# Computing Query Answers with Consistent Support

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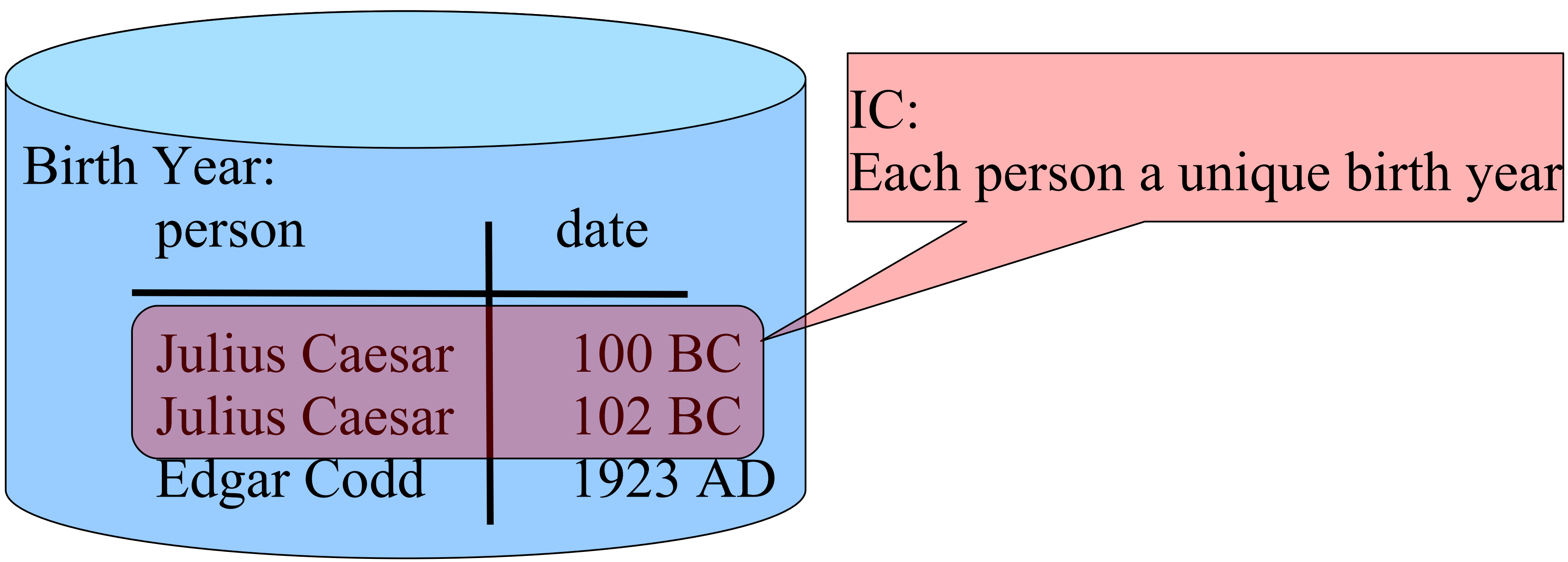
# Inconsistency in Databases

- If the data in a database violates the applicable ICs, we say the data is inconsistent.
- Care must be taken to avoid nonsensical answers e.g. Julius Caesar born twice!



# Why inconsistencies?

- integration of autonomous data sources.
  - –Two sources of data may show two surnames for the same person because
    - the two sources are out of sync
    - or one was incorrectly entered.
  - –two data sources may claim two different birth years for Julius Caesar.
- unenforced constraints.
  - –legacy system
  - –efficiency
  - –unsupported types
- preservation of information

# Consistent Support

- many methods proposed for querying inconsistent data
- we do EE
- motivate with pqr example
- define EE

# Example - Data

| institution <student, inst> |
|---|
| (id1, "Stanford University") |
| (id2, "Academy of Art") |

| dept <student, dept> |
|---|
| (id1, cs) |
| (id2, cs) |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| ca_institution <inst> |
|---|
| ("Stanford University") |
| ("Academy of Art") |
| ("Santa Clara University") |
| ("San Jose State") |

# Constraint

| institution <student, inst> |
|---|
| (id1, "Stanford University") |
| (id2, "Academy of Art") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| dept <student, dept> |
|---|
| (id1, cs) |
| (id2, cs) |

| ca_institution <inst> |
|---|
| ("Stanford University") |
| ("Academy of Art") |
| ("Santa Clara University") |
| ("San Jose State") |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

- Constraint (1)
  - institution(X,"Stanford University") ∧ department(X,"Computer Science") → ¬degree(X,"MA")

# Constraint

| institution <student, inst> |
|---|
| (id1, "Stanford University") |
| (id2, "Academy of Art") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| dept <student, dept> |
|---|
| (id1, cs) |
| (id2, cs) |

| ca_institution <inst> |
|---|
| ("Stanford University") |
| ("Academy of Art") |
| ("Santa Clara University") |
| ("San Jose State") |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

- Constraint (2)
  - institution(X,"Academy of Art University") → ¬department(X,"Computer Science")

# Answer

| institution <student, institution> |
|---|
| (id1, "Stanford University") |

| department <student, dept> |
|---|
| (id1, "Computer Science") |
| (id2, "Computer Science") |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| bayarea_institution <institution> |
|---|
| ("Stanford University") |
| ("Academy of Art University") |
| ("Santa Clara University") |
| ("San Jose State University") |

- answers(X) :- inst(X, Y), caInst(Y), dept(X, cs), name(X, alyssa)
- answers(id1)

# Answer

| institution <student, institution> |
|---|
| (id1, "Stanford University") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| department <student, dept> |
|---|
| (id1, "Computer Science") |
| (id2, "Computer Science") |

| bayarea_institution <institution> |
|---|
| ("Stanford University") |
| ("Academy of Art University") |
| ("Santa Clara University") |
| ("San Jose State University") |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

- answers(X) :- inst(X, Y), caInst(Y), dept(X, cs), name(X, alyssa)
- id2 is not an answer!

# Naïve Method

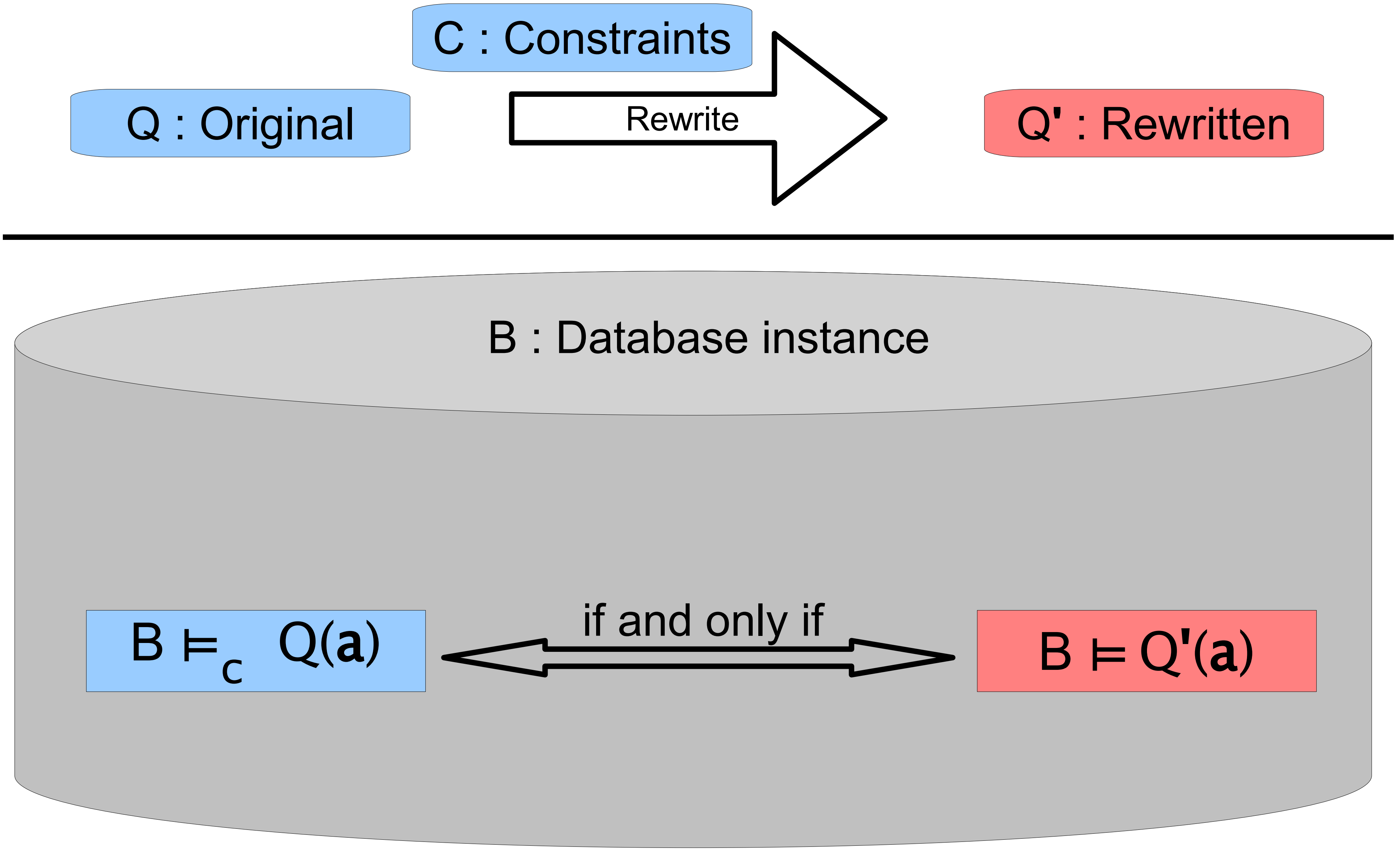
- Consider each consistent (maximal) subset of the data
- Find the the standard query answers on each subset
- Problem: There may be exponentially many consistent maximal subsets!

| p(A,B) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | a1 | a1 | a2 | a2 | ... | an | an |
| | B | b0 | b1 | b0 | b1 | ... | b0 | b1 |

FD: $A \rightarrow B$

A relation of **2n** tuples has **$2^n$** consistent maximal subsets!

# A Rewriting Approach



# A Rewriting Approach

- Given query Q and constraints C
- Rewrite Q as Q' so that for any database instance B:
  the strict entailment answers according to Q is exactly the standard answers according to Q'
- $B \vdash_C Q(\boldsymbol{a}) \Leftrightarrow B \vdash Q'(\boldsymbol{a})$

- Polynomial data complexity for first-order query
- Leverage standard database technologies and techniques to evaluate Q'

# Setting

- Constraints:
  - Function-free
  - Universal clauses (no existential quantifier)
  - Finite closure under resolution
- Queries:
  - First-order queries, equivalently:
    - Relational Algebra
    - Relational Calculus
    - Nonrecursive-Datalog¬
- Database:
  - Closed World Assumption

# Rewriting Algorithm

- Close constraints under resolution
- Write query body as unit clauses (b-clauses)
  - institution(X, Y)
  - bayarea_institution(Y)
  - department(X, "Computer Science")
  - name(X, "Alyssa")
- Apply unit resolutions between b-clauses and constraints. Each sequence of units resolutions that leads to an empty clause is a variable binding of the query body that violates the constraints

# Rewriting Examples

- q(X) :- inst(X,Y),caInst(Y),dept(X,cs), name(X,alyssa)


- q'(X) :- inst(X,Y),caInst(Y),dept(X,cs), name(X,alyssa)
  Y != art

# Blocking Inconsistent Data

- Given:
  - Datalog rule: $p(X)$ :- $\varphi(X,Y)$
  - constraint clause **c**
- Determine:
  - Which data bindings $\sigma$ make $\varphi(X,Y)\sigma$ violates clause **c**?
- Solution:
  - $\varphi(X,Y)\sigma$ violates c $\Leftrightarrow$ d subsumes $\neg\varphi(X,Y)\sigma$

# Blocking Inconsistent Data

¬dept(X,cs) ∨ ¬degree(X,ma)
¬inst(X,art) ∨ ¬dept(X,cs)

Closed under resolution

q(X) :- inst(X,Y),caInst(Y),dept(X,cs), name(X,alyssa)

inst(X,Y)
caInst(Y)
dept(X,cs)
name(X,alyssa)

# Rewriting Algorithm

- Clauses:
  - inst(X, Y)
  - ca_inst(Y)
  - dept(X, cs)
  - name(X, "Alyssa")
  - ¬dept(X,cs) ∨ ¬degree(X,ma) (1)
  - ¬inst(X,art) ∨ ¬dept(X,cs) (2)
- Y ← art
- Y != art

# Answer

| institution <student, institution> |
|---|
| (id1, "Stanford University") |
| (id2, "Academy of Art... [partially hidden] |

| department <student, dept> |
|---|
| (id1, "Computer Science") |
| (id2, "Computer Science") |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| bayarea_institution <institution> |
|---|
| ("Stanford University") |
| ("Academy of Art University") |
| ("Santa Clara University") |
| ("San Jose State University") |

- answers'(X) :- institution(X, Y),
  bayarea_institution(Y),
  department(X, "Computer Science"),
  name(X, "Alyssa"),
  Y != "Academy of Arts University"

- answers'(id1)

# Answer

| institution <student, institution> |
|---|
| (id1, "Stanford University") |

| department <student, dept> |
|---|
| (id1, "Computer Science") |
| (id2, "Computer Science") |

| name<student, name> |
|---|
| (id1, "Alyssa") |
| (id2, "Alyssa") |

| degree <student, degree> |
|---|
| (id1, "MA") |
| (id2, "MS") |

| bayarea_institution <institution> |
|---|
| ("Stanford University") |
| ("Academy of Art University") |
| ("Santa Clara University") |
| ("San Jose State University") |

- answers'(X) :- institution(X, Y),
  bayarea_institution(Y),
  department(X, "Computer Science"),
  name(X, "Alyssa"),
  Y != "Academy of Arts University"

- answer'(id2) is blocked

# Features

- Polynomial data complexity
- The the query rewriting is done once and may be evaluated on changing data
- standard techniques apply to rewritten query e.g.,
  - query planning
  - differential view maintenance
  - distributed query evaluation

# Limitations

- Univeral clauses express typical classes integrity constraints:
  - functional dependencies
  - denial constraints
  - etc.
- Cannot express referential integrity constraints
  - lacks existential quantification

# TODO: Query and Constraint Classes

- finding answers under broader classes of constraints
  - General first-order constraints
  - built-in predicates beyond =
- finding answers to broader classes of queries
  - recursive queries
  - aggregates
- Ideas:
  - careful skolemization
  - control resolution
  - interaction between constraint type and query type

# TODO: Stop Any Time

- Resolution closure may not terminate or may take a long time
- Idea: augment the query as resolution takes place
- Then the procedure can be stopped at any time and the most complete rewriting computed so far is returned

# TODO: View Maintenance

- Often, a query is not evaluated just once. Instead, a view is maintained.
- E.g., maintain list of emails of Bay Area CS students resulting from a query
- View can be updated "differentially" based on changes to the underlying data
- Investigate adapting and applying existing differential view maintenance techniques in the presence of inconsistencies
- Investigate algorithms and analyze complexity

# •TODO: others

- change constraints
- distributed query evaluation
  - In a federated databases setting, it is desirable to distribute the work of query evaluation.
  - push work down to data sources
- "local" constraints and "global" constraints
- Take or leave each data source in its entirety

# Applications

- Querying and updating federated autonomous databases
  - use strict entailment to find consistently supported consequences or update propagations
- Update through view
  - a change to view often cannot be uniquely resolved into changes to base relations
  - change the materialized view nonetheless and then draw consistently supported conclusions
- "Collaborative Data Management"
- Logical spreadsheets

# Prior Work

- Consistent Query Answers
  - (Arenas, Bertossi, Chomicki 98) (Fuxman & Miller 07) (Chomicki & Marcinkowski 04) (Bertossi 06)
- Argumentation
  - (Elvang-Goransson & Hunter 95) (Efstathiou & Hunter 08) (Besnard & Hunter 06) (Besnard & Hunter 05)
- Logical spreadsheets
  - (Kassoff & Genesereth 07)
- Possibilistic databases
  - (Pradhan 03) (Pradhan 05)

# Thank you

- Questions
- Comments
- Suggestions
- Advice

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# Strict Existential Entailment

- Developed by Kassoff and Genesereth for Logical Spreadsheets
- An answer is strictly existentially entailed iff it is supported by a consistent subset of the data
- Given a database instance B and constraint rules C, an answer *a* is strictly existentially entailed iff there is a subset B' of B such that
  $B' \cup \{C\} \nvdash \bot$ and $B' \cup \{C\} \vdash a$
- Finding all strictly existentially entailed answers to a query solves the problem on the previous slide.

# Querying and updating inconsistent data

- When a system integrates data from independent databases global constraints are often violated.
  - –Find-a-classmate search
  - –Product search
- How to query the data in the case of inconsistencies?
- If the system links independent databases, how can a change to one update the others?
  - –Changing customer information
  - –Changing information on social networks

[C] either remove update from the introduction or expound further in body

# The Problem

- Given a database that is (possibly) inconsistent with the integrity constraints,
- We can view answering a query as making an argument for an answer using the facts in the data.
- Standard query semantics asks for all query answers supported by an argument.
- But an argument that violates the ICs is clearly incorrect.
- Our goal is to find all query answers which are supported by an argument consistent w.r.t the ICs

# Related work

- Data integration
- Data warehousing / cleaning
- Update through views
- Probabilistic / uncertain databases
- Lineage and provenance
- Consistent query answers
- I would like to contribute mainly in update and query using credulous semantics

- composing credulous answers
  - conditional answers
- disjunctive information