Mappings as Building Blocks for Complex Integration

Lucian Popa
IBM Almaden Research Center

Outline

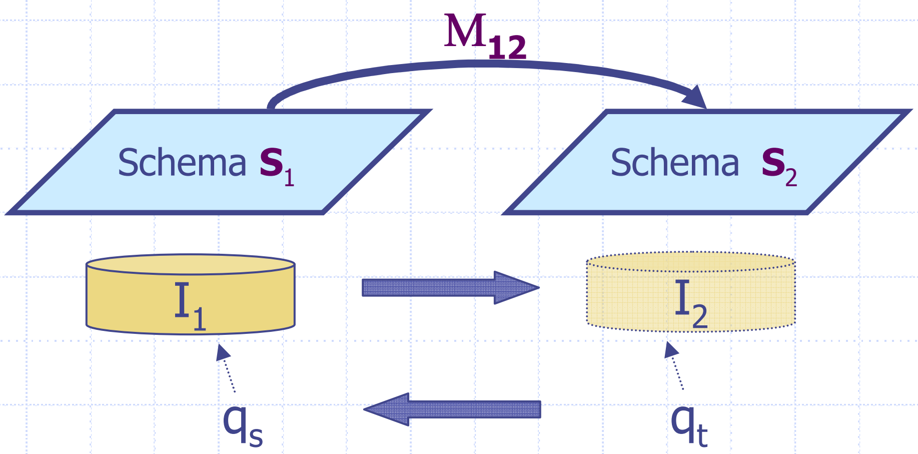
- Schema mapping research: what can we do now
  - Brief description of Clio
- What could be next:
  - Flows of mappings and transformations
  - How can we increase automation in creating such flows ?
  - Mappings as reusable objects
  - Repository of common mappings and types

- Disclaimer:
  - this is a very “mapping-biased” look at integration ☺
  - there are plenty of important pieces left out …

- Result of several discussions with: L. Haas, M. Hernandez, H. Ho, P.Kolaitis, R. Miller, M. Gubanov, H. Pirahesh, I.R.Stanoi, …

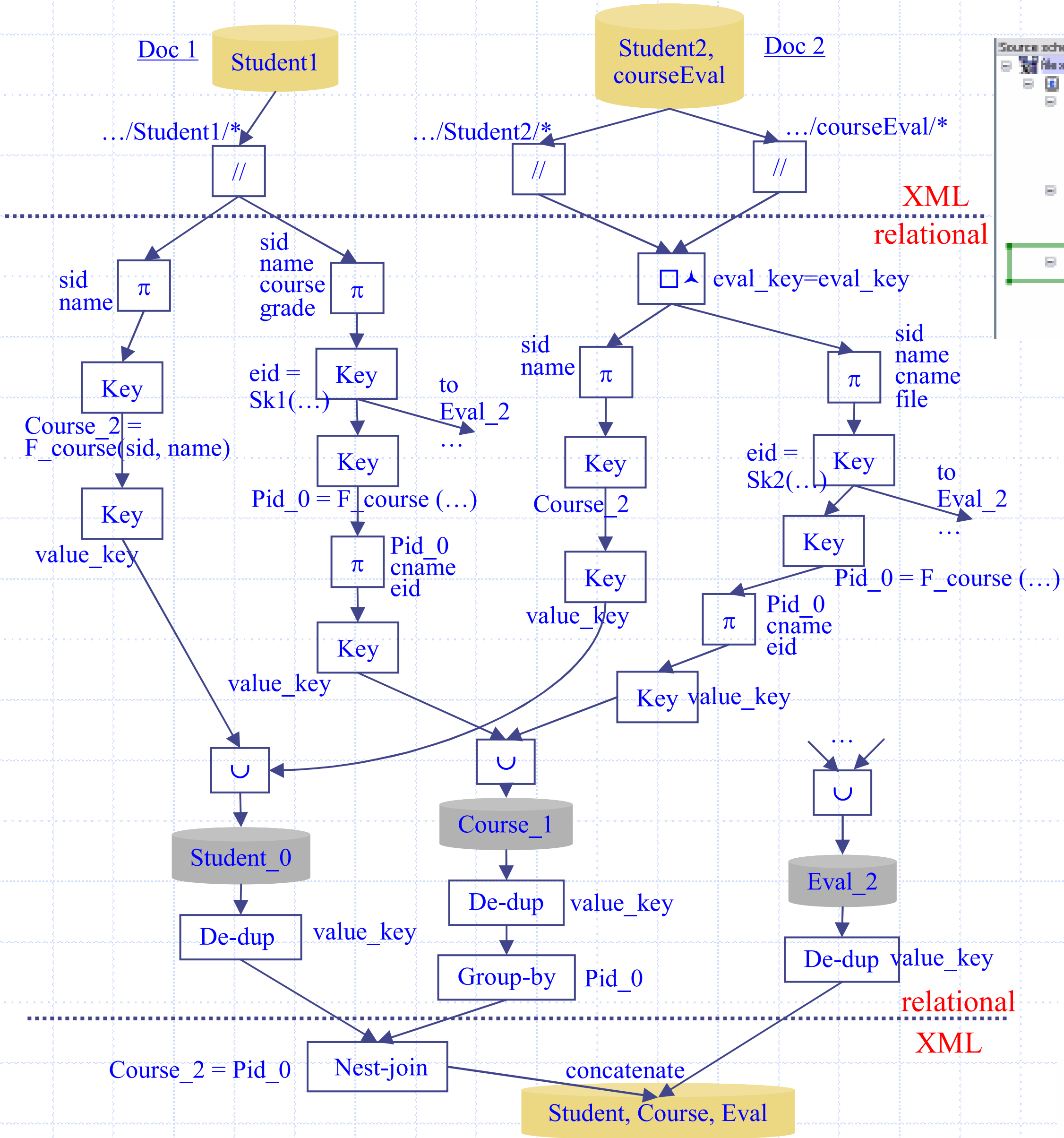
Schema Mappings (Recap)

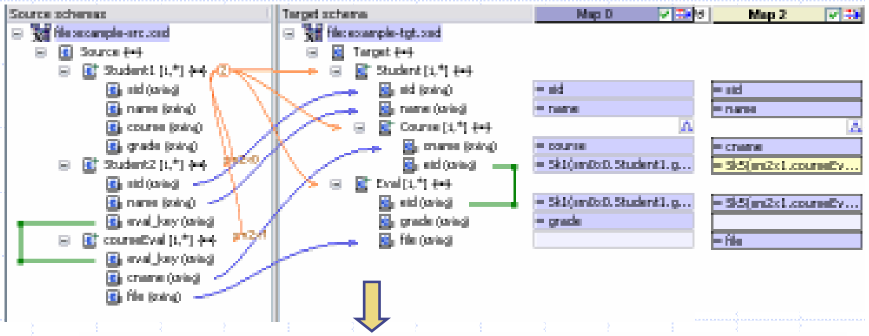
- A schema mapping is a useful abstraction that specifies a relationship between a source schema and a target schema
  - Can be used for: data transformation, query answering, to represent schema evolution, etc



- The power of the schema mapping concept relies in its *simplicity*
  - A set of *logical assertions* (e.g., dependencies) that can be manipulated
  - Independent of run-time engines (SQL, XQuery, ETL), but can be *compiled* into such engines

Clio: From Mappings to Runtime Artifacts





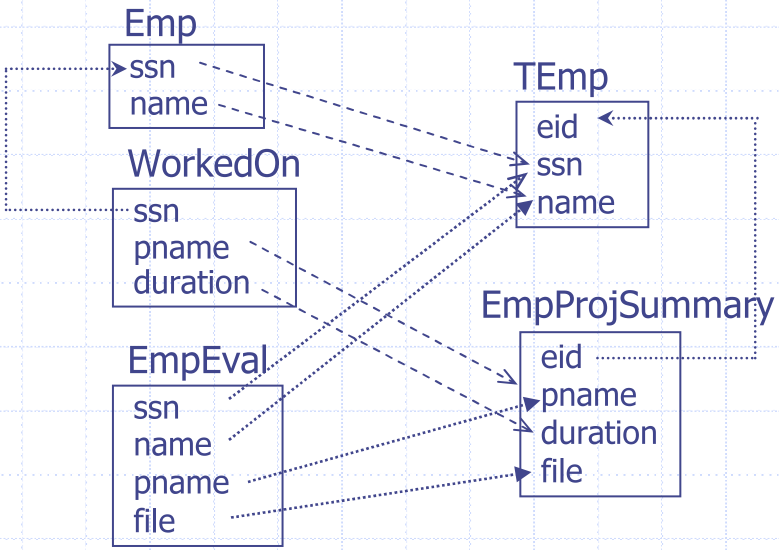

```
(: ======== Phase-1: shredding into relational views ========= :)
declare function local:shred($doc0 as element(root)) as element(root) {
<root>
 {
  for $sm0x0 in $doc0/Source/Student1
  return
   <Student_0>
    <sid_0>{ $sm0x0/sid/text() }</sid_0>
    <name_1>{ $sm0x0/name/text() }</name_1>
    <Course_2>{ fn:concat("F_course(", $sm0x0/sid/text(), ",", $sm0x0/name/text(), ")") }</Course_2>
    <value-key>{ fn:string-join(($sm0x0/sid/text(),$sm0x0/name/text(), fn:concat("F_course(", $sm0x0/sid/text(), ",",
$sm0x0/name/text(), ")")), "|") }</value-key>
   </Student_0>
 }
 {
  for $sm2x0 in $doc0/Source/Student2,
   $sm2x1 in $doc0/Source/courseEval
  where $sm2x0/eval_key = $sm2x1/eval_key
  return
   <Student_0>
    <sid_0>{ $sm2x0/sid/text() }</sid_0>
    <name_1>{ $sm2x0/name/text() }</name_1>
    <Course_2>{ fn:concat("F_course(", $sm2x0/sid/text(), ",", $sm2x0/name/text(), ")") }</Course_2>
    <value-key>{ fn:string-join(($sm2x0/sid/text(),$sm2x0/name/text(), fn:concat("F_course(", $sm2x0/sid/text(), ",",
$sm2x0/name/text(), ")")), "|") }</value-key>
   </Student_0>
 }
 {
  for $sm0x0 in $doc0/Source/Student1
  return
   <Course_1>
    <Pid_0>{ fn:concat("F_course(", $sm0x0/sid/text(), ",", $sm0x0/name/text(), ")") }</Pid_0>
    <cname_1>{ $sm0x0/course/text() }</cname_1>
    <eid_2>{ fn:concat("Sk0(", $sm0x0/grade/text(), ",", $sm0x0/course/text(), ",", $sm0x0/name/text(), ",", $sm0x0/sid/
text(), ")") }</eid_2>
    <value-key>{ fn:string-join((fn:concat("F_course(", $sm0x0/sid/text(), ",", $sm0x0/name/text(), ")"),$sm0x0/course/
text(),fn:concat("Sk0(", $sm0x0/grade/text(), ",", $sm0x0/course/text(), ",", $sm0x0/name/text(), ",", $sm0x0/sid/text(),
")")), "|") }</value-key>
   </Course_1>
 }
   • • •
(: ======== main query ======== :)
let $p0 := local:idgen(),
   $p1 := local:dupelim(local:shred($p0)),
   $p2 := local:nest($p1)
return $p2
```

A Detour into Clio

Clio: The System

- Clio has a 3-level mapping “architecture”, first introduced in [PVMHF '02]
  - Correspondences
  - Constraints
  - Queries (Transformation)
- Clio has two main generation components:
  - (1) Correspondences are compiled into s-t constraints (tgds [BV'84])
    - Constraints represent the real mapping (used in all Clio related tools for generation, composition, evolution, etc.)
    - IBM mapping specification language (MSL, used in Rational Data Architect), derived from Clio specification
  - (2) Constraints are then compiled into execution scripts (SQL, XSLT, ETL, Java, etc.)

Compilation of Correspondences into Constraints



- Source and target foreign key constraints are compiled into the mapping constraints
  - So, target constraints will be automatically satisfied
  - Data associations are preserved
- Some target fields are unspecified (e.g., eid)
  - But they will have to be generated (consistently)

Σ_{st}

t_1: $Emp(s,n) \wedge WorkedOn(s,p,d) \rightarrow \exists E\ \exists F\ (\ TEmp(E,s,n) \wedge EmpProjSummary(E,p,d,F)\ )$

t_2: $EmpEval(s,n,p,f) \rightarrow \exists E\ \exists D\ (\ TEmp(E,s,n) \wedge EmpProjSummary(E,p,D,f)\ )$

We can also write constraints as inclusion of CQs. For example, t_1 :

<u>select</u> e.ssn, e.name, w.pname, w.duration <u>from</u> Emp e, WorkedOn w <u>where</u> e.ssn = w.ssn	$\subseteq$	<u>select</u> e.ssn, e.name, s.pname, s.duration <u>from</u> TEmp e, EmpProjSummary s <u>where</u> e.eid = s.eid

Data Exchange: Theory

- [FKMP03]:
  - Given source instance (I), and given schema mapping Σ_{st} (and possibly target constraints, Σ_t), what is the best target instance and how do we compute it ?
- Constraints underspecify the problem and there are multiple solutions (e.g.,. multiple ways of putting nulls, for example,)
- Universal solutions are the most general solutions:
  - E.g., never assume that two nulls are equal unless specified by the constraints
- Chasing I with $\Sigma_{st} \cup \Sigma_t$ yields a canonical universal solution J
  - Populate the target with all the required tuples, adding fresh new nulls for the existential variables
  - For termination, needs the constraints in Σ_t to be weakly acyclic

Data Exchange in Clio: Query Generation

- In Clio, target fk constraints are already taken into account
  - No need to chase them
- Clio implements universal solutions via query generation
- Main idea:
  - Skolemize and normalize the s-t tgds:

$$Emp(s,n) \wedge WorkedOn(s,p,d) \rightarrow TEmp(E_1[s,n,p,d],s,n)$$
$$Emp(s,n) \wedge WorkedOn(s,p,d) \rightarrow EmpProjSummary(E_1[s,n,p,d],p,d,F[s,n,p,d])$$
$$EmpEval(s,n,p,f) \rightarrow TEmp(E_2[s,n,p,f],s,n)$$
$$EmpEval(s,n,p,f) \rightarrow EmpProjSummary(E_2[s,n,p,f],p,D[s,n,p,f],f)$$

  - We obtain single-headed rules (can also describe this as an SO tgd where E_1, E_2, D and F are existential functions)
- These are "GAV" mappings, so we can write SQL queries to populate the target.

The Rest of the Theory vs. Clio

- Other target constraints (non fks):
  - Target tgds (e.g., transitive closure), cyclic fks, target egds
  - One problem: target query languages are not able, in general, to express chasing with such constraints
  - Target egds (e.g., fds) may induce conflicts, which need to be resolved on a tuple by tuple basis, or by more specialized rules
  - Better pushed into a separate phase
- Computing the core (smallest of the universal solutions)
  - Why would we do that ? Less redundancy in the target data
  - But again, cannot be compiled into a query (need specialized code)
  - Better pushed into a separate phase

- Composition
  - Important (schema evolution, data flows)
  - Clio implements composition of SO tgds (part of RDA too)

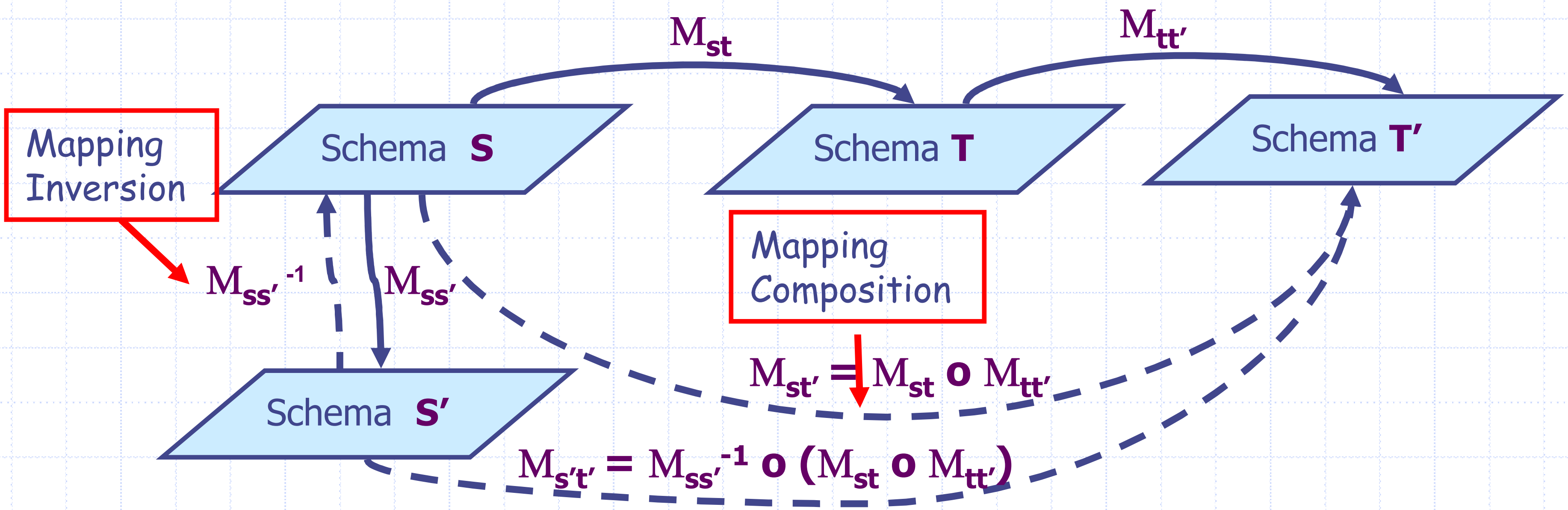
- Data exchange theory is formulated in relational terms (to keep things clear!)
- But in Clio, everything is extended to deal with XML too

Back to mappings

- So, a mapping can be used at design-time as an (indirect, declarative) model of the run-time execution

- But there are other uses of a mapping (in addition to being a model for execution) …

Applications to Schema Evolution



- But there are other uses of composition and inversion:
  - store data with one mapping but query it using its inverse
  - *reuse of mappings*: design a mapping between two logical schemas but deploy it between two physical schemas (to come back at this)
- Same vision here as the model management of Phil Bernstein
  - schemas and mappings are at its core

Schema Mappings: A summary of where we are

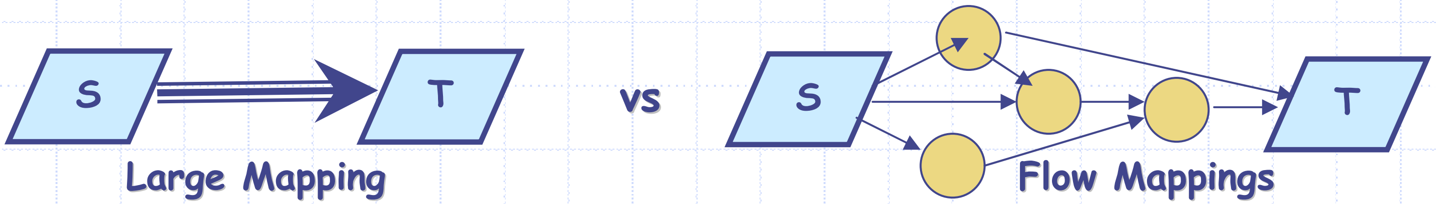
- We have developed tools and methods for:
  - mapping generation (including extensive work on schema matching),
  - mapping compilation into data transformation scripts
  - mapping-based query answering/rewriting, updates, invertibility
  - we are starting to make *small steps* towards interaction between the tools and the users
    - (e.g., visualization, debugging and explanation of mappings)
- We have also developed pieces of the theory (e.g., data exchange, query answering, composition, inversion)

So, what's missing ?

- A mapping is often only one piece of a larger set of components (other mappings, transformations, black-box procedures) that need to be orchestrated together.

- Why ? Several reasons, but they mainly have to do with **complexity of integration**:

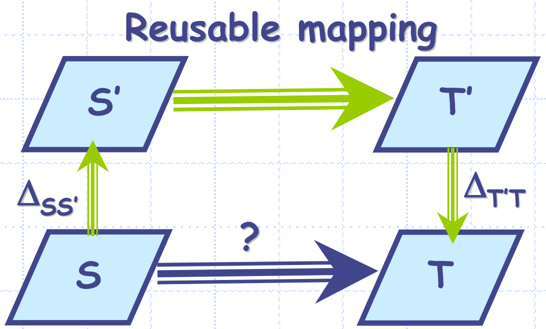
- 1) It may be easier to design a "flow" of small mappings that use intermediate results ("small" schemas) than a large complex mapping that goes directly from S to T.
  - The designer may not know what the target is or how to get there, so the transformation needs to be built incrementally in small steps
  - ETL and data mashup systems have the data flow flavor
    - but their level of abstraction is low (physical operators), with little opportunity for automation, optimization and reuse

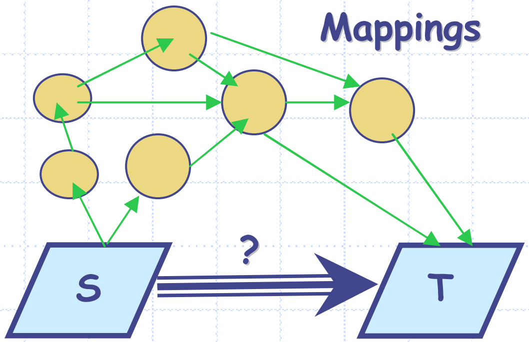


- 2) The schemas S and T are complex but are built out of smaller modules (e.g., types). It may be easier to map the types individually.
  - Need to assemble an umbrella mapping to invoke and correlate the smaller mappings (MapMerge)
  - (And this could go on multiple levels, if we have complex types)

"Type-to-type" mappings

- 3) Finally, there may already exist other reusable mappings out there. One of them may not work but putting together several of them may do the job.



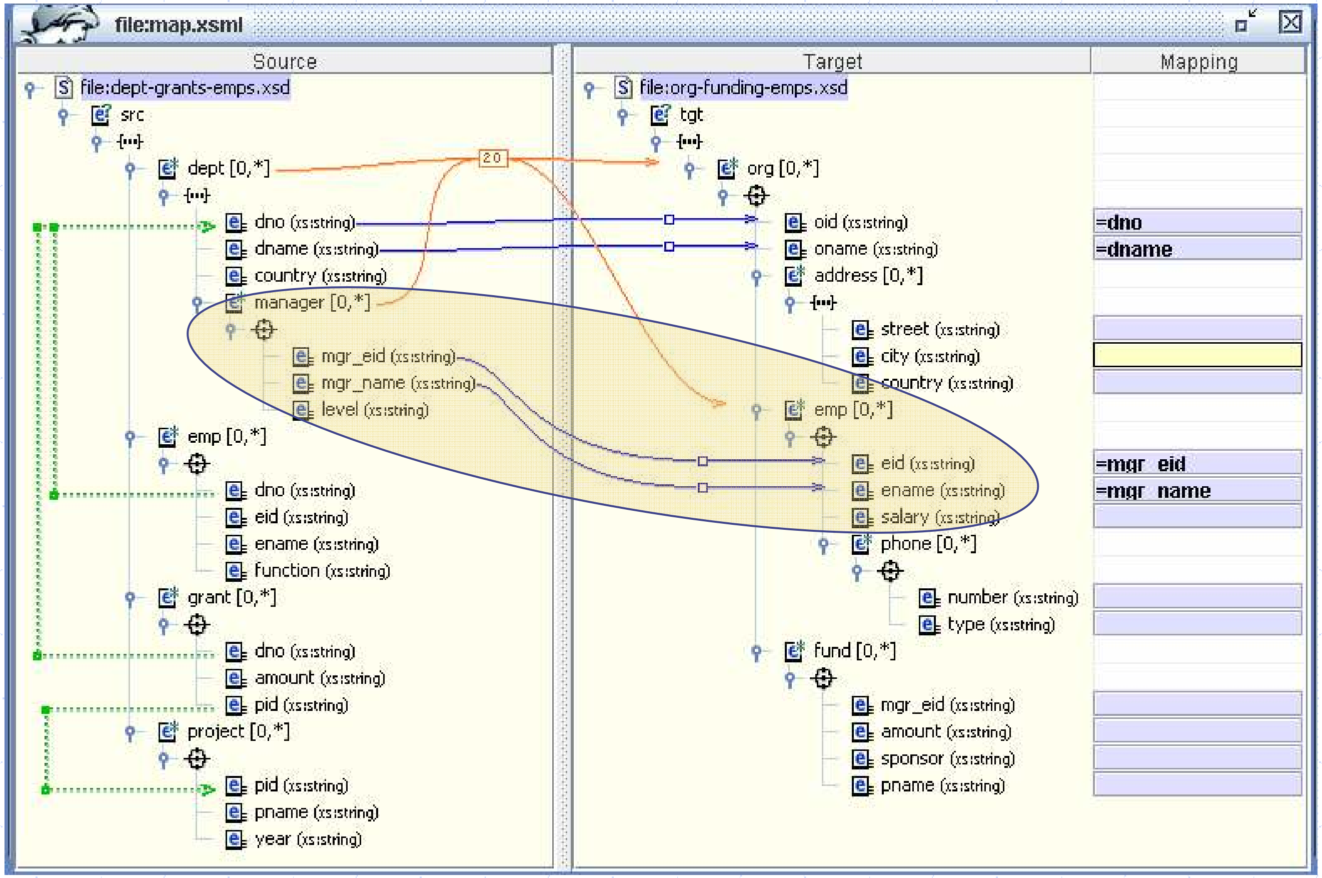


So, what's missing ?

- A system to support the semi-automatic assembly of complex integration flows (or large mappings) from existing small mappings
- Sharing and reuse of mappings within different integration applications
  - "Someone, somewhere, must have done something similar"
- (General theme: making our integration tools more usable and more modular)

Mapping Reuse

- First idea:
  - There are not that many ways in which a piece of data can be transformed from a certain type to another type
- Second idea:
  - Applications in the same domain tend to use the same "common" types of data (although the concrete representations may vary)
  - Example: most integration scenarios in the HR domain will manipulate data about employees, jobs, departments, etc.
  - Thus, there is a small set of common and frequently used types that are "buried" in a potentially large number of heterogeneous schemas



- "manager-emp": example of a small reusable mapping between two common types

Mappings in Terms of Common Types

- If all our mappings are saved and stored in terms of these common types, then there is a significant potential for reuse
  - Relatively few common types (and mappings) but huge number of concrete data sources and schemas
  - We just need to “adapt” them to various, concrete, schemas
    - In the example, a mapping between the “common type” of manager and the “common type” of employee is reused between two concrete schemas that “contain” manager and employee
- One key issue: how do we come up with the common types ?
  - Possibly, similar techniques used for schema integration,
  - There are already open source efforts towards standardizing (by popular consensus) the “common types”
    - Freebase (www.freebase.com)

Metadata Repository Challenges

- Metadata repository:
  - common types and their mappings,
  - concrete schemas and their mappings,
  - relationships between concrete schemas and common types

- Some of the issues:
  - Index/query the repository based on the common types
    - Find me all schemas about "employee"
  - Identify the "common types" in a concrete schema
    - What is this schema about ?
    - May require matching
  - Search for similar schemas in the repository
  - Search for mappings or paths of mappings between a source concrete schema and a target concrete schema
    - By finding similar schemas that may have mappings, or
    - By identifying common types and using them as intermediate nodes

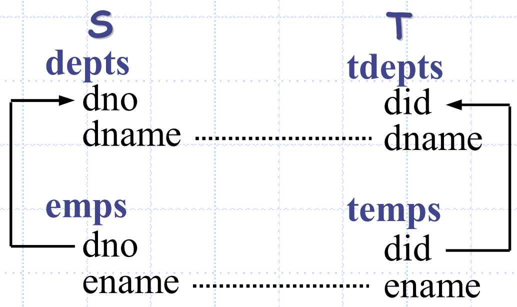
Example of Interaction with the Repository

- Suppose we need a mapping (or flow) from S to T
- Alternative 1:
  - Find schemas S_1, T_1 that are similar to S, T, respectively, and
  - Find paths of mappings in the repository that "connect" S_1 and T_1
  - Filter, compose, merge, union, or chose among the different mapping paths
- Alternative 2:
  - Find common types O_1, … O_k in schema S,
  - Find common types U_1, … U_l in schema T
  - Find mapping paths that connect $\{O_1, …, O_k\}$ to $\{U_1, …, U_l\}$
  - Filter, compose, merge, union, or chose among the different mapping paths
  - Note: merge is really needed here, since O_1, …, O_k are only components in S (similar for T and its components)

Operations on Mappings Become Essential

- There is a small set of operations on mappings that are essential for the “assembly” process
- Some of them are simple or relatively well-understood:
  - Union, filter, composition
- Other are relatively new or less understood:
  - Merge, inverse
  - Comparing alternative mapping paths (so that we can choose the “right” path)

More on MapMerge



"Dept" and "Emp" are the basic components in these schemas

Uncorrelated mappings (tgds):

depts (d, dn) $\rightarrow \exists$X tdepts(X, dn)

emps (d, en) $\rightarrow \exists$X (temps (X, en))

Could be adapted from some generic dept$\rightarrow$dept, emp$\rightarrow$emp mappings

Better mappings:

depts (d, dn) $\rightarrow \exists$X tdepts(X, dn)

depts (d, dn) $\wedge$ emps (d, en) $\rightarrow \exists$X (tdepts (X, dn) $\wedge$ temps (X, en))

Put emp$\rightarrow$emp mapping in the context by relating it to dept

An even better mapping:

depts (d, dn) $\rightarrow \exists$X (tdepts(X, dn)

$\wedge$ (emps (d, en) $\rightarrow$ temps (X, en))

)

Put emp$\rightarrow$emp mapping in the context by making it a submapping of dept$\rightarrow$dept

This is an example of a nested mapping [FHHMPP'06]

Concluding Remarks

- There are still many issues left unexplored on the semantics of mappings and their operations
  - Map merge may be more complex (may need user interaction)
  - What's the theory behind this ?
- There is still little we know on comparing and selecting between alternative mappings (or mapping paths)
  - Visualization and browsing of the alternatives is essential
- There is significant potential for automation by enabling mapping reuse
  - Types and their mappings → finer granularity than monolithic schema mappings, better abstraction
  - Types are closer to application logic
- Flows are important