CNRS interview

The Fine-Grained Complexity of Evaluating Database Queries

Nofar CARMELI

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- 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?

My Past Work

- Query decompositions [PODS 17, DAM 20]
- Constant delay query answering:
  - DBs with constraints [ICDT 18, TOCS 19]
  - Unions of CQs [PODS 19, TODS 21]
  - Random order [PODS 20]
  - Ranked access [PODS 21, PODS 22]
- Uncertain data:
  - Repairing noisy DBs [ICDT 21]
  - Representing probabilistic DBs [PODS 21]
- Structured review summarization [WWW 20, WWW 21]

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Enumeration Complexity of UCQs

- Goal
- Overview
- Explanations
  - Easy ∪ Hard
    - Why isn't it always hard?
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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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Join + Project

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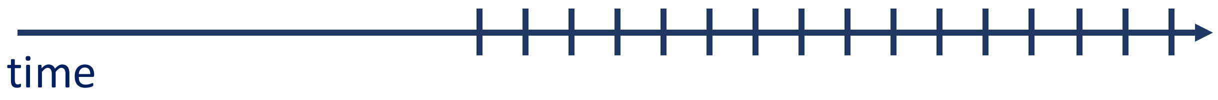

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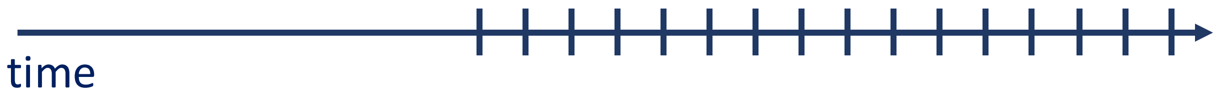

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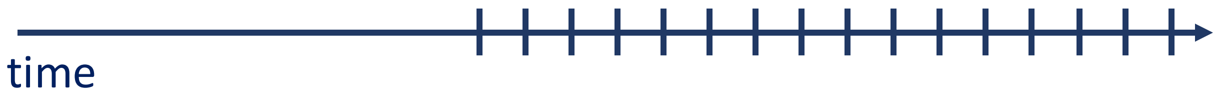
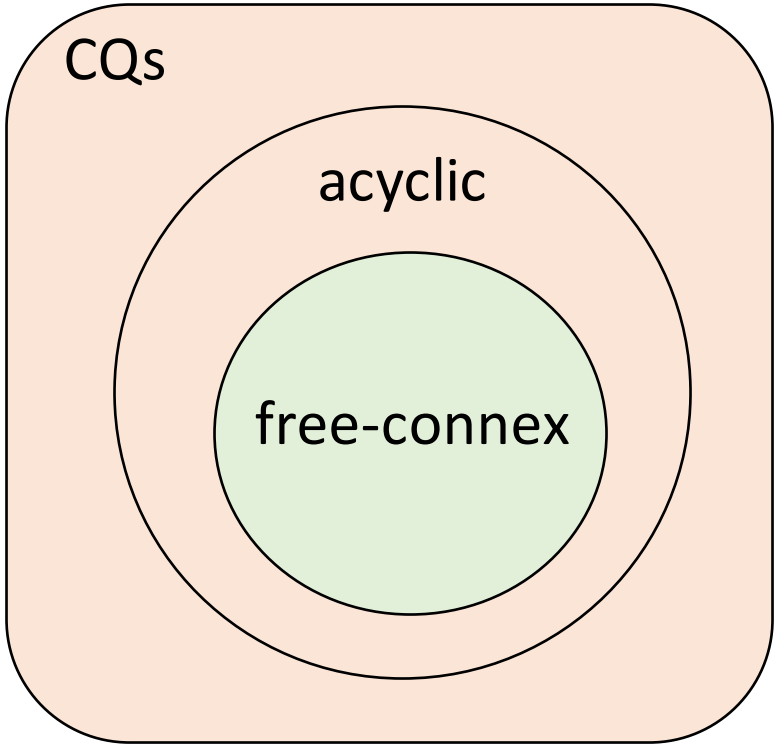


Which queries are in $\mathrm{DelayC_{lin}}$?

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

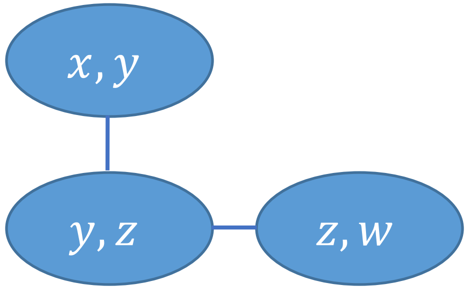
1. a node for every atom

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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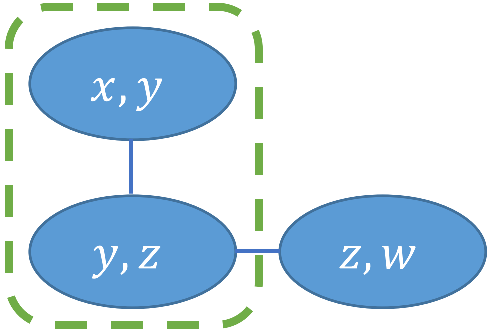

4. a subtree with exactly the free variables

Free-connex Definition

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possibly also subsets

2. tree

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$\boxed{\textbf{acyclic}}$ $\boxed{\textbf{free} - \textbf{connex}}$

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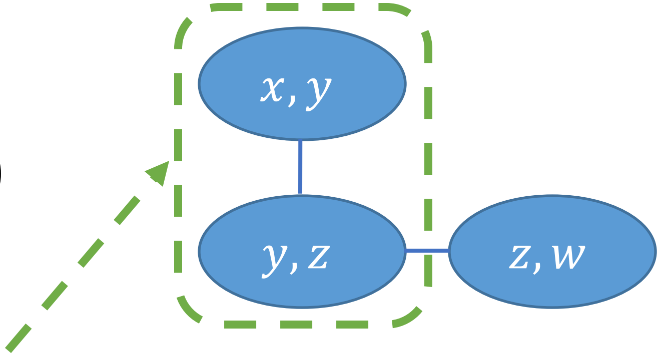

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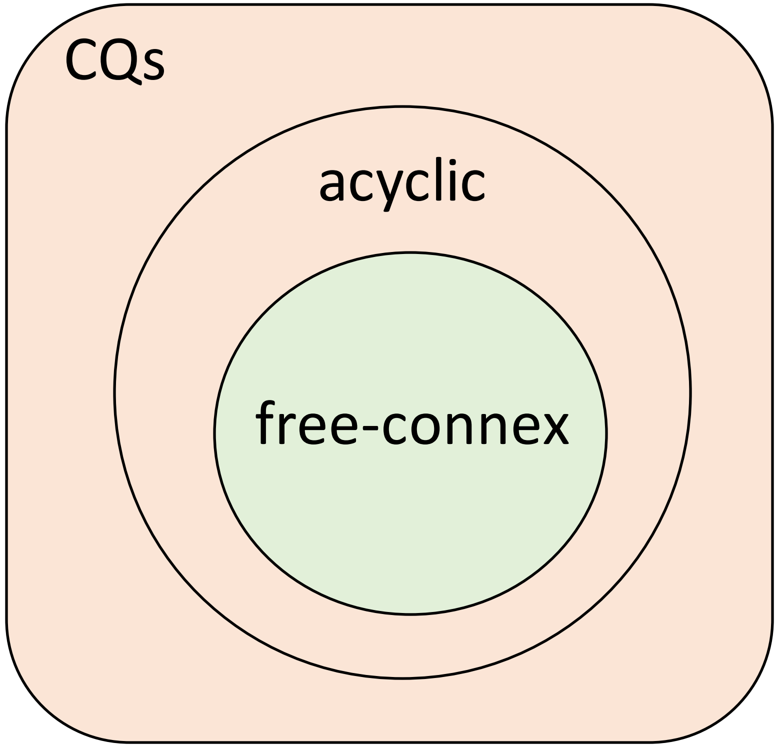

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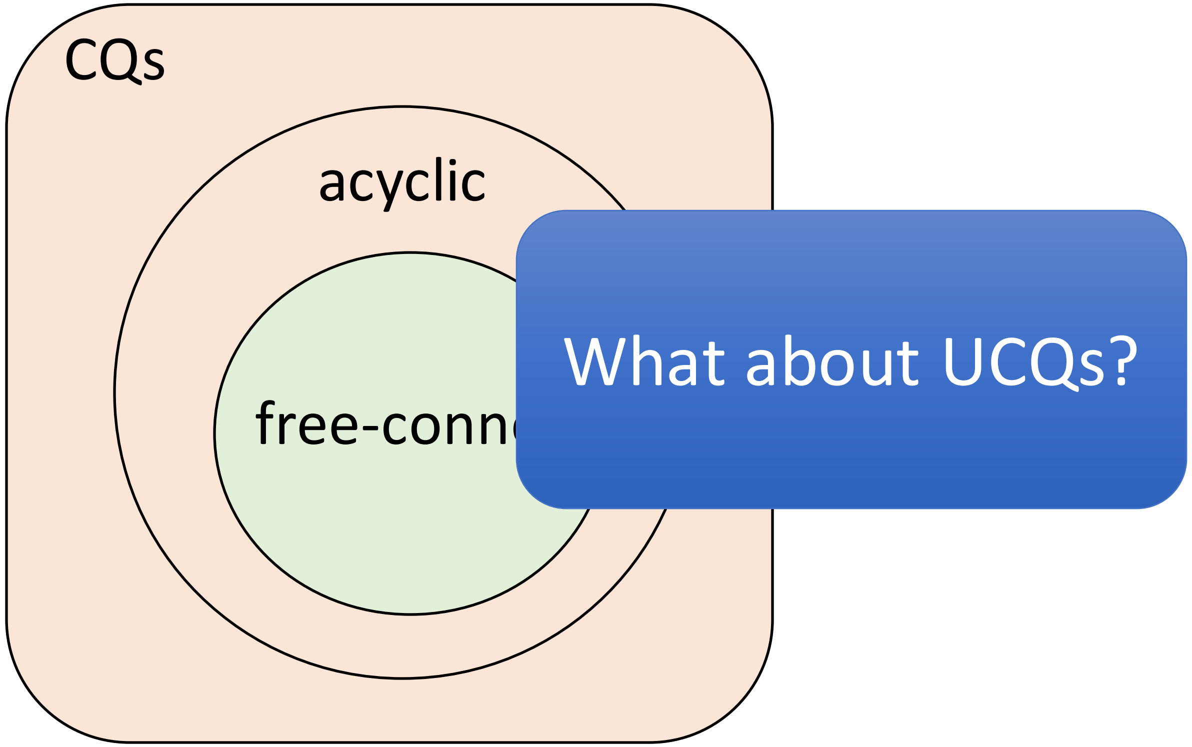

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All CQs are Hard

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

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If each CQ in Q is hard
and
there is no body-isomorphism $\Longrightarrow$ $Q \notin DelayC_{lin}$

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All CQs are Easy

always easy

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All CQs are Hard

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UCQs containing **only hard** CQs
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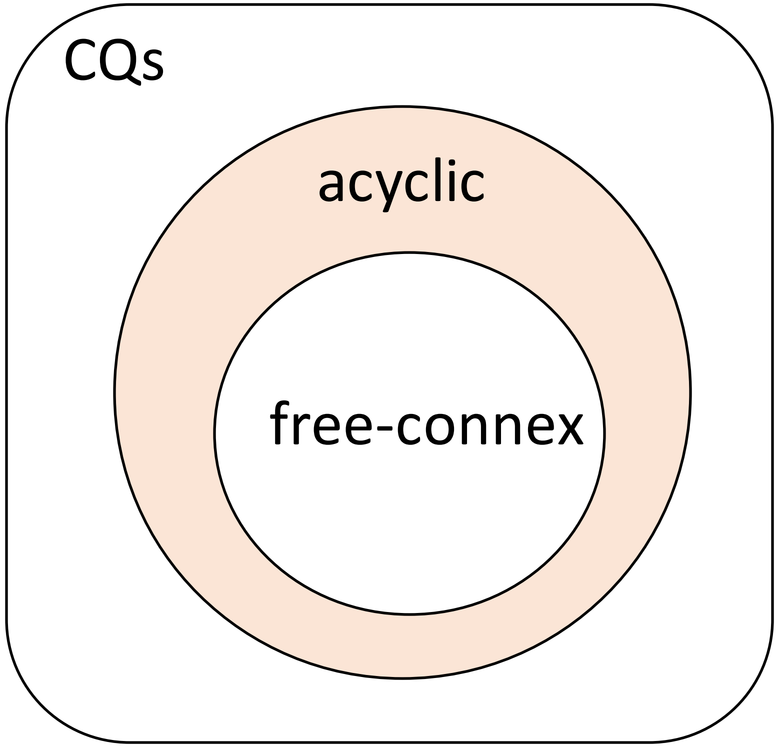
Lower Bound

[BaganDurandGrandjean CSL'2007]

Acyclic non-free-connex:

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



Lower Bound

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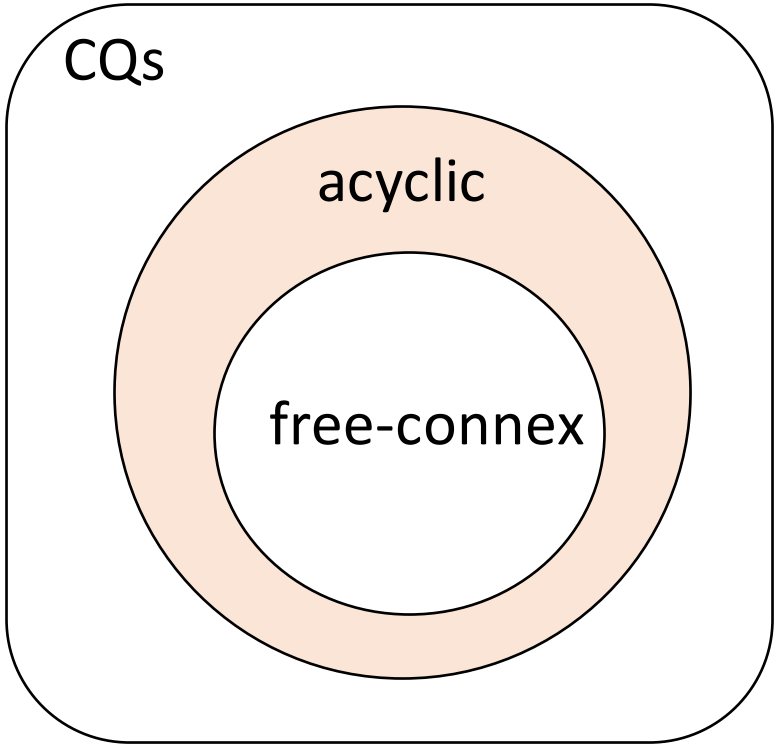
Assumption: Boolean $n \times n$ matrices cannot be multiplied in time $O(n^2)$

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



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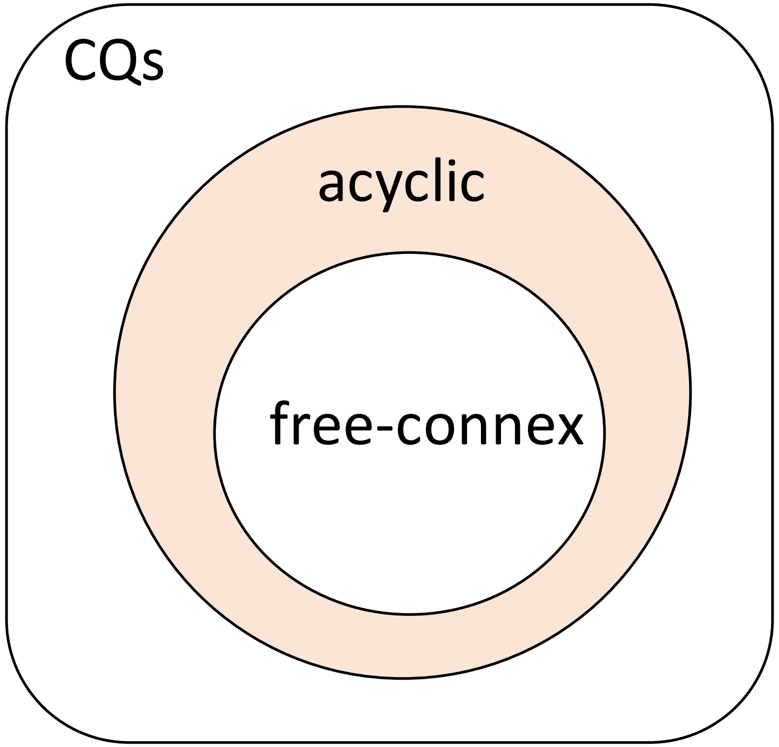

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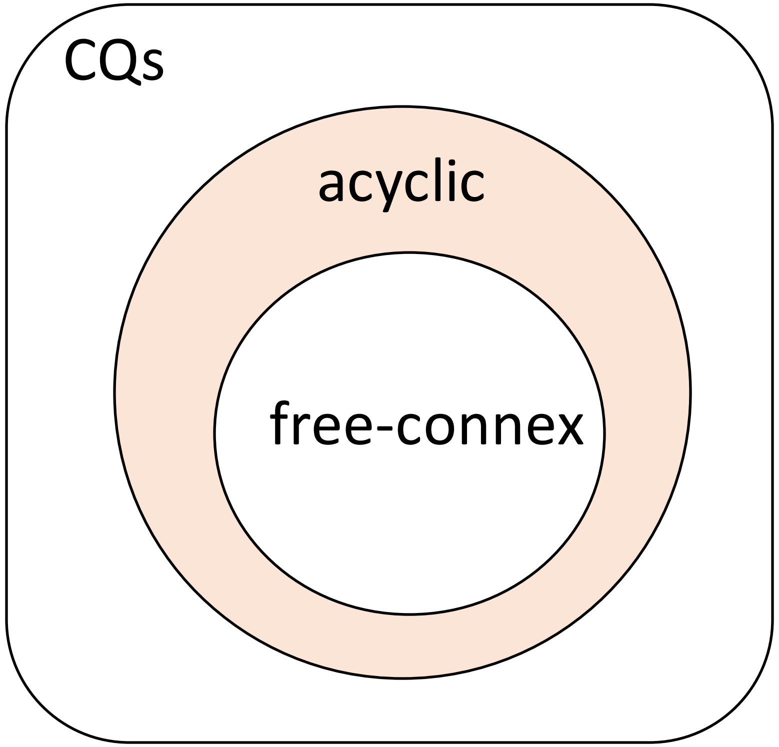

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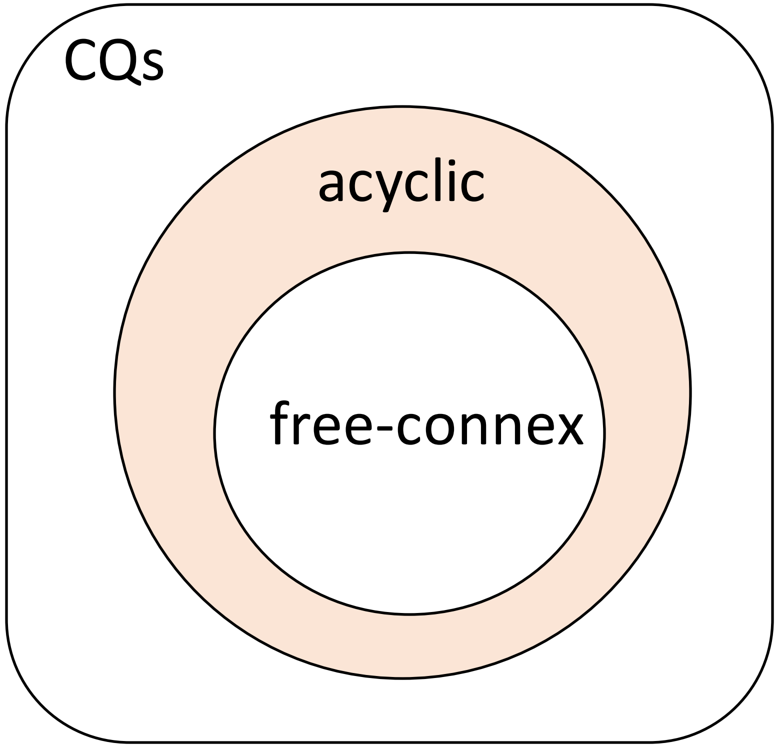

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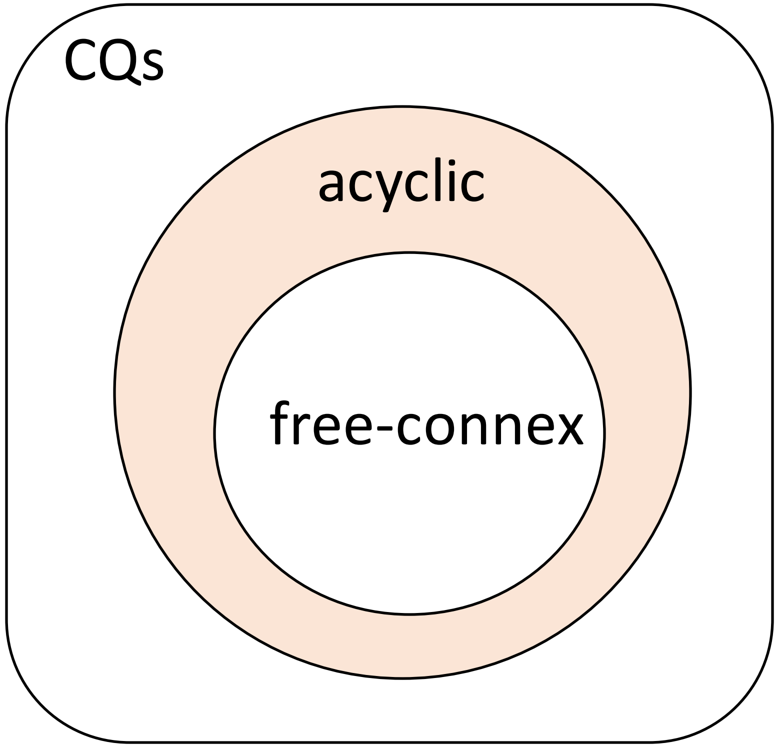

Acyclic non-free-connex:

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

Q

R	C
1	2
2	2

A

R	C
1	1
1	2
2	2

B

R	C
1	2
2	2

Lower Bound

[BaganDurandGrandjean CSL'2007]

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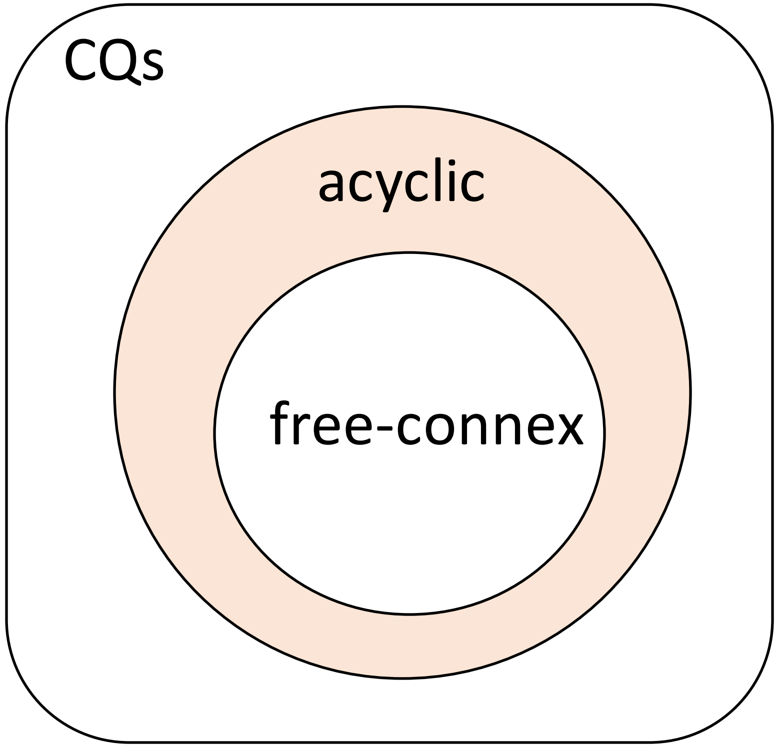

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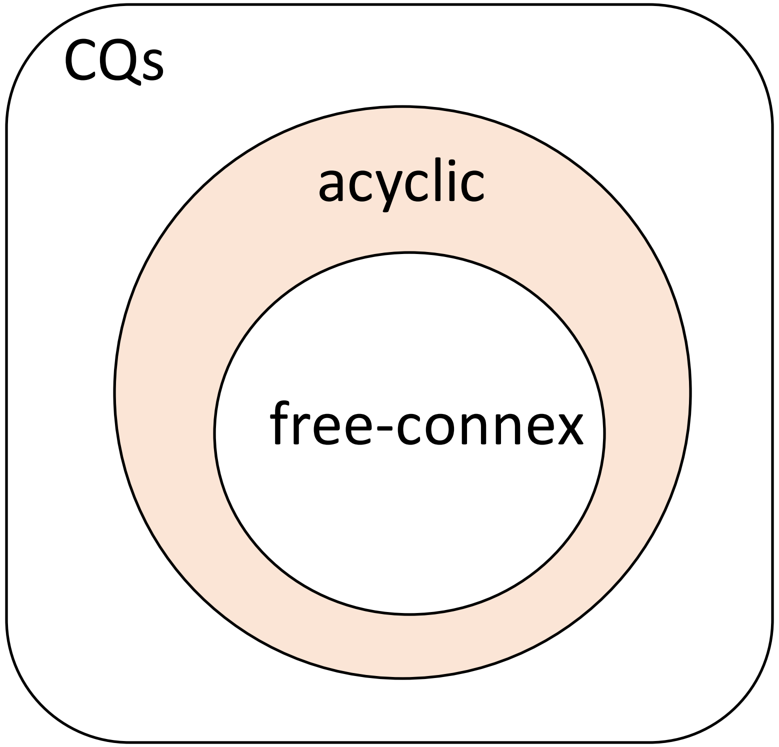

$\notin \mathbf{DelayC_{lin}}$

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Q

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1	2
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R	C
1	1
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B

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

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

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

not free connex

$$\cup$$

$$Q_2(x', y', z') \leftarrow R_1(x', y'), R_2(y', z')$$

Q_1		
1	2	$\perp$
2	2	$\perp$

R_1	
1	1
1	2
2	2

R_2	
1	2
2	2

R_3	
2	$\perp$

Within Unions

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

not free connex

$$\cup$$

$$Q_2(x', y', z') \leftarrow R_1(x', y'), R_2(y', z')$$

Q_1		
1	2	$\perp$
2	2	$\perp$

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	$\perp$

Within Unions

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

not free connex

$$\cup$$

$$Q_2(x',y',z') \leftarrow R_1(x',y'), R_2(y',z')$$

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

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

not free connex

$$\cup$$

$$Q_2(x',y',z') \leftarrow R_1(x',y'), R_2(y',z')$$

Q_1		
1	2	$\perp$
2	2	$\perp$

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	$\perp$

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

Providing Variables

$$\boxed{\text{non free} - \text{connex}}\; Q_1(x,z,w) \leftarrow R_1(x,y), R_2(y,z), R_3(z,w)$$

$$\cup$$

$$\boxed{\text{free} - \text{connex}}\; Q_2(x',y',z') \leftarrow R_1(x',y'), R_2(y',z')$$

$$\boxed{\in \text{DelayC}_{\text{lin}}}$$

Providing Variables

hard part

$$\boxed{\text{non free} - \text{connex}}\ Q_1(x,z,w) \leftarrow \boxed{R_1(x,y), R_2(y,z)}, R_3(z,w)$$

$$\cup$$

$$\boxed{\text{free} - \text{connex}}\ Q_2(x',y',z') \leftarrow R_1(x',y'), R_2(y',z')$$

$$\boxed{\in \text{DelayC}_{\text{lin}}}$$

Providing Variables

hard part

$\textbf{non free} - \textbf{connex}$ $Q_1(x,z,w) \leftarrow R_1(x,y), R_2(y,z), R_3(z,w)$

$\cup$

Body-homomorphism

$\textbf{free} - \textbf{connex}$ $Q_2(x',y',z') \leftarrow R_1(x',y'), R_2(y',z')$

$\in \textbf{DelayC}_{\textbf{lin}}$

Providing Variables

hard part

$\boxed{\text{non free} - \text{connex}}$ $Q_1(x,z,w) \leftarrow R_1(x,y), R_2(y,z), R_3(z,w)$

$\cup$

Body-homomorphism

$\boxed{\text{free} - \text{connex}}$ $Q_2(x',y',z') \leftarrow R_1(x',y'), R_2(y',z')$

$\boxed{\in \text{DelayC}_{\text{lin}}}$

$$Q_1{}'(x,z,w) \leftarrow R_1(x,y), R_2(y,z), R_3(z,w), Q_2(x,y,z)$$

Providing Variables

non free − connex $Q_1(x,z,w) \leftarrow \overbrace{R_1(x,y),R_2(y,z)}^{\text{hard part}},R_3(z,w)$

$\cup$

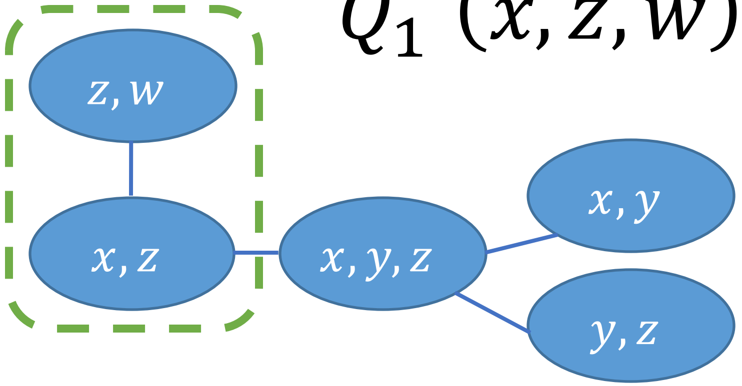
Body-homomorphism

free − connex $Q_2(x',y',z') \leftarrow R_1(x',y'),R_2(y',z')$

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

$$Q_1{}'(x,z,w) \leftarrow R_1(x,y),R_2(y,z),R_3(z,w),Q_2(x,y,z)$$

free − connex



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Hard ∪ Hard = Easy

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

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

Hard ∪ Hard = Easy

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

hard part

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

hard part

Hard ∪ Hard = Easy

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

$$Q_1(x,z,w,u) \leftarrow \underbrace{R_1(x,y), R_2(y,z)}_{\text{hard part}}, R_3(z,w), R_4(w,u)$$

$$Q_2(x,y,z,u) \leftarrow R_1(x,y), R_2(y,z), \underbrace{R_3(z,w), R_4(w,u)}_{\text{hard part}}$$

	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	

Enumeration Complexity of UCQs

- Goal
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  - Easy $\cup$ Hard
    - Why isn't it always hard?
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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?

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**?

more expressive
query classes

self-joins

[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]

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

The Fine-Grained Complexity of Evaluating Queries

time complexity

space complexity

practical performance

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

preprocessing / delay tradeoff

time complexity

space complexity

practical performance

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The Fine-Grained Complexity of Evaluating Queries

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

general relational database

sparsity / constraints

dynamic data

uncertainty

graph databases

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?

Integration

	IRIF	LaBRI	LIRMM
Example common interests	Graph DBs Uncertain data	DBs with constraints Ontologies	Ontologies Dynamic data
Natural collaborators	Cristina Sirangelo Amélie Gheerbrant	Diego Figueira Meghyn Bienvenu	David Carral Federico Ulliana

Thank you.