My Favourite Open Problem in Database Theory

(and a few other things)

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Part One: the Few Other Things

Overview

Computer Science

Computer Science

I like to think that working on

Computer Science

Overview

I like to think that working on

(theoretical) **Computer Science**

Overview

I like to think that working on

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splits into:

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I like to think that working on

(theoretical) **Computer Science**

splits into:

Theory Building

I like to think that working on

(theoretical) **Computer Science**

splits into:

Theory Building | Problem Solving

Overview

I like to think that working on

(theoretical) Computer Science

splits into:

Theory Building
(finding creative explanations)

Problem Solving

I like to think that working on

(theoretical) Computer Science

splits into:

Theory Building
(finding creative explanations)

Problem Solving
(finding interesting solutions)

Decision Problems

Entscheidungsproblem

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David Hilbert

the father of mathematical logic

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Decision problem:
Does there exists an algorithm that considers an inputted statement and answers “yes” or “no” according to whether it is universally valid?

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No

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No

Halting problem:
Can one write a program deciding whether the input’s program execution halts?

Programming in strange languages

Hilbert's 10th problem

Hilbert's 10th problem

Can one write a program deciding:

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$$3x^2 - 4xy + 12y + 2 = 0$$

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$3x^2 - 4xy + 12y + 2 = 0$ or

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$3x^2 - 4xy + 12y + 2 = 0$ or $xyz + 5x^7 - 2y^2 + 3 = 0$

Hilbert's 10th problem

Can one write a program deciding:

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$3x^2 - 4xy + 12y + 2 = 0$ or $xyz + 5x^7 - 2y^2 + 3 = 0$ or ...

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$3x^2 - 4xy + 12y + 2 = 0$ or $xyz + 5x^7 - 2y^2 + 3 = 0$ or ...

whether the equation has an integer solution?

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$3x^2 - 4xy + 12y + 2 = 0$ or $xyz + 5x^7 - 2y^2 + 3 = 0$ or ...

whether the equation has an integer solution?

Also undecidable!

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$$3x^2 - 4xy + 12y + 2 = 0 \quad \text{or} \quad xyz + 5x^7 - 2y^2 + 3 = 0 \quad \text{or} \quad \ldots$$

whether the equation has an integer solution?

Also undecidable! Why?

Hilbert's 10th problem

Can one write a program deciding:

Given a polynomial equation with integer coefficients

$3x^2 - 4xy + 12y + 2 = 0$ or $xyz + 5x^7 - 2y^2 + 3 = 0$ or ...

whether the equation has an integer solution?

Also undecidable! Why? Reductions!

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Can one write a program deciding:

Given a polynomial equation with integer coefficients

$3x^2 - 4xy + 12y + 2 = 0$ or $xyz + 5x^7 - 2y^2 + 3 = 0$ or ...

whether the equation has an integer solution?

Also undecidable! Why? Reductions!

If we could have such a program, then we would be able to make an algorithm deciding halting problem!

Part Two: The Problem

My favourite database theory problem

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Query Containment Problem

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Query Containment Problem

Given two queries Q_s and Q_b does it hold for every database $\mathcal{D}$:

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Query Containment Problem

Given two queries Q_s and Q_b does it hold for every database $\mathcal{D}$:

$$Q_s(\mathcal{D}) \subseteq Q_b(\mathcal{D})?$$

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Given two queries Q_s and Q_b does it hold for every database $\mathcal{D}$:

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Can one *decide* query containment problem?

My favourite database theory problem

Query Containment Problem

Given two queries Q_s and Q_b does it hold for every database $\mathcal{D}$:

$$Q_s(\mathcal{D}) \subseteq Q_b(\mathcal{D})?$$

Can one *decide* query containment problem?

What kind of query? What is a database in this context?

Queries

Conjunctive Queries (by example)

Queries

Conjunctive Queries **(by example)**

$$C_3(x, y, z) \;=\; \mathtt{E}(x, y) \wedge \mathtt{E}(y, z) \wedge \mathtt{E}(z, x)$$

Queries

Conjunctive Queries **(by example)**

$$
\begin{aligned}
C_3(x, y, z) &= \mathtt{E}(x, y) \wedge \mathtt{E}(y, z) \wedge \mathtt{E}(z, x) \\
M(x, z) &= \exists y\, \mathtt{Mother}(x, y) \wedge \mathtt{Mother}(y, z)
\end{aligned}
$$

Conjunctive Queries **(by example)**

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CQs are the `select-join-project` fragment of SQL

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CQs are the `select-join-project` fragment of SQL

Unions of CQs

Queries

Conjunctive Queries (by example)

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CQs are the `select-join-project` fragment of SQL

Unions of CQs

$$Q(x) = \texttt{Black}(x) \vee \texttt{While}(x)$$

Queries

Conjunctive Queries **(by example)**

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CQs are the `select-join-project` fragment of SQL

Unions of CQs

$$Q(x) = \mathtt{Black}(x) \vee \mathtt{While}(x)$$

$$P = V \vee \exists x,z\, M(x,z)$$

Boolean queries and homomorphisms

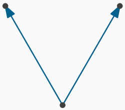
$$\text{Vee} = \exists x, y, z\ \mathtt{E}(x, y)\ \wedge\ \mathtt{E}(x, z)$$

Boolean queries and homomorphisms

$$\text{Vee} = \exists x, y, z\ \mathtt{E}(x, y)\ \wedge\ \mathtt{E}(x, z) \qquad \text{Tri} = \exists x, y, z\ \mathtt{E}(x, y) \wedge \mathtt{E}(y, z) \wedge \mathtt{E}(z, x)$$

Boolean queries and homomorphisms

$\text{Vee} = \exists x, y, z\ \texttt{E}(x, y)\ \wedge\ \texttt{E}(x, z)$



$\text{Tri} = \exists x, y, z\ \texttt{E}(x, y) \wedge \texttt{E}(y, z) \wedge \texttt{E}(z, x)$

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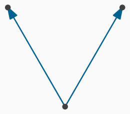

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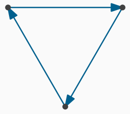

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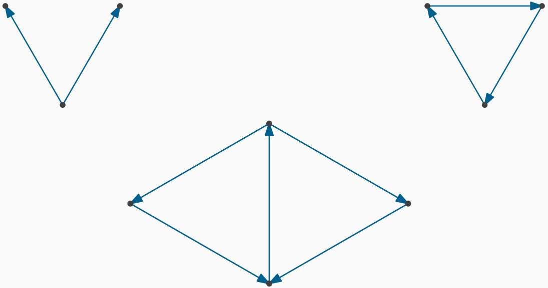

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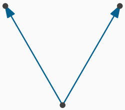

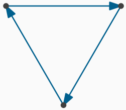

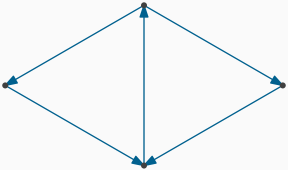

set semantics		
bag semantics		

Boolean queries and homomorphisms

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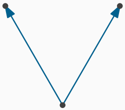

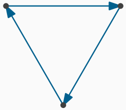

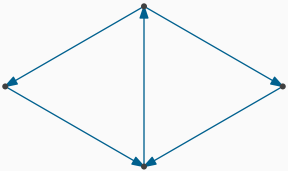

	$\mathsf{Vee}(\mathcal{D})$	$\mathsf{Tri}(\mathcal{D})$
set semantics		
bag semantics		

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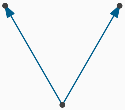

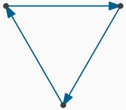

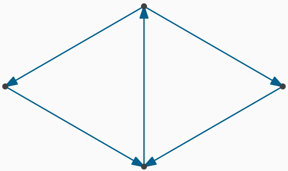

$Q(\mathcal{D})$	$\text{Vee}(\mathcal{D})$	$\text{Tri}(\mathcal{D})$
set semantics	yes	yes
bag semantics		

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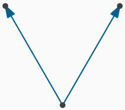

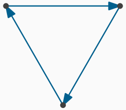

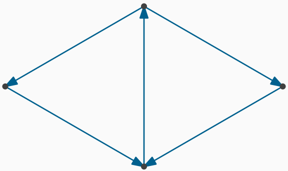

$Q(\mathcal{D})$	Vee($\mathcal{D}$)	Tri($\mathcal{D}$)
set semantics	yes	yes
bag semantics	7	

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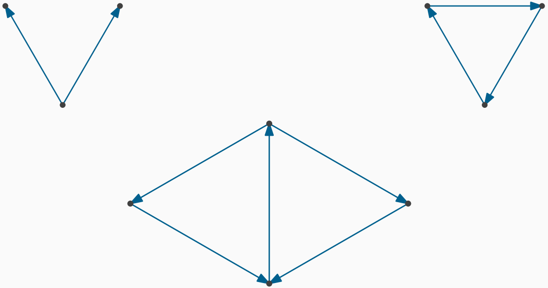

$Q(\mathcal{D})$	Vee($\mathcal{D}$)	Tri($\mathcal{D}$)
set semantics	yes	yes
bag semantics	7	6

Status of the problem

Status of the problem

Set Semantics

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CQ Containment:

Status of the problem

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CQ Containment: Closed and decidable

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(Existence of homomorphism from one query to the other)

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Bag Semantics

CQ Containment: Still open after 30 years!

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(Existence of homomorphism from one query to the other)

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CQ Containment: Still open after 30 years!

UCQ Containment: Closed and undecidable

UCQ containment under bag semantics

UCQ containment under bag semantics

$$Q_s = \exists z\ \mathtt{X}(z) \wedge \mathtt{X}(z)\ \vee\ \mathtt{Y}(z) \wedge \mathtt{Y}(z) \wedge \mathtt{Y}(z)$$

UCQ containment under bag semantics

$$Q_s = \exists z\ \mathtt{X}(z) \land \mathtt{X}(z)\ \lor\ \mathtt{Y}(z) \land \mathtt{Y}(z) \land \mathtt{Y}(z)$$
$$Q_b = \exists z\ \mathtt{X}(z) \land \mathtt{Y}(z)\ \lor\ \mathtt{X}(z) \land \mathtt{Y}(z)$$

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$$\mathcal{D}_1\quad \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{Y}} \qquad \mathcal{D}_2\quad \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{Y}}\ \underset{\bullet}{\mathtt{Y}}$$

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$\mathcal{D}_1$ X X X Y $\mathcal{D}_2$ X X Y Y

$Q(\mathcal{D})$	Q_b	Q_s
$\mathcal{D}_1$		
$\mathcal{D}_2$		

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$\mathcal{D}_1$ X X X Y $\mathcal{D}_2$ X X Y Y

$Q(\mathcal{D})$	Q_b	Q_s
$\mathcal{D}_1$	$3^2 + 1^3$	
$\mathcal{D}_2$		

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$\mathcal{D}_1$ X X X Y $\mathcal{D}_2$ X X Y Y

$Q(\mathcal{D})$	Q_b	Q_s
$\mathcal{D}_1$	$3^2 + 1^3$	$2 \cdot 3 \cdot 1$
$\mathcal{D}_2$		

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$\mathcal{D}_1$ X X X Y $\mathcal{D}_2$ X X Y Y

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$\mathcal{D}_1$ X X X Y $\qquad$ $\mathcal{D}_2$ X X Y Y

$Q(\mathcal{D})$	Q_b	Q_s
$\mathcal{D}_1$	$3^2 + 1^3$	$2 \cdot 3 \cdot 1$
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UCQ containment under bag semantics

$$Q_s = \exists z\ X(z) \wedge X(z)\ \vee\ Y(z) \wedge Y(z) \wedge Y(z)$$

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$\mathcal{D}_1$ X X X Y $\quad$ $\mathcal{D}_2$ X X Y Y

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$\mathcal{D}_1$	$3^2 + 1^3$	$2 \cdot 3 \cdot 1$
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$$Q_s(\mathcal{D}) \subseteq Q_b(\mathcal{D})$$

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$$Q_s = \exists z\ \mathtt{X}(z) \wedge \mathtt{X}(z)\ \vee\ \mathtt{Y}(z) \wedge \mathtt{Y}(z) \wedge \mathtt{Y}(z)$$

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$\mathcal{D}_1$ $\underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{Y}}$ $\mathcal{D}_2$ $\underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{X}}\ \underset{\bullet}{\mathtt{Y}}\ \underset{\bullet}{\mathtt{Y}}$

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$\mathcal{D}_1$	$3^2 + 1^3$	$2 \cdot 3 \cdot 1$
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$$Q_s(\mathcal{D}) \subseteq Q_b(\mathcal{D}) \quad \iff$$

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$Q(\mathcal{D})$	Q_b	Q_s
$\mathcal{D}_1$	$3^2 + 1^3$	$2 \cdot 3 \cdot 1$
$\mathcal{D}_2$	$2^2 + 2^3$	$2 \cdot 2 \cdot 2$

$$Q_s(\mathcal{D}) \subseteq Q_b(\mathcal{D}) \iff 2xy \leq x^2 + y^3$$

UCQ containment under bag semantics

$$Q_s = \exists z\ \mathtt{X}(z) \wedge \mathtt{X}(z)\ \vee\ \mathtt{Y}(z) \wedge \mathtt{Y}(z) \wedge \mathtt{Y}(z)$$

$$Q_b = \exists z\ \mathtt{X}(z) \wedge \mathtt{Y}(z)\ \vee\ \mathtt{X}(z) \wedge \mathtt{Y}(z)$$

$\mathcal{D}_1$ X X X Y $\mathcal{D}_2$ X X Y Y

$Q(\mathcal{D})$	Q_b	Q_s
$\mathcal{D}_1$	$3^2 + 1^3$	$2 \cdot 3 \cdot 1$
$\mathcal{D}_2$	$2^2 + 2^3$	$2 \cdot 2 \cdot 2$

$$Q_s(\mathcal{D}) \subseteq Q_b(\mathcal{D}) \iff 2xy \leq x^2 + y^3$$

Reduction from a variant of Hilbert's 10th problem!

My contribution

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Theorem

For each $\varepsilon > 0$ *the following problem is undecidable:*

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My contribution

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My contribution

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$$(1+\varepsilon) \cdot Q_s(\mathcal{D}) \leq Q_b(\mathcal{D})$$

My contribution

Theorem

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Bag Semantics Query Containment: The CQ vs. UCQ Case and Other Stories
Jerzy Marcinkowski, Piotr Ostropolski-Nalewaja

Principles of Database System (PODS 2026)

Thank you!