Uncertain Data Management
Open-World Query Answering

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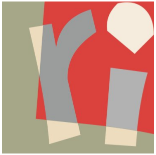

Thanks to Pierre Senellart for proofreading these slides.

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1. Basics
2. Contexts
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5. Advanced topics

Incompleteness

- We have an instance I
- The true state of the world is W
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→ Today, I is correct but not complete

Incompleteness and query evaluation

- We know: evaluate a query Q on I
- We want: evaluate Q on W

Incompleteness and query evaluation

- We know: evaluate a query Q on I
- We want: evaluate Q on W
- We don't have W

→ What can we do?!

Constraints to the rescue!

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Definition (Open-World Query Answering – OWQA)

Given an instance I, Boolean CQ Q, and constraints Θ, decide whether all $W \supseteq I$ that satisfy Θ also satisfy Q.

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Combined complexity. Input is I, Θ, Q

Data complexity. Input is I

Example

Relation Class in I

date	**teacher**	**resp**	**name**	**num**
2015-11-23	Antoine	Fabian	Uncert. Data Mgmt	1
2015-11-30	Antoine	Fabian	Uncert. Data Mgmt	2

Book in I

date	**room**	**prof**
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“Every class has a booking.”

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"Every class has a booking."

$$Q : \exists t\, r\ \mathrm{Book}(\text{“2015-11-23”}, t, r)$$

"Is there a room booked on Nov 23rd?"

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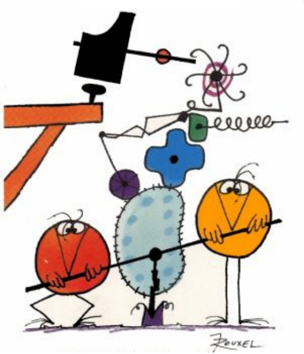
Logical satisfiability

OWQA is equivalent to:

is $I \wedge \Theta \wedge \neg Q$ satisfiable?

Logical satisfiability



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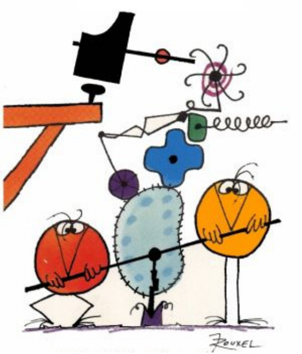

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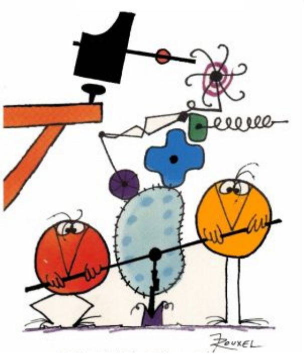

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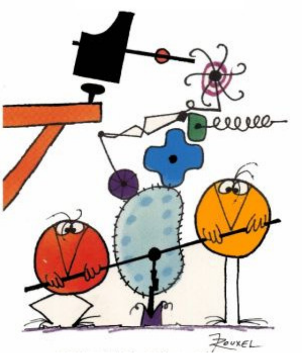

OWQA is equivalent to:

is $I \wedge \Theta \wedge \neg Q$ satisfiable?

Is it just logical satisfiability then?!

- I is where we want to scale
- Θ and Q are usually different languages...
- ... if we express both in the same language, it will be hard to achieve good complexities! (or even decidability...)

Repairing the database

Class

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Constraints:

- The responsible for a class must teach some class
- Every class must have a first session

→ What can we deduce?

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→ What can we deduce?

→ Q is true iff it is true on all completions

But why deal with broken databases?

- The data may have come from a different source
- The constraints may have been imposed after the fact
- User input may be incorrect
- You want a resilient system...

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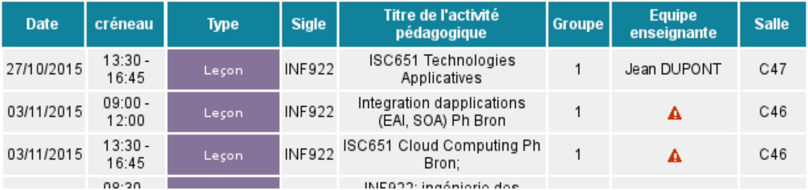

Date	créneau	Type	Sigle	Titre de l'activité pédagogique	Groupe	Equipe enseignante	Salle
27/10/2015	13:30 - 16:45	Leçon	INF922	ISC651 Technologies Applicatives	1	Jean DUPONT	C47
03/11/2015	09:00 - 12:00	Leçon	INF922	Integration dapplications (EAI, SOA) Ph Bron	1	⚠	C46
03/11/2015	13:30 - 16:45	Leçon	INF922	ISC651 Cloud Computing Ph Bron;	1	⚠	C46
	08:30			INF922: ingénierie des			

Reasoning (AI)

- Artificial reasoning: draw consequences from what you know
  - I contains the facts
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- Artificial reasoning: draw consequences from what you know
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→ Can we deduce Q from I using Θ?

→ Is Q certain to hold?

Data integration

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2015-11-23	?	?	UDM	?
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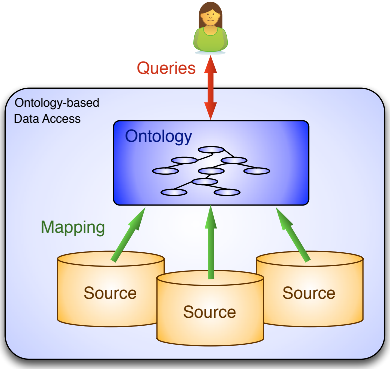
2015-12-14	?	?	UDM	?

Ontology-based data access

- In general: use a common schema for reasoning
- I contains heterogeneous data sources
- Θ describes mappings from sources to common schema and reasoning rules and constraints on the common schema
- Q is the query posed the common schema



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First-order logic

All constraints for Θ are in first-order logic (FO):

- contains atoms $R(x, y, z)$
- closed under Boolean AND, OR, NOT
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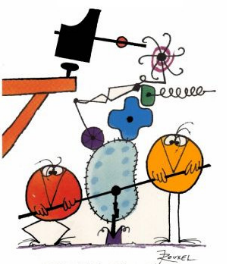

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→ Why not just use FO for constraints then?!

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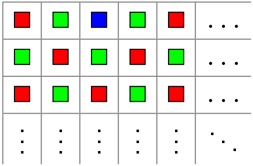

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- Proof: Encode a tiling system, or
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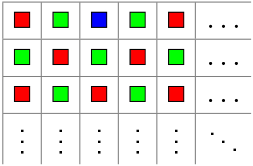

🟥	🟩	🟦	🟩	🟥	$\dots$
🟩	🟥	🟩	🟥	🟩	$\dots$
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$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

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→ We consider weaker languages

Tuple-generating dependencies

Tuple-generating dependencies (TGDs), classical database rules:

$$\forall \mathbf{x}\ Q'(\mathbf{x}) \Rightarrow \exists \mathbf{y}\ Q''(\mathbf{x}, \mathbf{y})$$

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Useful for:

- Integrity constraints: see above
- Schema mappings: copy facts from I_1 to I
- Reasoning: $\forall x\ \text{Human}(x) \Rightarrow \text{Mortal}(x)$

OWQA for TGDs is undecidable!

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→ We need less expressive languages

Inclusion dependencies

Inclusion dependencies (IDs), classical database rules:

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The TGD example was in fact also an ID:

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→ We will study other decidable classes of TGDs

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Book

date	**room**	**prof**
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→ Take the infinite result of this process

Infinite chase example

$$\forall t\, u\ \text{Mentor}(t, u) \Rightarrow \exists s\ \text{Mentor}(s, t)$$

Mentor

master	**padawan**

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?6	*?4*

Infinite chase example

$$\forall t\, u\ \mathrm{Mentor}(t, u) \Rightarrow \exists s\ \mathrm{Mentor}(s, t)$$

Mentor

master	**padawan**
Antoine	Arthur Dent
Silviu	Arthur Dent
?1	Antoine
?2	Silviu
?3	*?1*
?4	*?2*
?5	*?3*
?6	*?4*
⋮	⋮

Chase universality

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- *I and Θ entail Q*
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→ How to reason about this infinite chase?

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→ When is the chase finite?

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Full dependencies

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- Good: $\forall d\, r\, p\ \mathrm{Book}(d, r, p) \Rightarrow \mathrm{Room}(r)$
- Bad: $\forall \mathbf{x}\ \mathrm{Mentor}(\mathbf{x}) \Rightarrow \exists \mathbf{y}\ \mathrm{Mentor}(\mathbf{x}, \mathbf{y})$

Acyclicity

- Simple sufficient condition for finite chase:
  If a relation name occurs at the left of a TGD
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- More general acyclicity conditions

Infinite chase

- What can we do if the chase is infinite?
- Bounded derivation depth: we can truncate the chase:
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Infinite chase

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- Bounded derivation depth: we can truncate the chase:
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- Bounded treewidth: the chase is like a tree:
    - we can reason about infinite and regular trees
    - use tree automata, following Courcelle's theorem
    - some rules preserve this, e.g., the guarded fragments

Table of contents

1 Basics

2 Contexts

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Query rewriting

- The chase: reason about consequences of I under Θ
- Other option: reason about how to prove Q

Query rewriting

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$$\Theta : \forall \text{date, prof, r, n, i, } \text{Class}(\text{date}, \text{prof}, \text{r}, \text{n}, \text{i}) \Rightarrow \exists \text{room, } \text{Book}(\text{date}, \text{room}, \text{prof})$$

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Query rewriting and inclusion dependencies

- To show that OWQA for inclusion dependencies is decidable...

$$\forall \mathbf{x}\ A'(\mathbf{x}) \Rightarrow \exists \mathbf{y}\ A''(\mathbf{x}, \mathbf{y})$$

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- Replace Q by a union of conjunctive queries
  - → OWQA for IDs is decidable
  - → OWQA for IDs has tractable data complexity

Description logics

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→ Description logics: expressive rules

  - signature must have arity at most 2

Description logics (2)

- Description logics have a specific syntax

$$\mathrm{Teacher} \sqsubseteq \mathrm{Prof} \sqcup (\exists \mathrm{Advisor}^{-}.\mathrm{Prof})$$

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Languages	UNA	Complexity		
		Combined complexity	Data complexity	
		Satisfiability	Instance checking	Query answering
$\textit{DL-Lite}_{core}^{[\ \mid\mathcal{H}]}$	yes/no	NLogSpace $\geq$ [A]	in AC^0	in AC^0
$\textit{DL-Lite}_{horn}^{[\ \mid\mathcal{H}]}$		P $\leq$ [Th.8.2] $\geq$ [A]	in AC^0	in AC^0 $\leq$ [C]
$\textit{DL-Lite}_{krom}^{[\ \mid\mathcal{H}]}$		NLogSpace $\leq$ [Th.8.2]	in AC^0	coNP $\geq$ [B]
$\textit{DL-Lite}_{bool}^{[\ \mid\mathcal{H}]}$		NP $\leq$ [Th.8.2] $\geq$ [A]	in AC^0 $\leq$ [Th.8.3]	coNP
$\textit{DL-Lite}_{core}^{[\mathcal{F}\mid\mathcal{N}\mid(\mathcal{HF})\mid(\mathcal{HN})]}$	yes	NLogSpace	in AC^0	in AC^0
$\textit{DL-Lite}_{horn}^{[\mathcal{F}\mid\mathcal{N}\mid(\mathcal{HF})\mid(\mathcal{HN})]}$		P $\leq$ [Th.5.8, 5.13]	in AC^0	in AC^0 $\leq$ [Th.7.1]
$\textit{DL-Lite}_{krom}^{[\mathcal{F}\mid\mathcal{N}\mid(\mathcal{HF})\mid(\mathcal{HN})]}$		NLogSpace $\leq$ [Th.5.7,5.13]	in AC^0	coNP
$\textit{DL-Lite}_{bool}^{[\mathcal{F}\mid\mathcal{N}\mid(\mathcal{HF})\mid(\mathcal{HN})]}$		NP $\leq$ [Th.5.6, 5.13]	in AC^0 $\leq$ [Cor.6.2]	coNP
$\textit{DL-Lite}_{core/horn}^{[\mathcal{F}\mid(\mathcal{HF})]}$	no	P $\leq$ [Cor.8.8] $\geq$ [Th.8.7]	P $\geq$ [Th.8.7]	P
$\textit{DL-Lite}_{krom}^{[\mathcal{F}\mid(\mathcal{HF})]}$		P $\leq$ [Cor.8.8]	P	coNP
$\textit{DL-Lite}_{bool}^{[\mathcal{F}\mid(\mathcal{HF})]}$		NP	P $\leq$ [Cor.8.8]	coNP
$\textit{DL-Lite}_{core/horn}^{[\mathcal{N}\mid(\mathcal{HN})]}$		NP $\geq$ [Th.8.4]	coNP $\geq$ [Th.8.4]	coNP
$\textit{DL-Lite}_{krom/bool}^{[\mathcal{N}\mid(\mathcal{HN})]}$		NP $\leq$ [Th.8.5]	coNP	coNP
$\textit{DL-Lite}_{core/horn}^{\mathcal{HF}}$	yes/no	ExpTime $\geq$ [Th.5.10]	P $\geq$ [Th.6.7]	P $\leq$ [D]
$\textit{DL-Lite}_{krom/bool}^{\mathcal{HF}}$		ExpTime	coNP $\geq$ [Th.6.5]	coNP
$\textit{DL-Lite}_{core/horn}^{\mathcal{HN}}$		ExpTime	coNP $\geq$ [Th.6.6]	coNP
$\textit{DL-Lite}_{krom/bool}^{\mathcal{HN}}$		ExpTime $\leq$ [F]	coNP	coNP $\leq$ [E]

Equality-generating dependencies

- Another important constraint for Θ: functional dependencies
    - There can't be two bookings for one room at the same time
    - There can't be two rooms for one session

Equality-generating dependencies

- Another important constraint for Θ: functional dependencies
  - There can't be two bookings for one room at the same time
  - There can't be two rooms for one session
- Functional dependencies can be added to Θ for OWQA
  - Decidable for description logics
  - Undecidable with inclusion dependencies

Finite models

Definition (Open-World Query Answering – OWQA)

Given an instance I, Boolean CQ Q, and constraints Θ, decide whether all $W \supseteq I$ that satisfy Θ satisfy Q.

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Finite models

Definition (Finite Open-World Query Answering – FOWQA)

Given an instance I, Boolean CQ Q, and constraints Θ, decide whether all finite $W \supseteq I$ that satisfy Θ satisfy Q.

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- Imposing finiteness may make a difference

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Given an instance I, Boolean CQ Q, and constraints Θ, decide whether all finite $W \supseteq I$ that satisfy Θ satisfy Q.

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→ Very hard to reason about FOWQA!

Partial completeness

- We have assumed that *I* was incomplete
- Sometimes, we know which relations are complete
    - e.g., the list of rooms may be complete
    - the list of classes may be incomplete

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  - If I know the lecturer of a class, then I know all lecturers
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→ Partial completeness assumption [Galárraga et al., 2013]

Slide credits

- Slide 34: `http://www.slideshare.net/MartnRezk/slides-swat4-ls`, slide 17, licence CC-BY-SA 3.0[1]
- Slides 16 and 36: Jaques Rouxel, *Les Shadoks* (*reproduit en vertu du droit de citation*)
- Slide 34: [Artale et al., 2009], p 18

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[1] `http://creativecommons.org/licenses/by-sa/3.0/`

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