Semantics of Query Answering in Data Exchange

André Hernich

Department of Computer Science
Humboldt University Berlin

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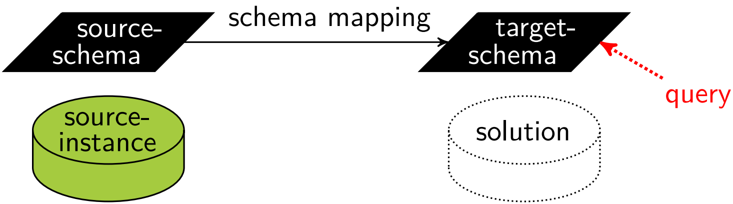
Outline

1. Goals of Query Answering in Data Exchange
2. The Basic Query Answering Semantics
3. Alternative Semantics

Query Answering in Data Exchange

Goal: Answer queries posed against target data
(Fagin, Kolaitis, Miller, Popa '03)



Example

Source instance:

Book

title	author
Algebra	Lang
Logic	Hodges

Solution:

Author

id	name
1	Lang
2	Hodges

Publ

title	a_id
Algebra	1
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Schema mapping:

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Example query over target schema

Who are the authors of “Algebra”?

$$Q(a)\ :=\ \exists id\, (\ \mathrm{Publ}(\text{“Algebra”}, id) \wedge \mathrm{Author}(id, a)\ )$$

Fundamental Issues

1. What is the “right” answer to/semantics of a query?

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   Problem: many solutions with *different* sets of answers
2. Which solutions are appropriate for query answering?
   Problem: queries have to be answered *without* source instance
3. What is the complexity of query answering?
   (computing the solution & evaluating the query)

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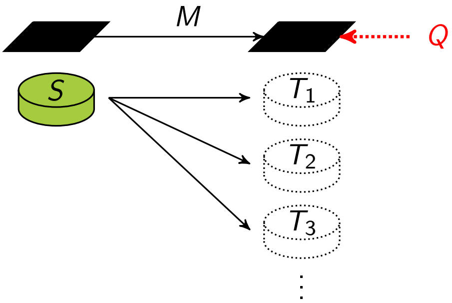

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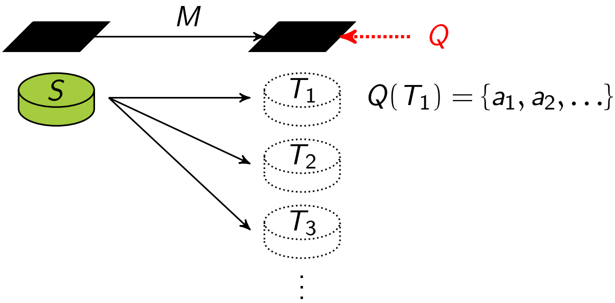

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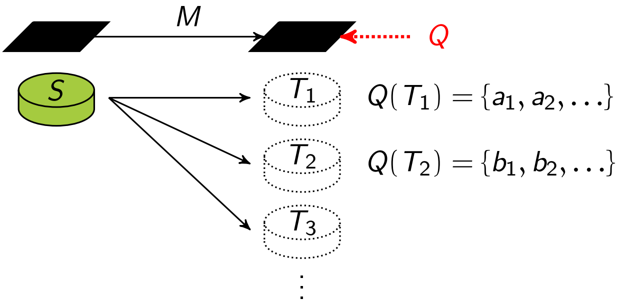

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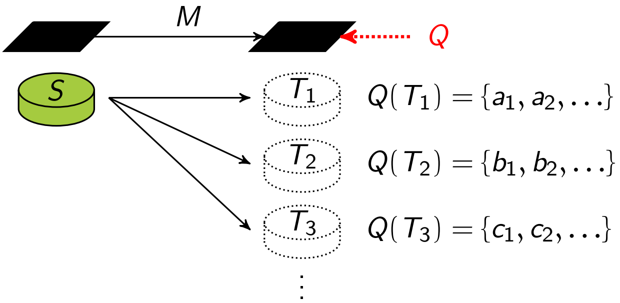

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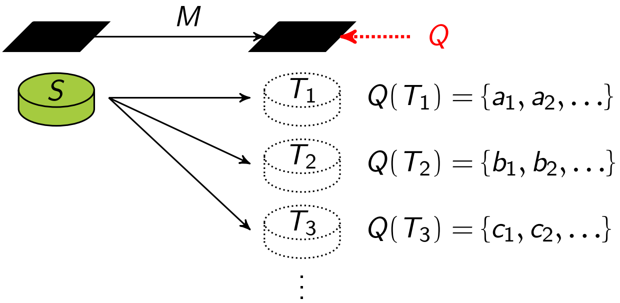

Definition (Fagin, Kolaitis, Miller, Popa '03)

a is a certain answer to Q on M and S

$\iff$ $a \in Q(T)$ for all solutions T for S under M

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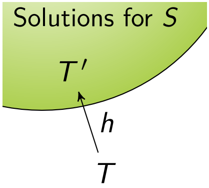

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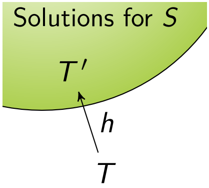

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More general: for queries preserved under homomorphisms

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(Data) complexity results:

- evaluation of UCQs with ≤ 1 inequality per disjunct in PTIME on universal solutions (Fagin, Kolaitis, Miller, and Popa '03)
- co-NP-complete for CQs with ≥ 2 inequalities (Mądry '05)
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"Generic" approach: based on extension of universal solutions (Deutsch, Nash, Remmel '08)

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Schema mapping: $\forall x \forall y (\ E(x,y) \rightarrow E'(x,y)\ )$

Source instance:

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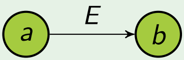

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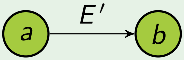

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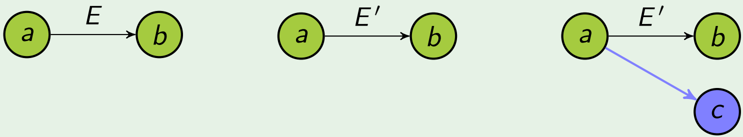

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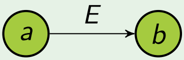

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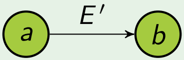

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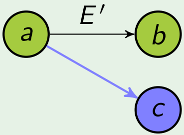

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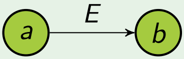

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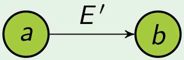

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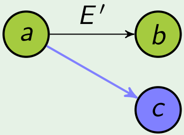

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Basis: variants of Closed World Assumption (CWA) (Reiter '78)

"If something is not mentioned, take it to be false."

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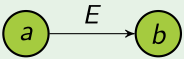

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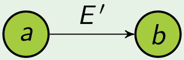

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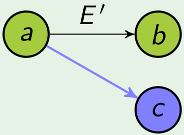

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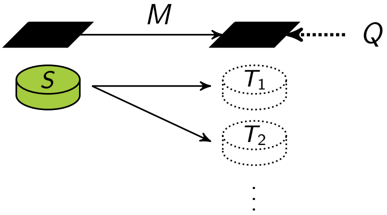

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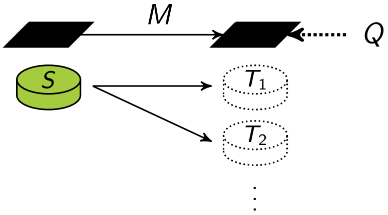

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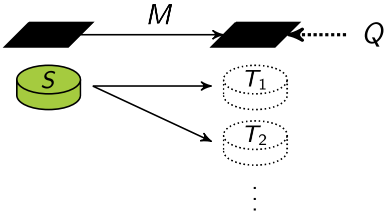

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- Q is evaluated under a special semantics for instances with nulls

CWA-Solutions

Rule: all atoms and facts in CWA-solutions must be justified by the source instance and the schema mapping

Criteria

Example

$S = \{ P(a) \} \quad \forall x \big(\; P(x) \; \rightarrow \; \exists y \; E(x, y) \; \big)$

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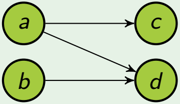

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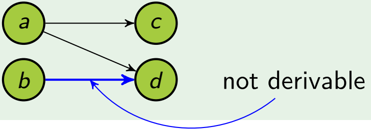

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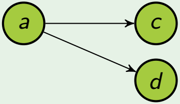

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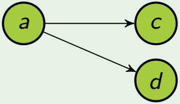

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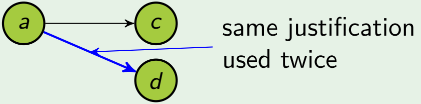

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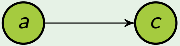

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1. Derivability
2. Parsimony
3. No invented facts

Example

$S = \{ P(a) \} \quad \forall x \big(\; P(x) \; \rightarrow \; \exists y \; E(x, y) \; \big)$

Solution:

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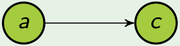

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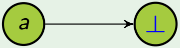

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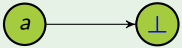

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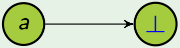

Characterization (Libkin '06; H., Schweikardt '07)

CWA-solutions = universal solutions derivable from the source instance using a certain variant of the chase

E.g., core solution = minimal CWA-solution

Query Evaluation under the CWA-Semantics

Theorem (Libkin '06)

For every schema mapping M defined by s-t tgds, every source instance S, and every query Q,

$$\text{CWA-certain answers to } Q \text{ on } M \text{ and } S \;=\; \Box Q(T),$$

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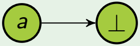

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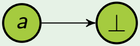

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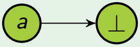

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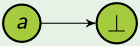

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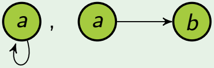

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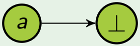

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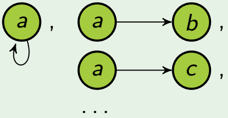

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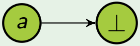

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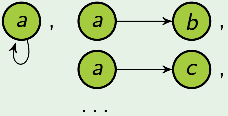

Generalization and Restriction of the CWA-Semantics

Modifications of the CWA-semantics
(both for schema mappings defined by s-t tgds only):

- "Mixed world" semantics (Libkin, Sirangelo '08)

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- Endomorphic images semantics (Afrati, Kolaitis '08)
  - based on restricted notion of possible worlds of an instance
  - shown to be suitable for special aggregate queries

Two Natural Properties

Two natural properties are "missing":

1. Invariance under logically equivalent schema mappings
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$$\forall x (\ P(x) \rightarrow \exists y\, E(x, y)\ )$$

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Unique CWA-solution: $a \longrightarrow \perp$

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Desired answer: no

The GCWA*-Semantics

Definition (H. '10, restricted version)

1. GCWA*-solutions:
   ground solutions that are unions of minimal solutions
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- inspired by semantics for deductive databases:
  GCWA (Minker '82) and EGCWA (Yahya, Henschen '85)
- invariant under logically equivalent schema mappings
- *intuitively:* reflects "standard semantics" of constraints

Motivating Example Revisited

Example

Schema mapping: $\forall x (\ P(x) \rightarrow \exists y\, E(x, y)\ )$

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GCWA*solutions: $\left. a \longrightarrow b \;\right\}$ union of one minimal solution

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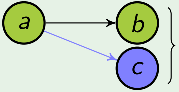

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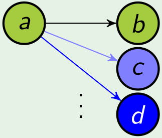
GCWA*solutions: 

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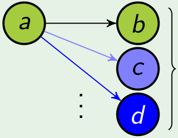

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Query: $Q :=$ Is there exactly one y with $E(a,y)$?

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Evaluation of Universal Queries

universal query: FO query of the form $\forall \bar{x}\, \varphi$, φ quantifier-free

Theorem (H. '10)

For every properly restricted schema mapping M and for each universal query Q there is a polynomial time algorithm for:

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Recall: Here the core solution can be computed in polynomial time

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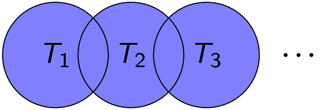

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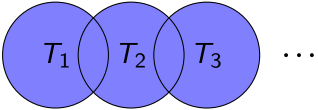

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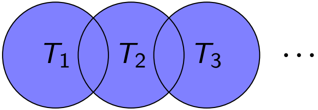

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Query: $\exists \bar{x}\, \varphi(\bar{x})$, φ conjunction of atoms and neg. atoms

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Step 3/4: Find Appropriate Minimal Instances

Lemma

M: schema mapping defined by packed s-t tgds
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There is a polynomial time algorithm for

Input:	*core solution C for some source instance S for M*
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Problems to overcome:

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- Still exponentially many instances
  Solution: reduce set of instances that need to be considered to polynomial size

Step 4/4: A Special Case

Reduction for special case: given atom $R(\bar{a})$, test whether $R(\bar{a})$ belongs to some minimal instance in $poss(C)$

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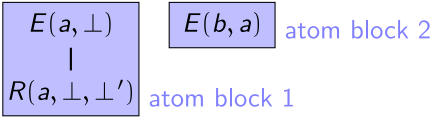

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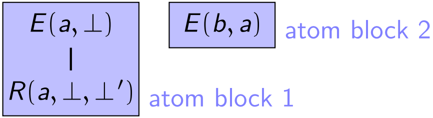

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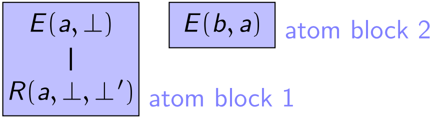

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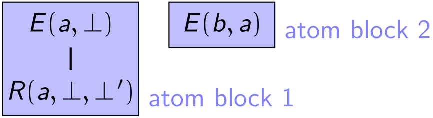

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$\boxed{E(a, \perp) \text{ — } R(a, \perp, \perp')}$ atom block 1

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- Several semantics for non-monotonic queries
  - based on rules for excluding undesired solutions
  - each reflects a certain intuition about what "not mentioned" by a source instance and schema mapping means
  - query evaluation may be hard, is not really understood

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- Alternative approaches, e.g., stick with the certain answers, but use richer constraint language

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