Mapping Maintenance in XML P2P Databases

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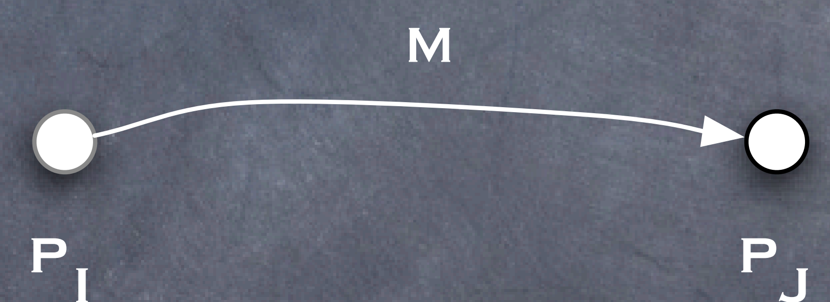
Motivating Example (1/3)

```
PisaBib = bib[(Author)*]
Author = author[Name, Affiliation, Paper*]
Name = name[String]
Affiliation = affiliation[String]
Paper = paper[Title, Year]
Title = title[String]
Year = year[Integer]
```

```
NYBib = bib[(Article|Book)*]
Article = article[Author*,Title,Year, RefCode]
Author = author[String]
Title = title[String]
Year = year[Integer]
Book = book[Author*,Title,Year, RefCode]
RefCode = refCode[String]
```

S_i S_j



M:

```
...
for $aut in $input/author,
    ...
return author[$aut/name/text()]]
...
```

Motivating Example (2/3)

```
for $aut in $bib/author,
    ...
where $aut/name = ‘‘Mary F. Fernandez’’
...
```

CORRECT!

```
for $aut in $bib/author,
    ...
where $aut = ‘‘Mary F. Fernandez’’
...
```

Motivating Example (3/3)

- p_j changes its schema

```
...
Author = author[first[String],second[String]]
...
```

- mapping M remains unchanged
- the reformulated query does not match the target schema

Introduction

- we want to study the maintenance of mappings in XML p2p databases
  - detecting when a mapping becomes corrupted due to changes in the peer schemas
- relevant for the data exchange problem too

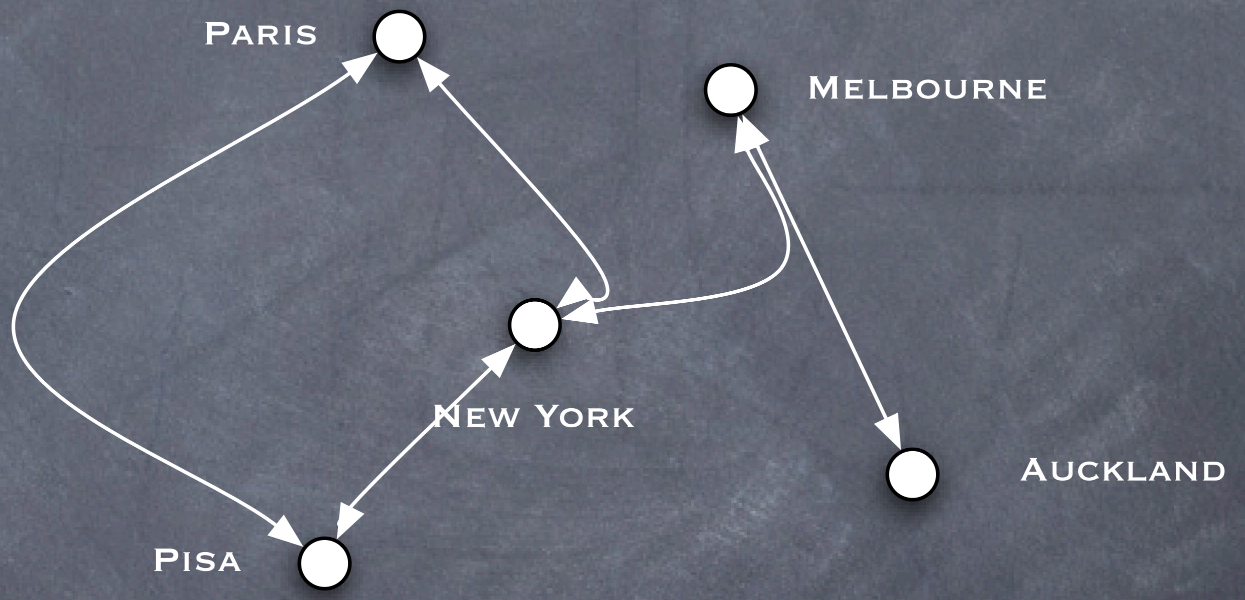
Outline

- reference scenario
- mapping correctness
- correctness checking
- complexity remarks
- conclusions and future work

Reference Scenario

System Model

- an unstructured p2p system inspired by Piazza
- each peer comprises
  - a local schema
  - a peer view
  - a set of neighbors
  - a set of schema mappings connecting its view to the views of its neighbors



Query Language

- simple query language inspired by XQuery (μXQuery)
- `for/let/where/return` clauses
- simple predicate language
  - conjunction, disjunction, or negation of variable comparisons

Grammar

$$
\begin{array}{lcl}
Q & ::= & () \mid b \mid l[Q] \mid Q, Q \mid \overline{x}\,\texttt{child} :: \mathit{NodeTest} \mid \overline{x}\,\texttt{dos} :: \mathit{NodeTest} \\
 & & \mid \texttt{for}\ \overline{x}\ \texttt{in}\ Q\ \texttt{return}\ Q \mid \texttt{let}\ x ::= Q\ \texttt{return}\ Q \\
 & & \mid \texttt{for}\ \overline{x}\ \texttt{in}\ Q\ \texttt{where}\ P\ \texttt{return}\ Q \mid \texttt{let}\ x ::= Q\ \texttt{where}\ P\ \texttt{return}\ Q \\
\mathit{NodeTest} & ::= & \texttt{l} \mid \texttt{node}() \mid \texttt{text}() \\
P & ::= & \texttt{true} \mid \chi\ \delta\ \chi \mid \texttt{empty}(\chi) \mid P\ \texttt{or}\ P \mid \texttt{not}\ P \mid (P) \\
\chi & ::= & \overline{x} \mid x \\
\delta & ::= & = \mid <
\end{array}
$$

Semantics

$$
\begin{array}{llll}
[\![b]\!]_\rho & \triangleq b & [\![x]\!]_\rho & \triangleq \rho(x) \\
[\![\overline{x}]\!]_\rho & \triangleq \rho(\overline{x}) & [\![()]\!]_\rho & \triangleq () \\
[\![Q_1, Q_2]\!]_\rho & \triangleq [\![Q_1]\!]_\rho, [\![Q_2]\!]_\rho & [\![l[Q]]\!]_\rho & \triangleq l[[\![Q]\!]_\rho]
\end{array}
$$

$$[\![\overline{x} \texttt{ child} :: NodeTest]\!]_\rho \triangleq childr([\![\overline{x}]\!]_\rho) :: NodeTest$$

$$[\![\overline{x} \texttt{ dos} :: NodeTest]\!]_\rho \triangleq dos([\![\overline{x}]\!]_\rho) :: NodeTest$$

$$[\![\texttt{let } x ::= Q_1 \texttt{ return } Q_2]\!]_\rho \triangleq [\![Q_2]\!]_{\rho, x \mapsto [\![Q_1]\!]_\rho}$$

$$[\![\texttt{for } \overline{x} \texttt{ in } Q_1 \texttt{ return } Q_2]\!]_\rho \triangleq \prod_{t \in trees([\![Q_1]\!]_\rho)} [\![Q_2]\!]_{\rho, \overline{x} \mapsto t}$$

$$[\![\texttt{let } x ::= Q_1 \texttt{ where } P \texttt{ return } Q_2]\!]_\rho \triangleq \text{if } P(\rho, x \mapsto [\![Q_1]\!]_\rho) \text{ then } [\![Q_2]\!]_{\rho, x \mapsto [\![Q_1]\!]_\rho} \text{ else } ()$$

$$[\![\texttt{for } \overline{x} \texttt{ in } Q_1 \texttt{ where } P \texttt{ return } Q_2]\!]_\rho \triangleq \prod_{t \in trees([\![Q_1]\!]_\rho)} (\text{if } P(\rho, \overline{x} \mapsto t) \text{ then } [\![Q_2]\!]_{\rho, \overline{x} \mapsto t} \text{ else } ())$$

Type Language

- inspired by XDuce
- a variation of the language presented in [ICFP04]
  - unordered types
  - no vertical recursion

$$T \ ::= \ () \ \mid B \ \mid l[T] \ \mid T,T \ \mid T\,|\,T \ \mid T*$$

$$B \ ::= \ \texttt{String}$$

Mapping Correctness

Desiderata

- to capture
  - errors wrt the source schema
    - obsolete or dead rules
  - errors wrt the target schema
    - transforming a source instance into a fragment of a target schema instance
- independence from
  - the type system being used
  - query reformulation and answering

Mapping Validity

- a mapping $\omega = \{q_k\}_k : V_i \rightarrow V_j$ is valid iff, for each query q_k, q_k is **correct** wrt V_i
  - for each non-empty subquery q of q_k, $\exists d{:}V_i$ such that $q(d) \neq ()$
- based on the query correctness notion of [ICFP04] and [PlanX05]
- it allows for the detection of obsolete rules

```
for $aut in $bib/author,
    $ssn in $aut/ssn,
...
```

Mapping Correctness

- a mapping $\omega = \{q_k\}_k : V_i \rightarrow V_j$ is correct iff, $\forall q_k$, $\forall d_h : V_i$, $\exists d_l : V_j$, such that, $q_k(d_h) \lesssim d_l$
- based on the value projection relation $\lesssim$
- independent from the type system and the reformulation and answering algorithms

$$
\begin{array}{rcl}
() & \lesssim & f \\
b_1 & \lesssim & b_2 \\
f & \lesssim & f, () \\
f_1, f_2 & \lesssim & f_2, f_1
\end{array}
\qquad
\begin{array}{rcll}
f_1, f_2 & \lesssim & f_3, f_4 & \text{if } (f_1 \lesssim f_3 \wedge f_2 \lesssim f_4) \\
f_1 & \lesssim & f_3 & \text{if } \exists f_2 : f_1 \lesssim f_2 \wedge f_2 \lesssim f_3 \\
l[f_1] & \lesssim & l[f_2] & \text{if } f_1 \lesssim f_2
\end{array}
$$

Mapping Correctness Example (1/3)

```
PisaBib = bib[(Author)*]
Author = author[Name, Affiliation, Paper*]
Name = name[String]
Affiliation = affiliation[String]
Paper = paper[Title, Year]
Title = title[String]
Year = year[Integer]
```

source schema

```
NYBib = bib[(Article|Book)*]
Article = article[Author*,Title,Year, RefCode]
Author = author[first[String], second[String]]
Title = title[String]
Year = year[Integer]
Book = book[Author*,Title,Year, RefCode]
RefCode = refCode[String]
```

target schema

Mapping Correctness Example (2/3)

mapping

```
NYBibliography <-
Q1($input):  for $y in $input/year return $y
Q2($input):  for $t in $input/title return $t
Q3($input):  for $p in $input//paper,
                 $t in $p/title
             return article[ Q2($p), Q1($p),
                             for $aut in $input/author,
                                 $pap in $aut/paper
                                 $title in $pap/title
                             where $title = $t
                             return author[$aut/name/text()]]
Q4($input):  for $bib in /bib return bib[Q3($bib)]
```

Mapping Correctness Example (3/3)

```
bib[
    author[name["Luca Cardelli"],
       affiliation["Microsoft Research"],
       ...
      ]
   ]
```

source instance

```
bib[
    article[...,
            ...,
           author["Luca Cardelli"]]
    ...
   ]
```

transformed instance

- the transformed instance cannot be projected into any target instance
  - author name mismatch

Correctness Checking

Towards an Operational Notion

- the notion of mapping correctness is not operational
  - universal quantification on data instances
- two steps
  - switch to types
  - type projection

Type System

- a variant of those of [ICFP04] and [PlanX05]
- focused on type inference
  - rather precise thanks to type splitting
- upper bound property
  - for any well-formed Γ and query Q:
  - $\Gamma \vdash Q : U \wedge \rho \in R(\Gamma) \Rightarrow [[Q]]_\rho \in [[U]]$

Type Projection

- extension of the relational projection
- given two type T_1 and T_2 , we say that T_1 is a projection of T_2 ($T_1 \lesssim T_2$) if and only if:

  $\forall d_1 : T_1 \; \exists d_2 : T_2 \; .d_1 \lesssim d_2$
- a form of injective simulation among types

Type Projection Completeness

- given a mapping $\omega = \{q_k\}_k$ from V_i to V_j , ω is correct if $\forall q_k \,.\, \Gamma \vdash q_k : T$ and $T \lesssim V_j$,

  where Γ is an environment obtained from V_i
- this theorem ties mapping correctness and type projection
- we need now a way to check for type projection!

Type Approximation

$$
\begin{array}{lcllcl}
()^{\lhd} & \triangleq & () & T \mid U^{\lhd} & \triangleq & T^{\lhd} \mid U^{\lhd} \\
l[T]^{\lhd} & \triangleq & l[T^{\lhd}]? & B^{\lhd} & \triangleq & B? \\
T,U^{\lhd} & \triangleq & T^{\lhd},U^{\lhd} & T*^{\lhd} & \triangleq & T^{\lhd}*
\end{array}
$$

Type Projection As Subtyping

- $T \precsim U \Leftrightarrow T < U^{\triangleleft}$
- consequences
  - type projection is decidable [DalZilio04]
  - type projection can be checked by relying on subtype-checking algorithms

Complexity Remarks

Type Inference

- exponential
  - type splitting
- in most cases the algorithm is polynomial
  - *-guarded union types
  - fully specified paths

Type Projection

- [DalZilio04] proved that subtype-checking is super-exponential for a superset of our type language
  - unordered sequence types
  - union types
  - par types
  - negation types
  - repetition types

Differences

- our type language does not contain
  - par types
  - negation
- much simpler

Complexity Claim

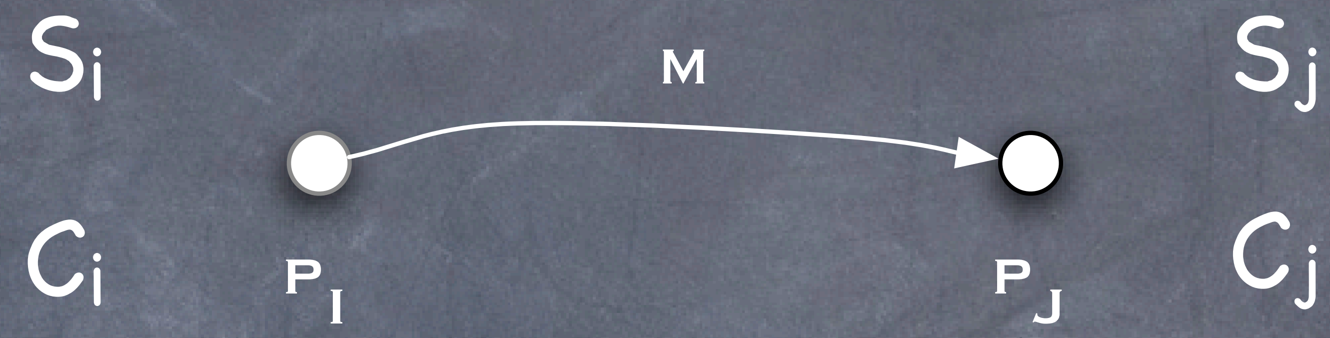
- type projection for our type language is supposed to be polynomial
- projection for union and product types is equivalent to the Wombat Eating Assignment (WEA) problem [GJ79]
  - can be efficiently solved by using 0-1 maximum flow algorithms for bipartite graphs
  - $O(nm(n+m)^3)$

Conclusions and Future Work

Conclusions

- we defined a “semantic” notion of schema mapping correctness
  - independent from the type system
  - independent from query reformulation and answering algorithms
- we related correctness to type projection, as well as type projection to subtyping
- we proved decidability and complexity of type projection

Future Work
First Direction



- constraints
- M is correct if it is correct wrt S_i and S_j, and if $M(C_i)$ is “compatible” with C_j

Future Work
Second Direction

- recursive types
  - type projection as subtyping should hold in the presence of recursive types too
  - recursive type as (infinite) union of non-recursive types

Future Work
Third Direction

- improving type inference precision
  - less false negatives

References

- [ICFP04] Colazzo, D., Ghelli, G., Manghi, P., Sartiani, C.: Types for Path Correctness of XML Queries. In: Proceedings of the 2004 International Conference on Functional Programming (ICFP), Snowbird, Utah, September 19-22, 2004. (2004)
- [PlanX05] Colazzo, D., Sartiani, C.: Typechecking Queries for Maintaining Schema Mappings in XML P2P Databases. In: Proceedings of the 3th Workshop on Programming Language Technologies for XML (Plan-X), in conjunction with POPL 2005.
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- [GJ79] Michael Garey and David Johnson: Computers and Intractability - A Guide to the Theory of NP-completeness; Freeman, 1979