2007]
[Brault-Baron 2013]

CQs: $\in DelayC_{lin} \Leftrightarrow^{*}$ free-connex



* Hardness results assume:
(1) no self-joins
(2) hardness of Boolean matrix multiplication and hyperclique

Free-connex Definition

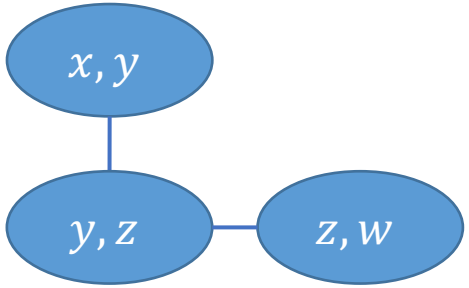
1. a node for every atom

2. tree

3. for every variable X:
the nodes containing X form a subtree

acyclic

$$Q(x, y, z) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$



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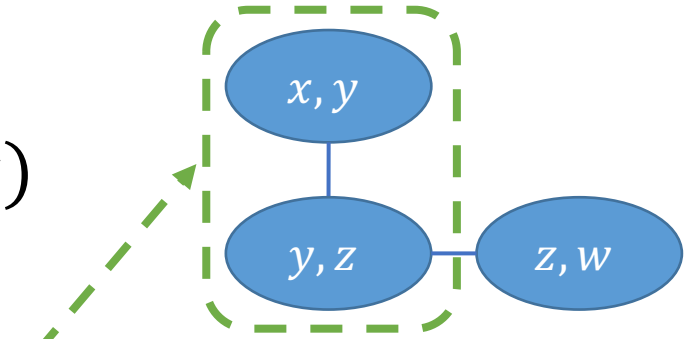

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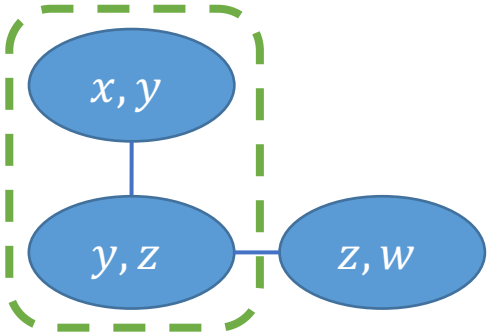

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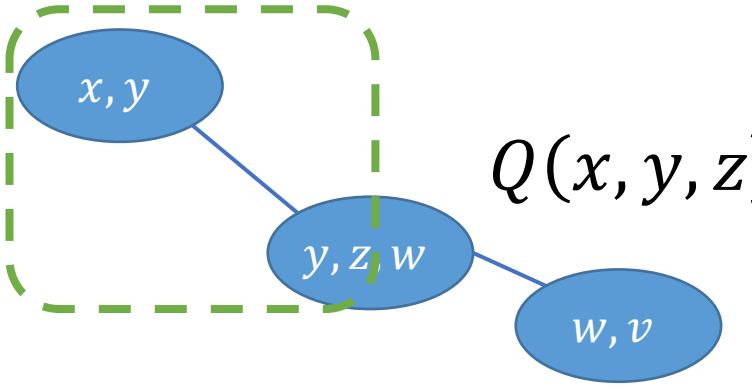

$$Q(x, y, z) \leftarrow R_1(x, y), R_2(y, z, w), R_3(w, v)$$

free − connex

Free-connex Definition

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   possibly also subsets

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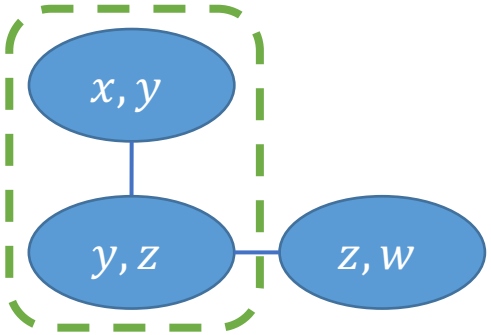

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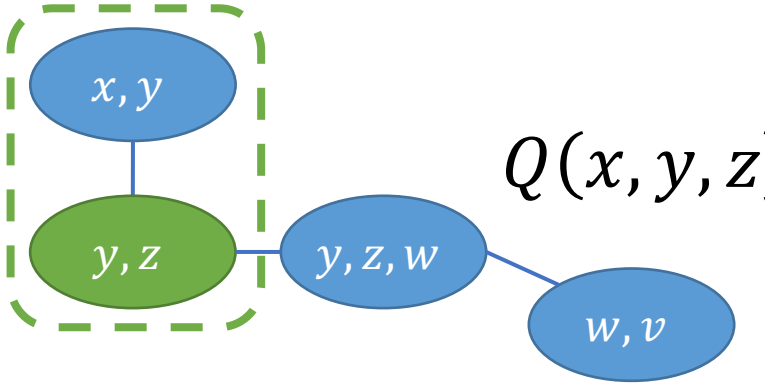

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[BaganDurandGrandjean CSL'2007]
[Brault-Baron 2013]

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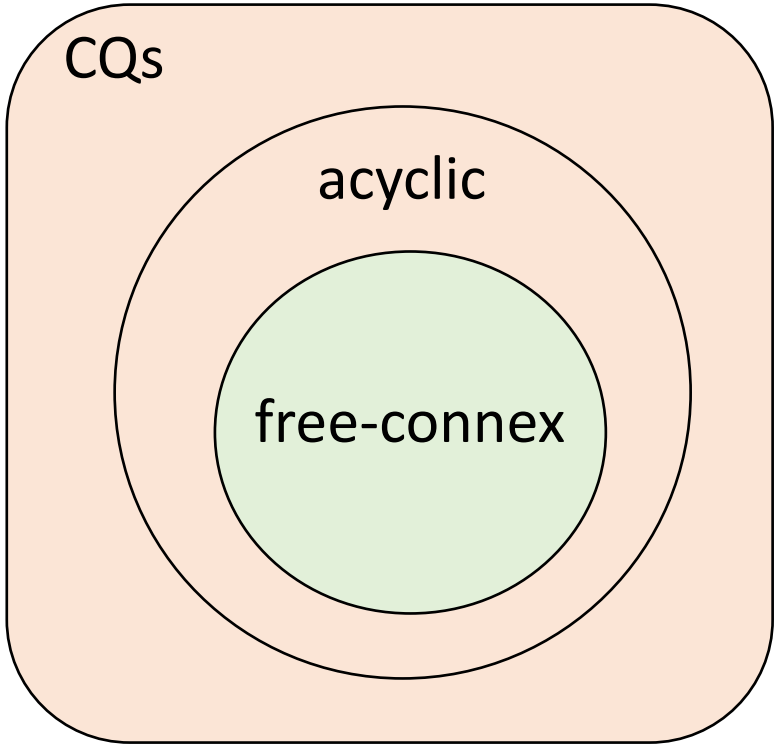

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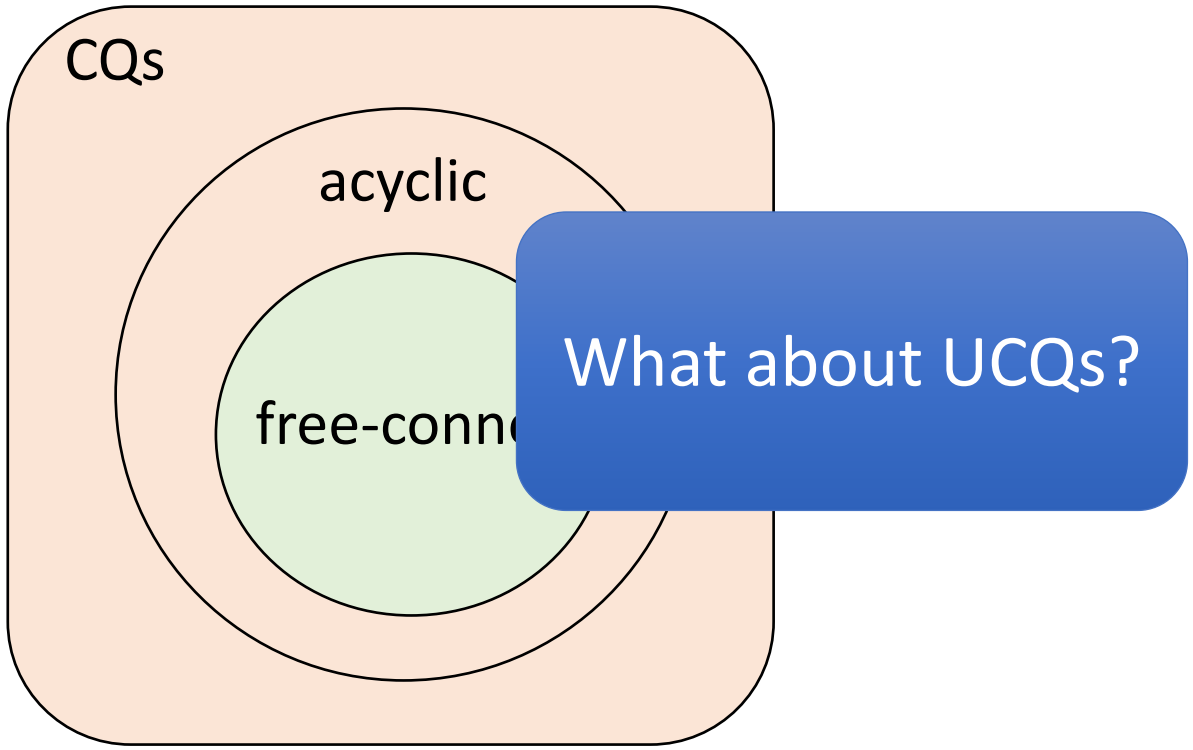

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Cases for UCQs

All CQs are Easy

Some Easy, Some Hard

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non free − connex

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non-redundant unions?

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Claimed [ICDT 2018]:
hard if contains a hard CQ

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some **non-redundant** unions
with a hard CQ
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Cases for UCQs

* Even for non-redundant unions

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If each CQ in Q is hard
and
there is no body-isomorphism

$\Rightarrow \quad Q \notin DelayC_{lin}$

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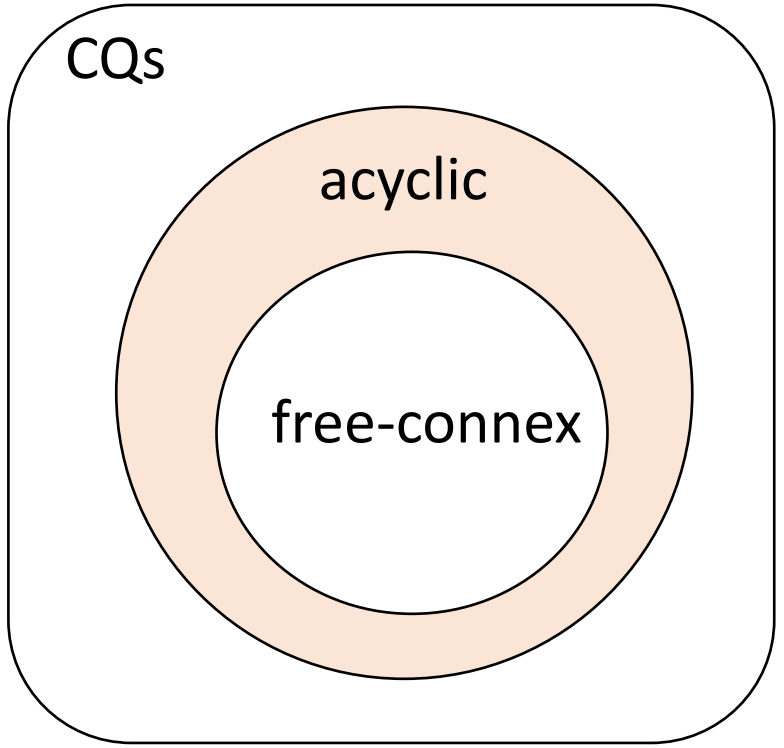
Lower Bound

[BaganDurandGrandjean CSL'2007]

Acyclic non-free-connex:

$$Q(x, z) \leftarrow R_1(x, y), R_2(y, z)$$



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Assumption: Boolean $n \times n$ matrices cannot be multiplied in time $O(n^2)$

$$\begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} ? & ? \\ ? & ? \end{pmatrix}$$

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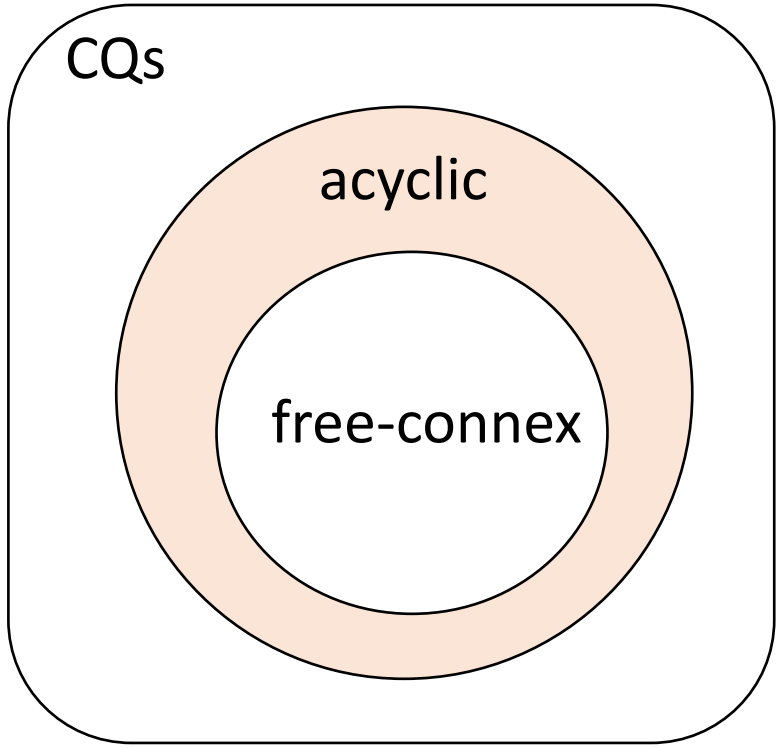

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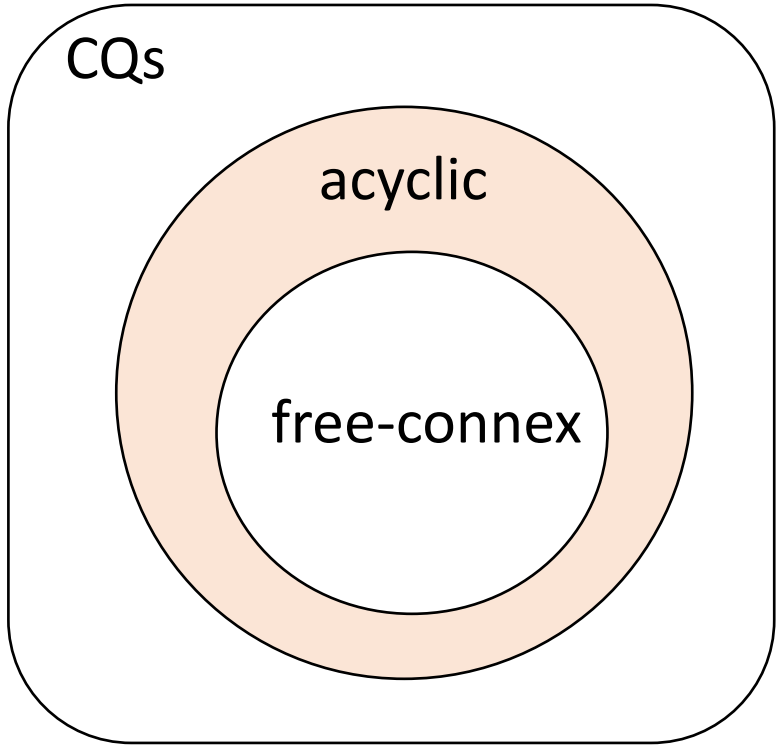

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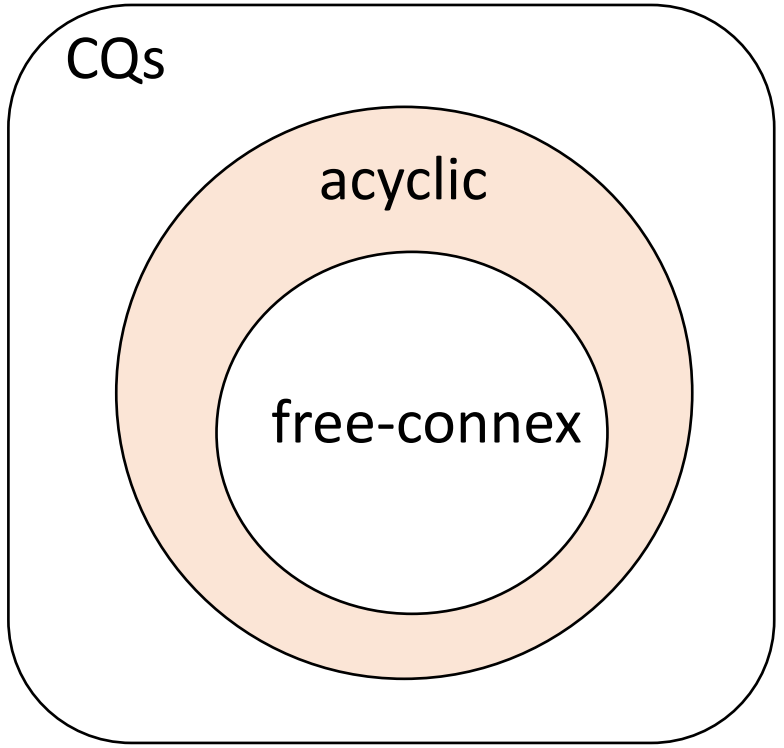

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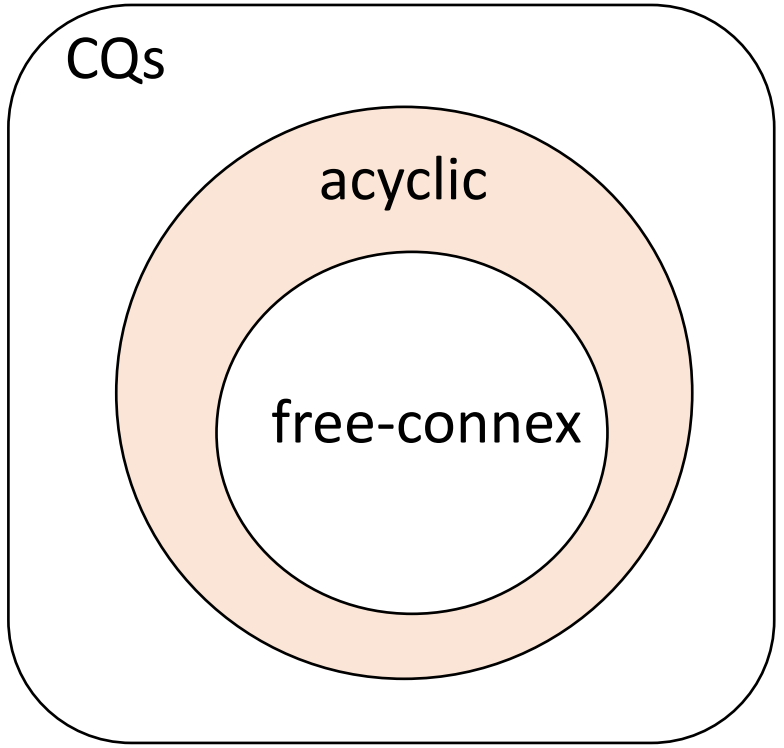

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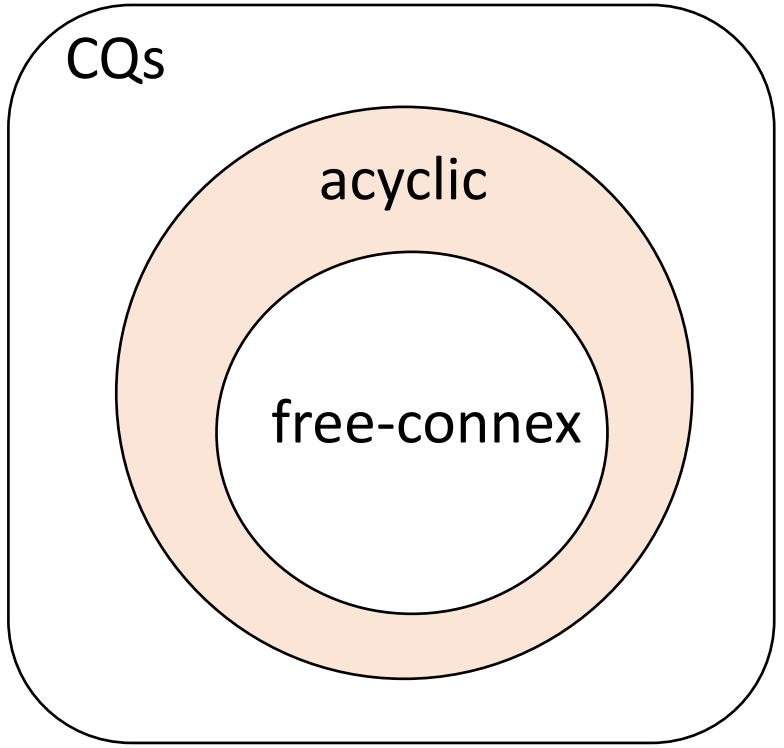

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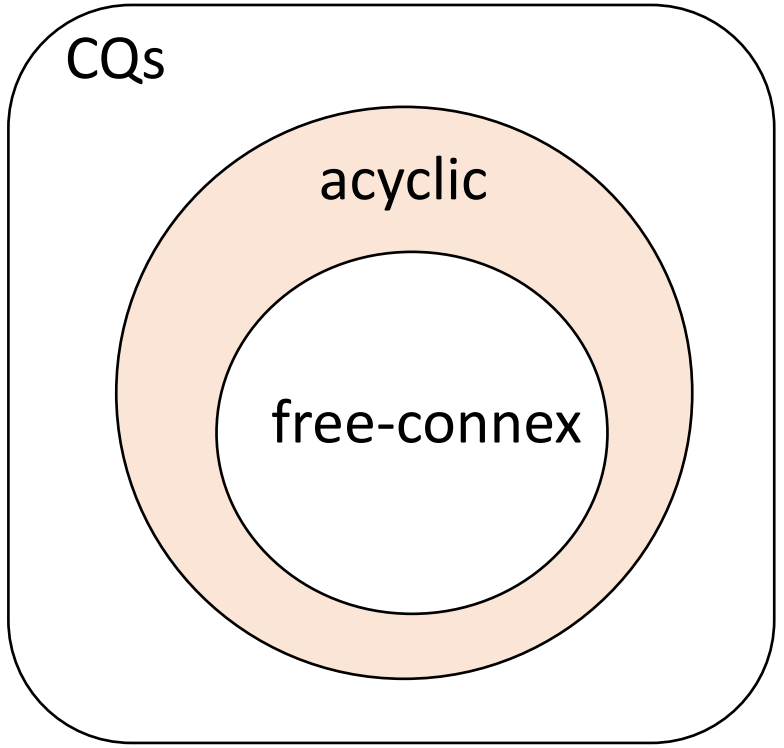

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$\notin \mathbf{DelayC_{lin}}$

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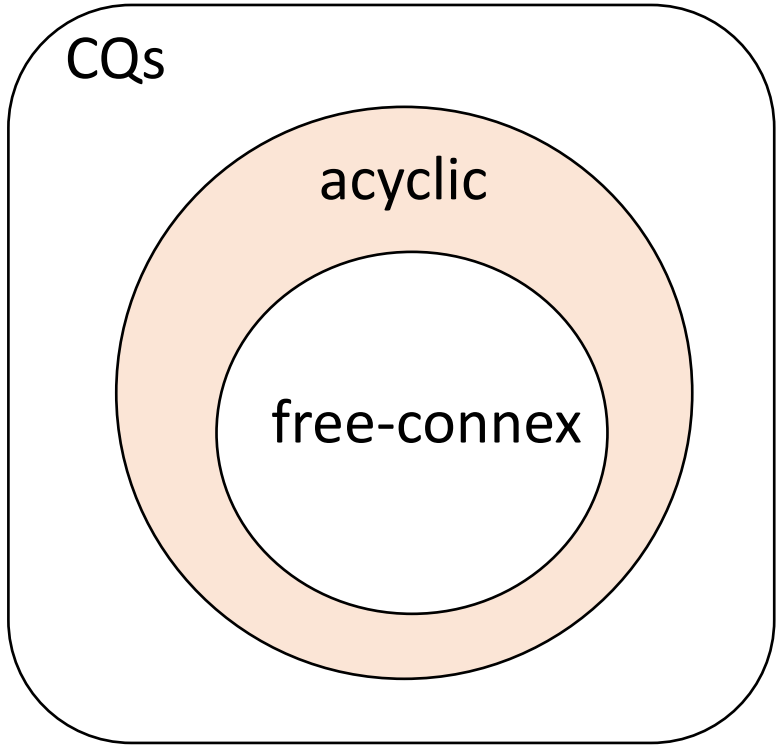
1	2
2	2



Within Unions

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

not free connex

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not free connex

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

Within Unions

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

not free connex

Q_1		
1	2	⊥
2	2	⊥

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

R_3	
2	⊥

Within Unions

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

$$\cup$$

$$Q_2(a, b, c) \leftarrow R_1(a, b), R_2(b, c)$$

not free connex

Q_1		
1	2	⊥
2	2	⊥

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

R_3	
2	⊥

Within Unions

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

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$$Q_2(a, b, c) \leftarrow R_1(a, b), R_2(b, c)$$

not free connex

Q_1		
1	2	⊥
2	2	⊥

Q_2		
1	1	2
1	2	2
2	2	2

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

R_3	
2	⊥

Within Unions

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

U

$$Q_2(a, b, c) \leftarrow R_1(a, b), R_2(b, c)$$

not free connex

Q_1		
1	2	⊥
2	2	⊥

Q_2		
1	1	2
1	2	2
2	2	2

$O(n^3)$ solutions:
The computation does not contradict the assumption

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

R_3	
2	⊥

Within Unions

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

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Q_1		
1	2	⊥
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Q_2		
1	1	2
1	2	2
2	2	2

$O(n^3)$ solutions:
The computation does not contradict the assumption

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

R_3	
2	⊥

The hardness results do not hold within a union

Enumeration Complexity of UCQs

- Goal
- Overview
- Explanations
  - Easy ∪ Hard
    - Why isn't it always hard?
    - **When is it easy?**
  - Hard ∪ Hard
    - Sometimes it is easy
    - Dichotomy

Providing Variables

non free − connex

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

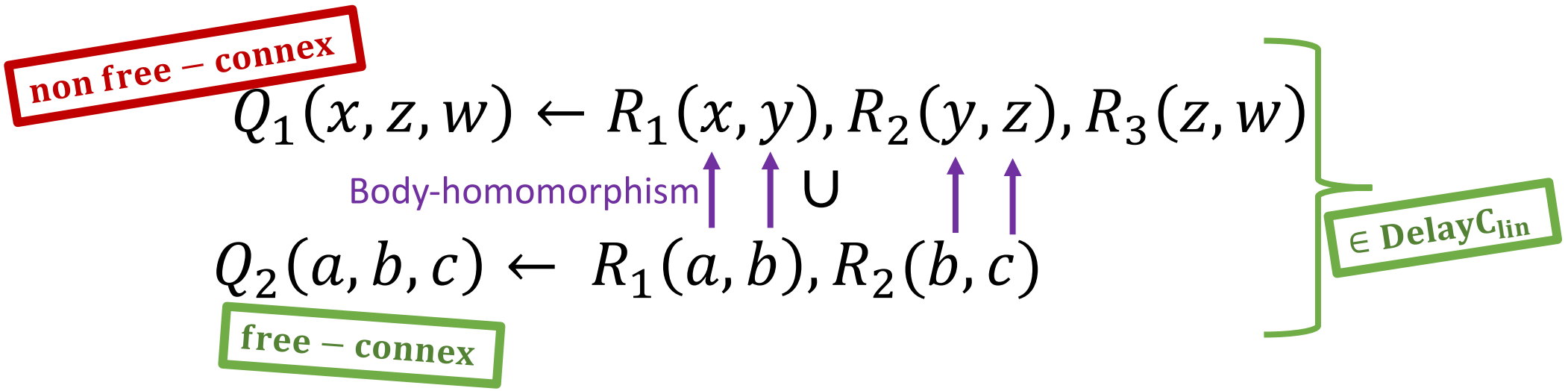
$$\cup$$

$$Q_2(a, b, c) \leftarrow R_1(a, b), R_2(b, c)$$

free − connex

$\in \mathbf{DelayC_{lin}}$

Providing Variables



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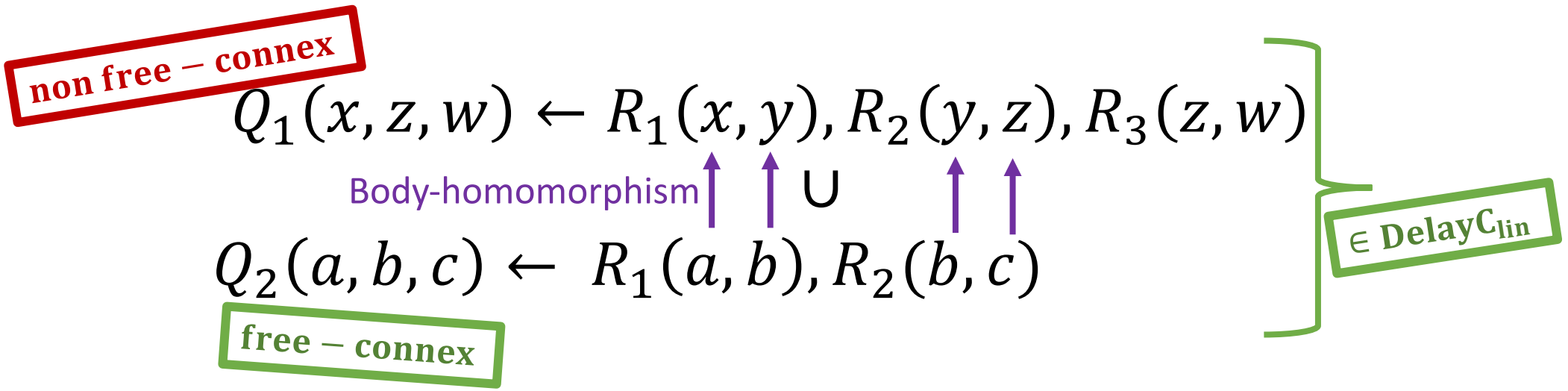
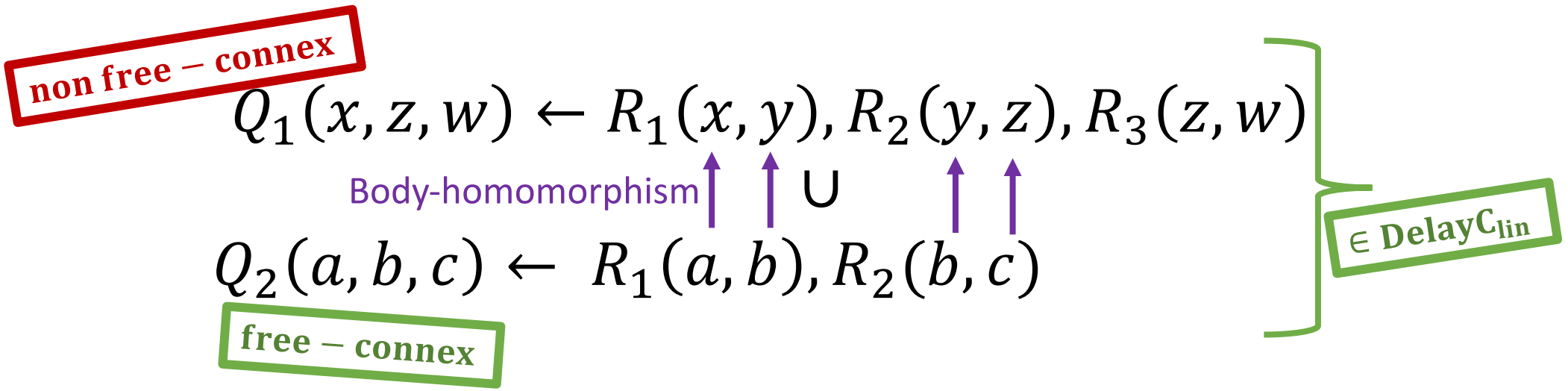


Q_2 computes $R_1 \bowtie R_2$

Providing Variables



Q_2 computes $R_1 \bowtie R_2 \implies Q_2$ provides $\{x, y, z\}$ to Q_1

Providing Variables

non free − connex

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

Body-homomorphism ↑ ↑ ∪ ↑ ↑

$$Q_2(a, b, c) \leftarrow R_1(a, b), R_2(b, c)$$

free − connex

$\in \mathbf{DelayC_{lin}}$

Q_2 computes $R_1 \bowtie R_2 \implies Q_2$ provides $\{x, y, z\}$ to Q_1

$$Q_1'(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w), R'(x, y, z)$$

Providing Variables

non free − connex

$$Q_1(x, z, w) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w)$$

Body-homomorphism ↑ ↑ ∪ ↑ ↑

$$Q_2(a, b, c) \leftarrow R_1(a, b), R_2(b, c)$$

free − connex

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Q_2 computes $R_1 \bowtie R_2 \implies Q_2$ provides $\{x, y, z\}$ to Q_1

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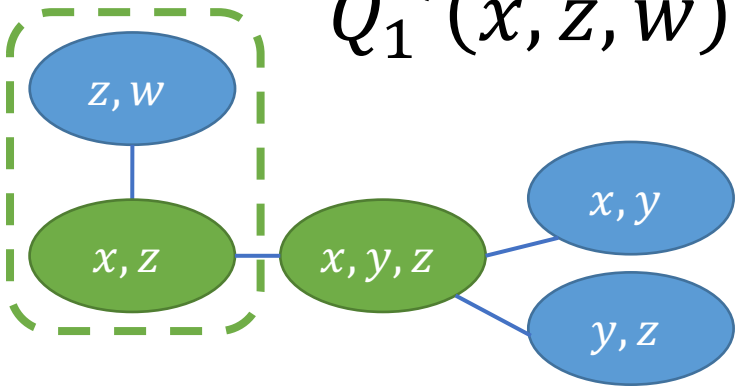

Enumeration Complexity of UCQs

- Goal
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  - Easy ∪ Hard
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Hard ∪ Hard = Easy

- Example: CQs with **isomorphic bodies**.

$$Q_1(x, z, w, u) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w), R_4(w, u)$$
$$Q_2(x, y, z, u) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w), R_4(w, u)$$

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- Example: CQs with **isomorphic bodies**.

hard part

$$Q_1(x, z, w, u) \leftarrow R_1(x, y), R_2(y, z), R_3(z, w), R_4(w, u)$$

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hard part

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hard part

	Step	Output	Side Effect
1	Solve Q_2'	$\subseteq Q_2$	Find $R_1 \bowtie R_2$
2	Solve Q_1^+	Q_1	Find $R_3 \bowtie R_4$
3	Solve Q_2^+	Q_2	

Theorem

We can classify every UCQ of the form Hard ∪ Hard:

Both queries are body-isomorphic, free-path guarded and bypass guarded $\iff$ Both queries become free-connex by adding provided atoms $\iff$ $\in \mathrm{DelayC_{lin}}$

* Hardness results assume:
(1) no self-joins
(2) hardness of Boolean matrix multiplication, hyperclique detection and 4-clique detection.

In the Slides

- Updates to CV
- One result: Enumeration Complexity of Unions of Conjunctive Queries
- **Research project**

The Fine-Grained Complexity of Evaluating Queries

- To use data: store & **query**
- Big data requires extremely efficient algorithms
  - **Fine-grained** complexity: ‘polynomial’ is not enough
- What is the **most efficient way** of answering a database query?

The Fine-Grained Complexity of Evaluating Queries

What is the most efficient way
of answering a database query?

The Fine-Grained Complexity of Evaluating Queries

What is the most efficient way
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The Fine-Grained Complexity of Evaluating Queries

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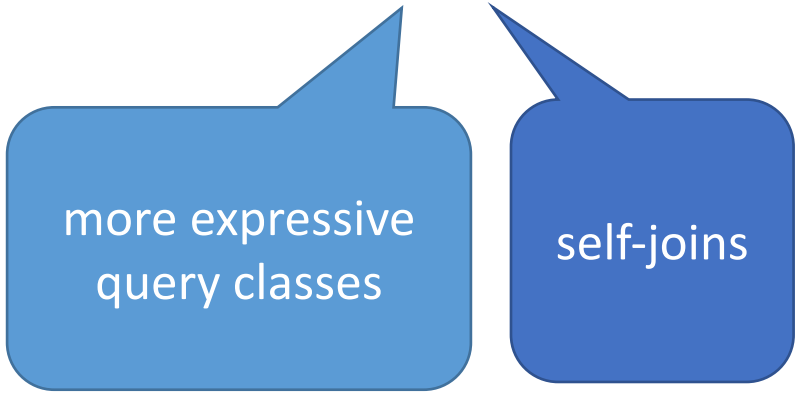


[C+, PODS'19][C+, TODS'21]

The Fine-Grained Complexity of Evaluating Queries

What is the most efficient **way of answering** a database query?

The Fine-Grained Complexity of Evaluating Queries

What is the most efficient **way of answering** a database query?

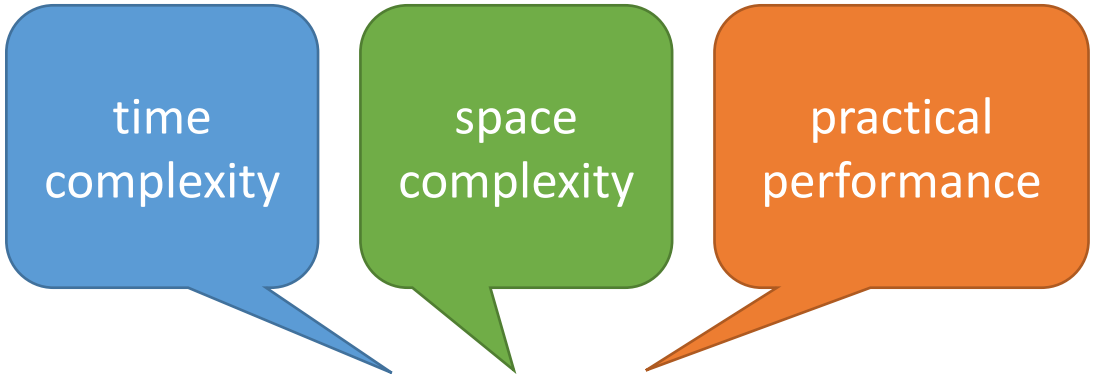
enumeration
vs.
direct access

[C+, PODS'20]
[C+, PODS'21]

The Fine-Grained Complexity of Evaluating Queries

What is the most **efficient** way
of answering a database query?

The Fine-Grained Complexity of Evaluating Queries



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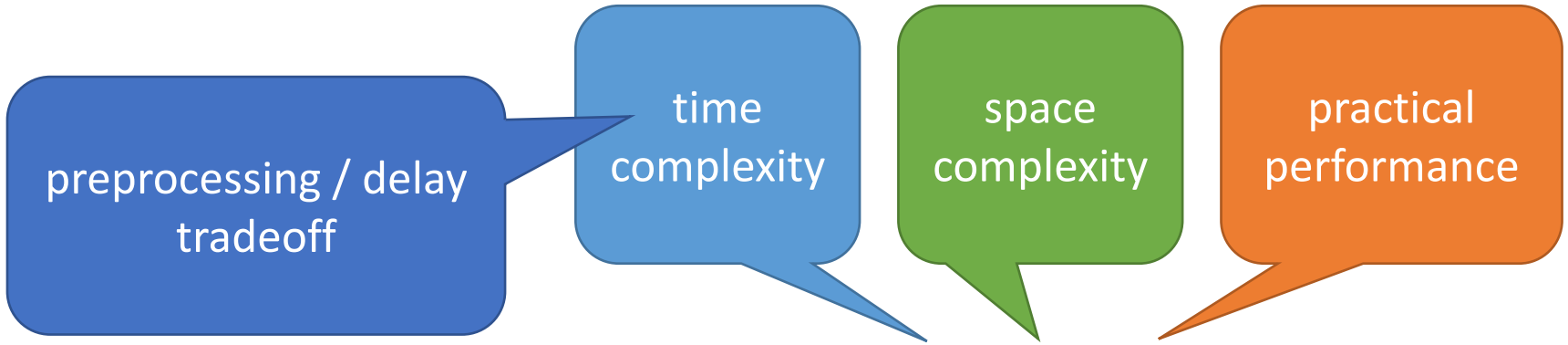
The Fine-Grained Complexity of Evaluating Queries



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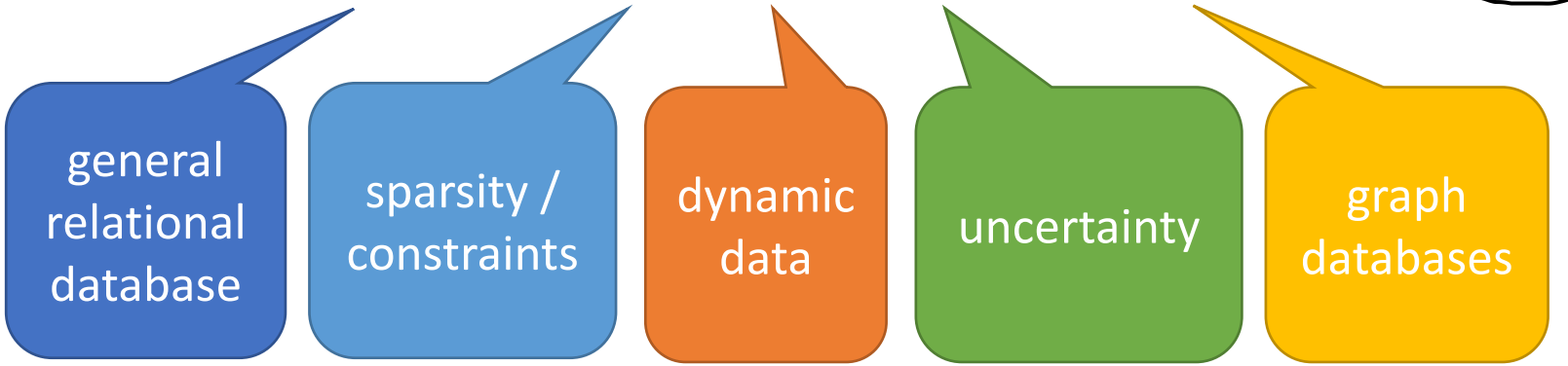

Ontologies

[C+, ICDT'18][C+, TOCS'19]

The Fine-Grained Complexity of Evaluating Queries

What is the most efficient way of answering a database query?

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