Laconic schema mappings: computing the core with SQL queries

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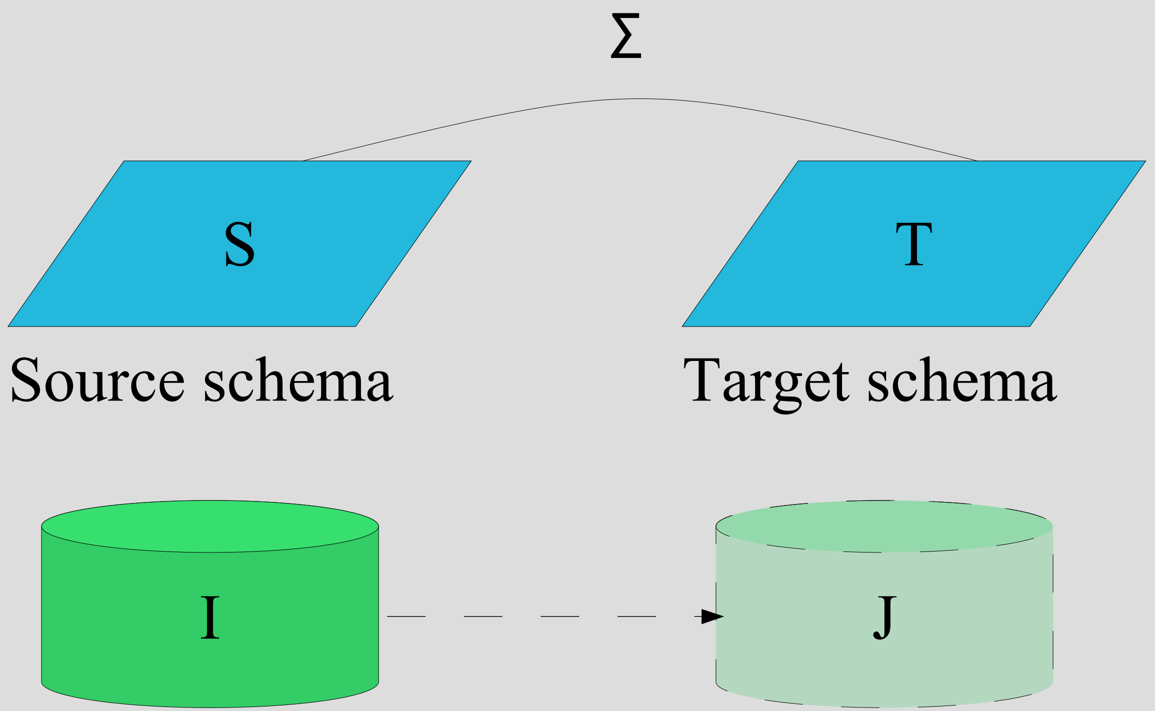
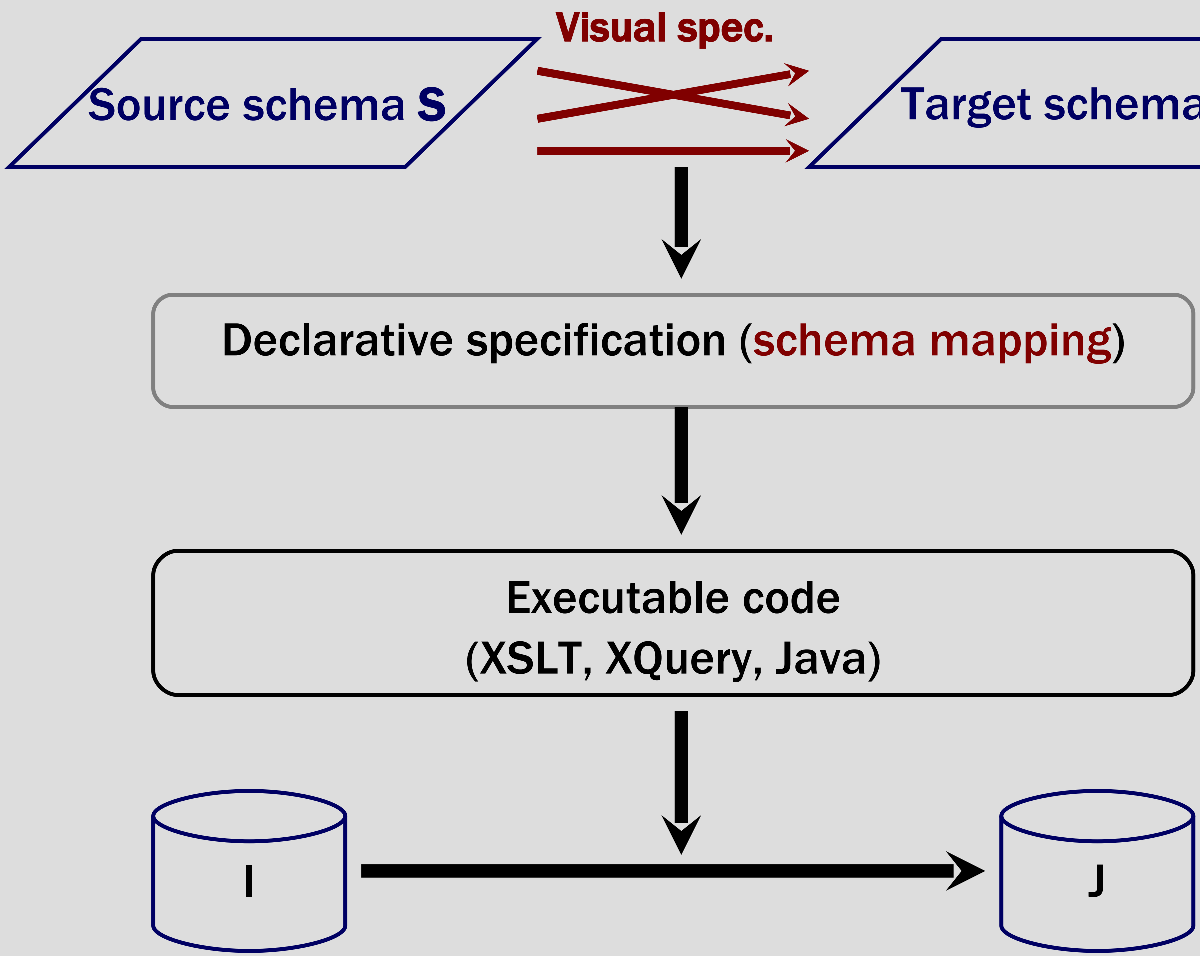
Data exchange

- Data exchange: transforming data structured under a source schema into data structured under a different target schema.



Generic architecture

- One of the first steps is to specify the relationships between the schemas. This is known to be a difficult task.



Generic architecture of mapping systems

e.g.,
IBM Clio
HePToX
Altova MapForce
Stylus Studio
MS Biztalk Mapper
BEA Aqualogic

Schema mappings and data exchange

- Schema mapping $M=(S,T,\Sigma)$:

  a declarative specification of the relationships between two database schemas (a source schema S and a target schema T), in the form of a list Σ of constraints (sentences of some logical language to be specified)

- Data exchange (formal definition [FKMP'05]):

  given a schema mapping and a source instance I of the source schema, construct a solution of I: an instance J of the target schema, such that $(I,J) \models \Sigma$.

- NB: Schema mappings are used also in other data-interoperability tasks such as data integration.

Schema mapping specification language

- The constraints Σ are commonly specified by source-to-target tuple generating dependencies (s-t tgds) [FKMP'05]:
- An s-t tgd is a FO-sentence $\forall \mathbf{x}(\varphi_S(\mathbf{x}) \rightarrow \exists \mathbf{y}.\psi_T(\mathbf{x},\mathbf{y}))$ with
  - $\varphi_S(\mathbf{x})$ a conjunction of atomic formulas over the source schema.
  - $\psi_T(\mathbf{x},\mathbf{y})$ a conjunction of atomic formulas over the target schema.
- Example: $\forall x_1 x_2 (R x_1 x_2 x_3 \rightarrow \exists y. T x_1 x_2 y)$

  "Whenever the source instance contains a fact Rabc, the target instance should contain Tabd for *some* value d."

Which solution?

- A source instance may have many solutions. Example:
  - Schema mapping: $\Sigma = \{ \forall x_1 x_2 x_3 (R x_1 x_2 x_3 \to T x_1 x_2) \}$
  - Source instance: $I = \{ Rabc \}$
  - Solutions $J_1 = \{ Tab \}$ and $J_2 = \{ Tab, Tac \}$
- Definition: a universal solution is a solution that maps homomorphically into every other solution [FKMP'05].
  - Intuitively, univ. solutions contain no more information than needed.
  - In the above example, J_1 is universal while J_2 is not.
- Two particular universal solutions: the canonical universal solution and the core universal solution.

Canonical universal solution

- Recall that s-t tgds are logical constraints expressing relationships between the source schema and target schema.
- They also have another, procedural reading. For example,
  - $\forall x_1 x_2 (R x_1 x_2 \rightarrow \exists y. T x_1 x_2 y)$
  - Declarative semantics: for every fact Rab, the target instance needs to contain Tabc for some c.
  - Procedural reading: for every fact Rab, choose a fresh null value *N* and add Tab*N* to the target instance.
- The target instance obtained by "executing" the s-t tgds (as instructions) is the canonical universal solution [FKMP'05].
- This procedure is known as the chase.

- **Note**: the "procedural reading" of the s-t tgds (i.e., the chase) is just one way to compute a universal solution.
- Advantage: the canonical universal solution is easy to compute
  - A schema mapping specified by s-t tgds can be compiled into a list of SQL queries computing the canonical universal solution.
  - We can compute the canonical univ. solution using any RDBMS.
  - This is how data exchange systems such as Clio work.
- Disadvantage: the canonical universal solution may contain more null values and more facts than strictly necessary.

Core universal solution

- The core universal solution is the smallest universal solution (unique-up-to-isomorphism) [FKP'05]
- Nice properties of the core universal solution:
  - It is the universal solution that contains the fewest null values.
  - It is the universal solution that satisfies the most dependencies
  - It is the universal solution that gives the most conservative answers to $CQ^{\neq}$ queries
- Formally,
  - the core of an instance is smallest homomorphically equivalent instance (unique-up-to-isomorphism)
  - the core universal solution of a source instance is the core of the canonical universal solution (or, of any other universal solution).

Computing the core universal solution

- Computing the core of an arbitrary instance (with nulls) is NP-hard.
- Computing core universal solutions for schema mappings specified by s-t tgds can be done in PTime (data complexity) due to special properties of the canonical universal solution.
- Several algorithms have been proposed:
  - Greedy [FKP'05], Blocks [FKP'05], Gottlob-Nash [GN'08]
- all these algorithms involve recursively performing two steps
  1. testing for the existence of a homomorphism from J into a proper subinstance of J, and
  2. removing facts from J.

which goes beyond SQL, i.e., out-of-the-box data transformation.

Example

Schema mapping

S: PTStudent(age,name)
GradStudent(age,name)

T: Advised(sname,facid)
WorksWith(sname,facid)

Σ: PTStudent(x,y) → ∃z. Advised(y,z)
GradStudent(x,y) → ∃z.(Advised(y,z) ∧ WorksWith(y,z))

Source instance

PTStudent

age	name
32	John
30	Ann

GradStudent

age	name
27	Bob
30	Ann

Canonical univ. sol.

Advised

sname	facid
John	N1
Ann	N2
Bob	N3
Ann	N4

WorksWith

sname	facid
Bob	N3
Ann	N4

Core univ.sol.

Advised

sname	facid
John	N1
Bob	N3
Ann	N4

WorksWith

sname	facid
Bob	N3
Ann	N4

Why core universal solutions are not used in practice

- Canonical universal solution: less preferred but easy to compute (can be done using SQL queries).
- Core universal solution: most preferred solution but hard to compute (out-of-the-box).
- Clio (the IBM Almaden prototype data exchange engine) constructs only canonical universal solutions:
  - No need to implement a data transformation engine
  - Leverage optimizations built into the DBMS.
- Can we compute core universal solution using SQL queries?

Laconicity: have the cake and eat it

- A schema mapping is laconic if, for every source instance, the canonical universal solution **is** the core universal solution.
- Our main contribution: an algorithm for transforming every schema mapping specified by s-t tgds into an equivalent laconic schema mapping (assuming a linear order on the source domain).
- Algorithm for computing core universal solution:
  - Transform schema mapping M into equivalent laconic M'.
  - Compile M' into SQL queries computing canonical univ. sol.
  - Apply SQL queries to the source instance to obtain core univ. sol.
- Thus, **yes** we can compute the core universal solution with SQL queries using any RDBMS.

Example revisited

Schema mapping

S: PTStudent(age,name)
GradStudent(age,name)

T: Advised(sname,facid)
WorksWith(sname,facid)

Σ: PTStudent(x,y) $\wedge$ **¬∃u.Gradstudent(u,y)** $\rightarrow \exists$z. Advised(y,z)
GradStudent(x,y) $\rightarrow \exists$z.(Advised(y,z) $\wedge$ WorksWith(y,z))

Source instance

PTStudent

age	name
32	John
30	Ann

GradStudent

age	name
27	Bob
30	Ann

Canonical univ. sol.

Advised

sname	facid
John	N1
~~Ann~~	~~N2~~
Bob	N3
Ann	N4

WorksWith

sname	facid
Bob	N3
Ann	N4

Core univ.sol.

Advised

sname	facid
John	N1
Bob	N3
Ann	N4

WorksWith

sname	facid
Bob	N3
Ann	N4

Idea behind the translation

- For schema mappings given by a finite set of s-t tgds,

  1. each core universal solution can be decomposed into small fact blocks, each having disjoint sets of null values.
  2. there is a finite set of fact-block types that can arise
  3. for each fact-block type *t*, there is an SQL query precon_t that tells exactly when a fact block of type *t* needs to be created.

- Complications arise with source instances are non-rigid (i.e., have non-trivial automorphisms). These are solved by assuming a linear order on the source domain

Example revisited

Schema mapping

S: Collegue(name,name)

T: ReportsTo(name,name)

Σ: Collegue(x,y) → ∃z. ReportsTo(x,z) ∧ ReportsTo(y,z)

Source instance

Collegue

name	name
John	Mary
Mary	John

Canonical univ. sol.

ReportsTo

name	name
John	N1
Mary	N1
Mary	N2
John	N2

Core univ.sol.

ReportsTo

sname	facid
John	N1
Mary	N1

Has a non-trivial automorphism:
{ John |→ Mary, Mary |→ John }

Hence, whenever a null is created for the pair (John,Mary), another null is created for the pair (Mary,John). Can be avoided by requiring that x ≤ y.

Optimality of the results

- Our laconisation algorithm is optimal in several ways:
  1. Exponential blow-up in size of schema mapping is unavoidable.
  2. The use of negation in the left-hand sides is necessary (in general the left-hand sides will be Boolean combinations of conjunctive queries)
  3. The use of a linear order on the source domain is necessary (unless the right-hand side of each s-t tgd is selfjoin-free)
  4. Our method cannot be extended with target constraints.

Summary and outlook

- In data exchange there is a choice which solution to materialize: canonical universal solution vs core universal solution.
- Laconic schema mappings: have the cake and eat it
  - the canonical universal solution **is** the core universal solution
- Our main contributions:
  1. an algorithm to transform schema mappings given by s-t tgds into equivalent laconic schema mappings (given by FO s-t tgds)
  2. a set of results showing that the translation is optimal
- Future work: implementation and empirical evaluation.
- Note: In [Mecca, Papotti, and Raunich SIGMOD'09], similar results were obtained independently for a restricted class of s-t tgds and used to obtain considerable performance gains.