Uncertain Data Management
Open-World Query Answering

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November 28th, 2016

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Incompleteness

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- We may have $I \neq W$
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$\rightarrow$ 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

$\rightarrow$ What can we do?!

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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
2016-11-28	Antoine	Fabian	Uncert. Data Mgmt	2
2016-12-05	Antoine	Fabian	Uncert. Data Mgmt	3

Book in I

date	room	prof
2016-12-05	E242	John

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

"Every class has a booking."

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"Every class has a booking."

$$Q : \exists t\, r\ \mathrm{Book}(\text{“2016-11-28”}, t, r)$$

"Is there a room booked on Nov 28th?"

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Logical satisfiability

OWQA is equivalent to:

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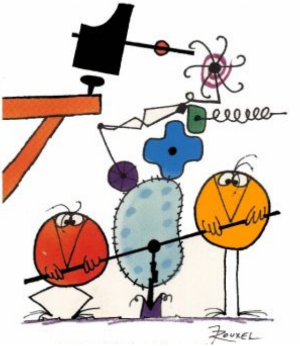

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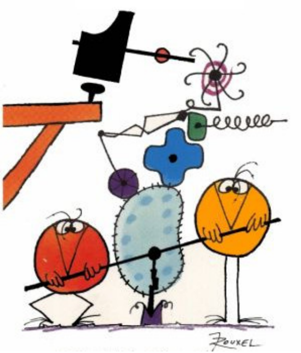

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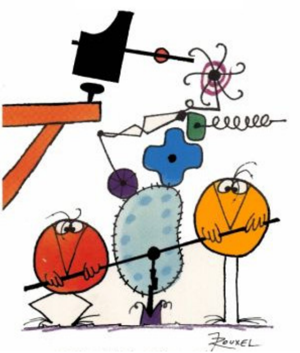

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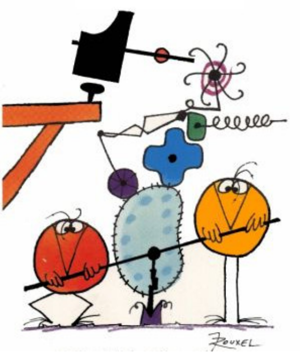

- I is where we want to scale
- Θ and Q are usually different languages...
- ... if we express both in the same language,
  it will be hard to achieve good complexities!
  (or even decidability...)

Repairing the database

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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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?	Fabian	?	?	?
?	?	?	?	1

Constraints:

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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
    - Θ are the reasoning rules
    - Q is what we want to figure out

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$\rightarrow$ Can we deduce Q from I using Θ?

$\rightarrow$ Is Q certain to hold?

Data integration

- I contains $I_1, \ldots, I_n$, the course databases of all D&K schools
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Class1

date	**name**
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2016-12-05	?	?	UDM	?
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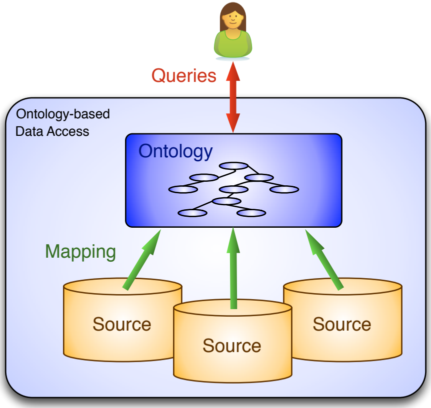
Ontology-based data access

- 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
- existential quantification $\exists x\ \phi(x)$
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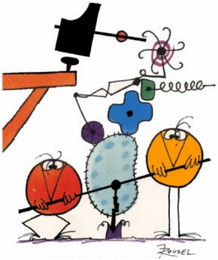

$\rightarrow$ Why not just use FO for constraints then?!

FO is undecidable!

Given an input FO formula Θ, is it satisfiable?
(i.e., OWQA with $I = \emptyset$ and Q : False).

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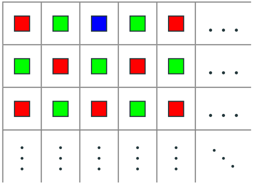

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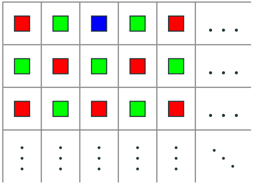

- $\rightarrow$ This problem is undecidable!
    - Proof: Encode a tiling system, or
      encode transition rules for a Turing machine
- $\rightarrow$ We consider weaker languages

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: $\forall x$ Human(x) $\Rightarrow$ Mortal(x)

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$\rightarrow$ 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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$\rightarrow$ We will study other decidable classes of TGDs

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Chase example

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$\rightarrow$ 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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Theorem

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Theorem

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$\rightarrow$ How to reason about this infinite chase?

Chase termination

- Sometimes, the chase of I by Θ is finite
- We can then decide whether a query Q is entailed:

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- Sometimes, the chase of I by Θ is finite
- We can then decide whether a query Q is entailed:
  - Construct the chase
  - Evaluate Q on the chase

Chase termination

- Sometimes, the chase of I by Θ is finite
- We can then decide whether a query Q is entailed:
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$\rightarrow$ When is the chase finite?

Full dependencies

- If no TGD has an $\exists$, then the chase is 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

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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

Query rewriting

- The chase: reason about consequences of I under Θ
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Query rewriting and inclusion dependencies

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

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- Replace Q by a union of conjunctive queries
  - $\rightarrow$ OWQA for IDs is decidable
  - $\rightarrow$ 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)

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

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$\rightarrow$ 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

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

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