Model Management 2.0: Manipulating Richer Mappings

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Data Programmability

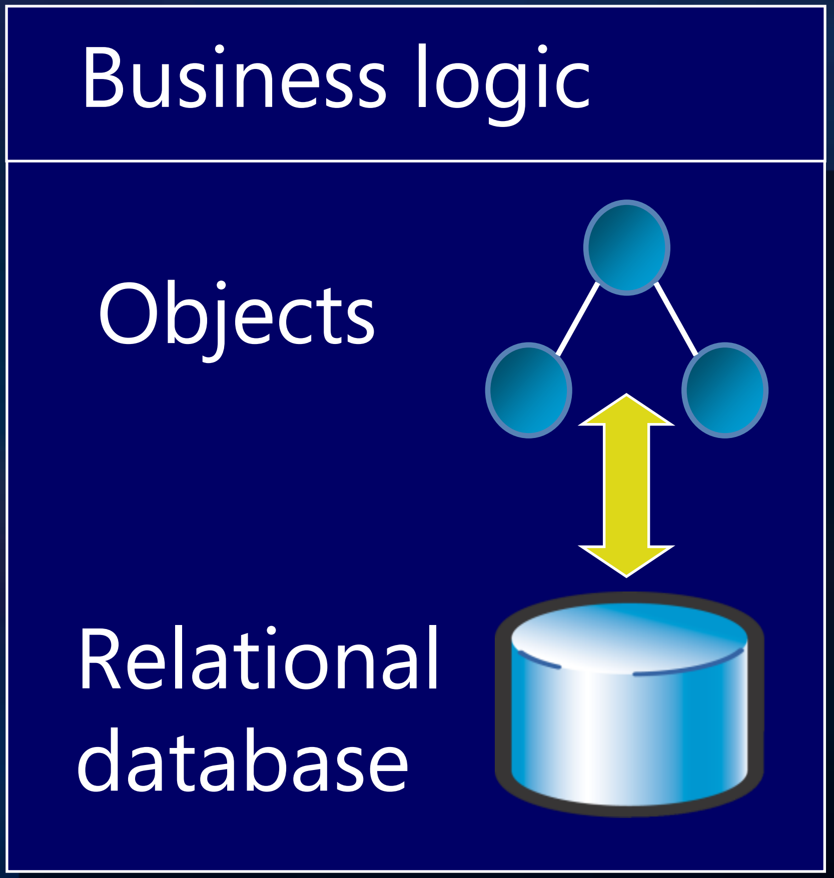
- Make it easier to write programs that access databases
- Traditionally, for large IT departments
- Much progress, but it's still ~40% of the work
- Core problem is developing and using complex mappings between schemas

Mapping Problems are Pervasive
And it's a Growth Industry

- Data translation
- XML message mapping
- Data warehouse loading
- Query mediators
- Forms managers
- Report writers
- Query designers
- Object-relational wrappers
- Portal generation from DB
- OLAP databases
- Application integration
- Composing web services

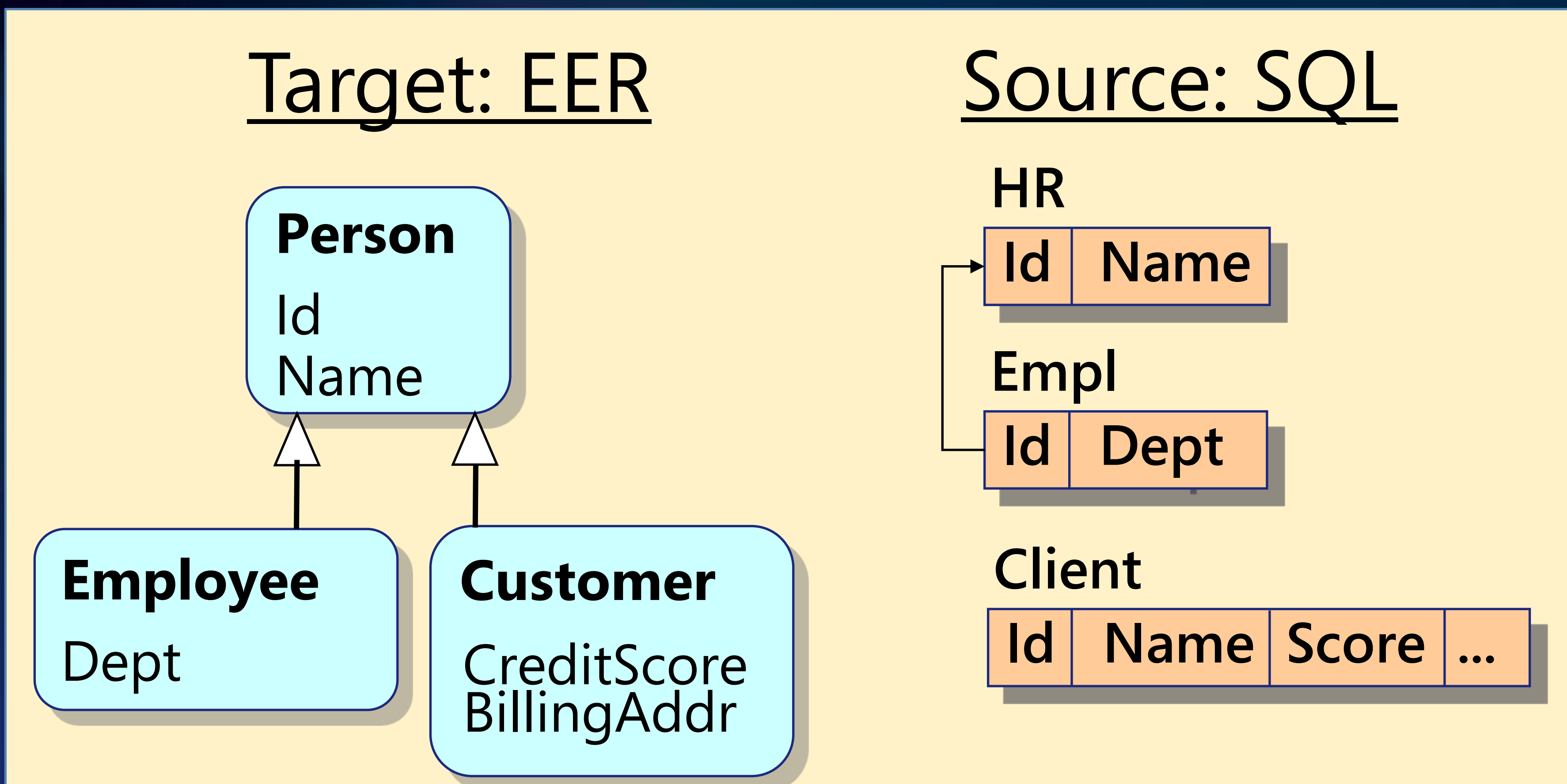
Object-Relational Wrappers

- Most packaged business apps need to access an OO view of relational data
- Requires an OR mapping



An Example Mapping

- Person = HR $\cup\ \pi_{ID,Name}$(Client)
- Employee = HR $\bowtie$ Empl
- Customers = Client



Constructing Persons

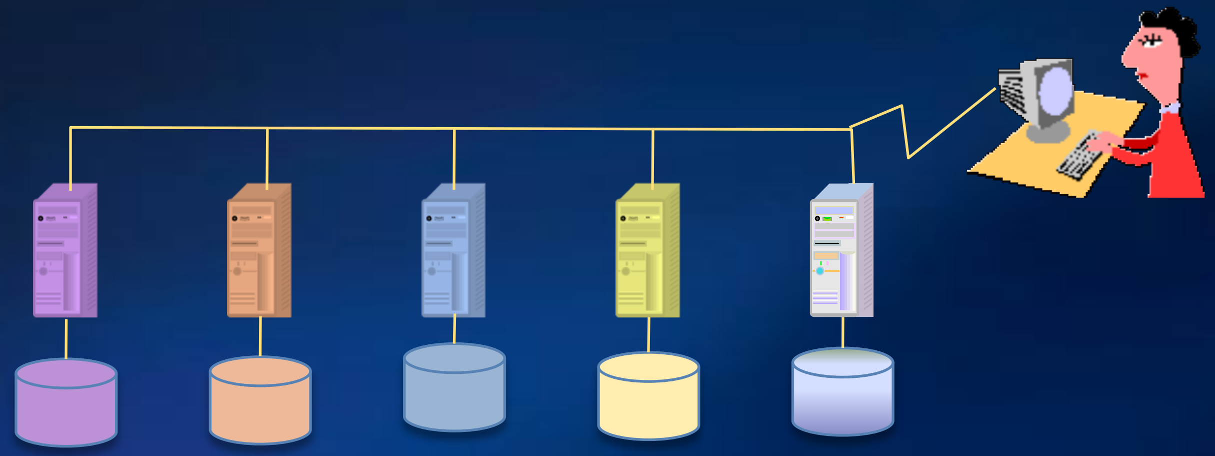
[Melnik, Adya, Bernstein, SIGMOD 07]

```
SELECT VALUE
    CASE
      WHEN (T5._from2 AND NOT(T5._from1))   THEN Person(T5.Person_Id, T5.Person_Name)
      WHEN (T5._from1 AND T5._from2)
         THEN Employee(T5.Person_Id, T5.Person_Name,  T5.Employee_Dept)
         ELSE Customer(T5.Person_Id, T5.Person_Name,  T5.Customer_CreditScore,
                 T5.Customer_BillingAddr)
    END
FROM (   (SELECT T1.Person_Id, T1.Person_Name,  T2.Employee_Dept,
                   CAST(NULL AS SqlServer.int) AS Customer_CreditScore,
                   CAST(NULL AS SqlServer.nvarchar) AS Customer_BillingAddr, False AS _from0,
                   (T2._from1 AND T2._from1 IS NOT NULL) AS _from1,  T1._from2
          FROM  ( SELECT  T.Id AS Person_Id, T.Name AS Person_Name, True AS _from2
                    FROM HR AS T) AS T1
                    LEFT OUTER JOIN (
                      SELECT  T.Id AS Person_Id,  T.Dept AS Employee_Dept, True AS _from1
                      FROM dbo.Empl AS T) AS T2
                   ON T1.Person_Id = T2.Person_Id )
          UNION ALL (
                   SELECT  T.Id AS Person_Id,  T.Name AS Person_Name,
                          CAST(NULL AS SqlServer.nvarchar) AS Employee_Dept,
                          T.Score AS Customer_CreditScore,  T.Addr AS Customer_BillingAddr,
                          True AS _from0,  False AS _from1,  False AS _from2
                   FROM Client AS T)
     ) AS T5
```

Why is mapping hard?

[Haas, ICDT 07]

- Heterogeneity
- Impedance mismatch
- Insufficient abstraction
- Potpourri of tools

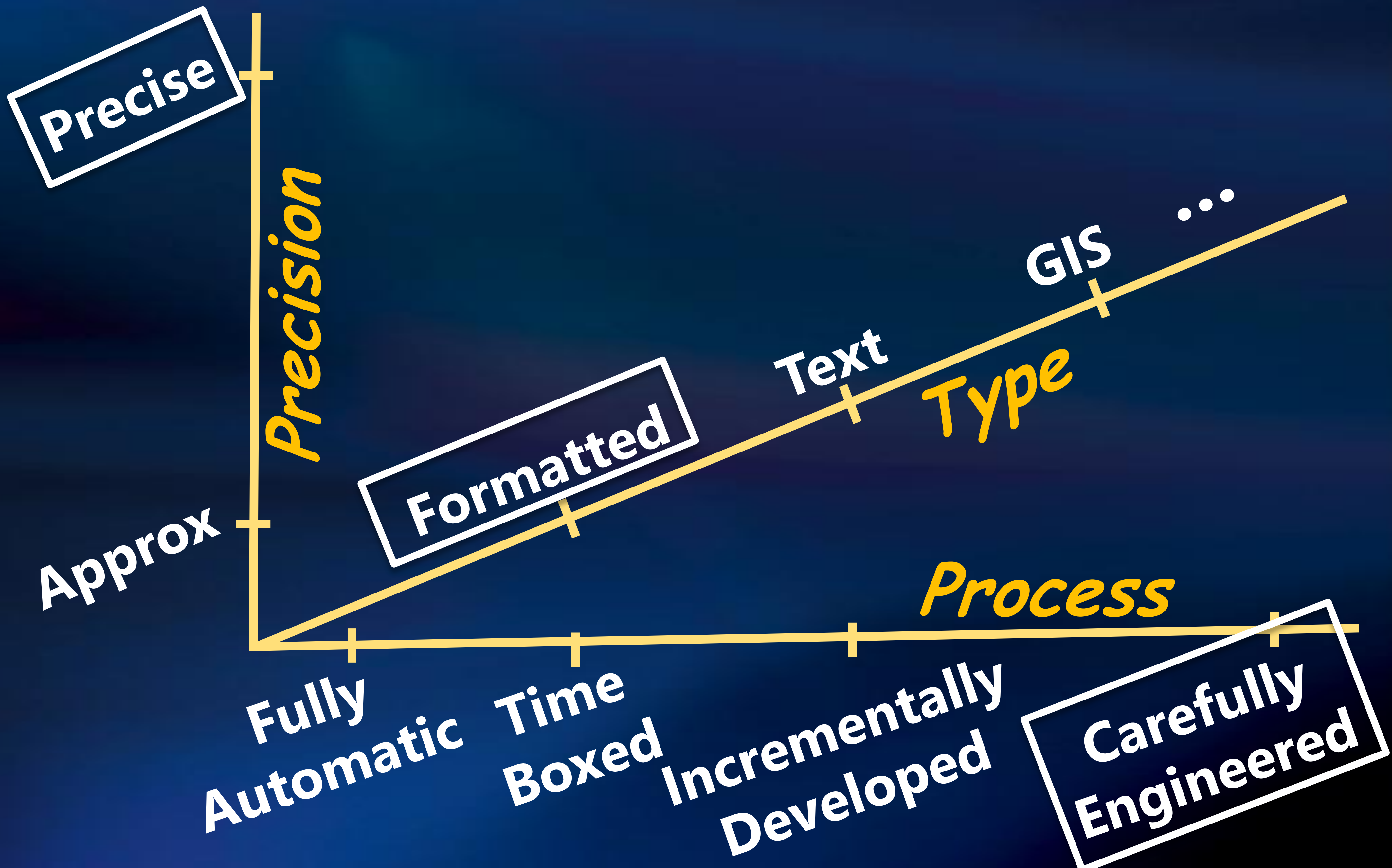


And It's Getting Harder

- More data models
  - Java, ODMG, XSD, .NET
  - RDF, OWL, EDM, SML
- More programming languages
- More types of tools
- More schema sources
  - Web site wrappers
  - Google Base
  - Generic info extractors [Gubanov, Bernstein WebDB 06]

Mapping Space

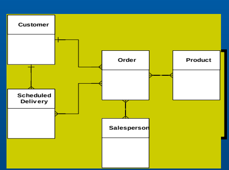
Info Integration Workshop
http://db.cis.upenn.edu/iiworkshop/



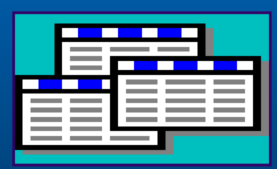
Model Management 1.0

[Bernstein, Halevy, Pottinger
SIGMOD Record 00]

Manipulate
models & mappings
as bulk objects



mapping

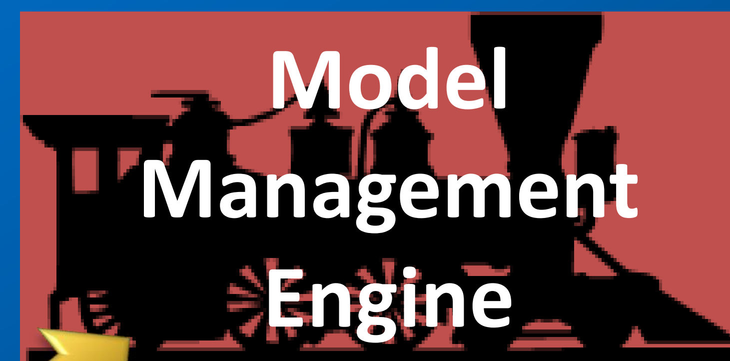


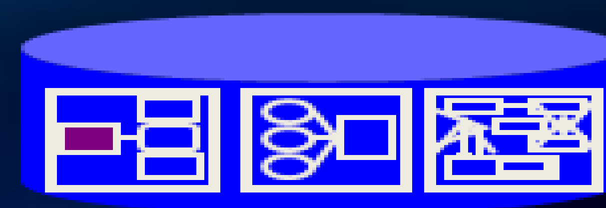
Meta-model independent
- relational, ER, OO, XML, RDF, OWL, SML, …

Operations
- Match
- Compose
- Merge
- Diff/Extract
- ModelGen
- Inverse

Tools

Wrapper Generator | Query Mediator | ETL





Metadata Repository

Model Management 1.0 Benefits

- More research focus on primary operations
  - More powerful operations
  - Hence better tools
- More leverage from tool investments
- More uniform behavior across tools

Good News / Bad News

- Good News
  - Lots of progress on operations
  - Some practical applications
  - A lot has been learned
- Bad News
  - Still waiting for the first reasonably-complete practical implementation
- Good news
  - A lot of research left to do

Outline

- What has changed: Use richer mappings
- What has changed: Include the runtime
- Model Management 2.0 in detail

What Has Changed?
Use Richer Mappings

2000
Structural mappings

- Mappings are structural
  - Relate schemas, *not* data
- Operations oblivious to mapping semantics
- Semantics is a plug-in

2007
Semantic mappings

- Mappings are semantic
  - Relate schemas *and* data
- Operations sensitive to mapping semantics
- Semantics is built-in

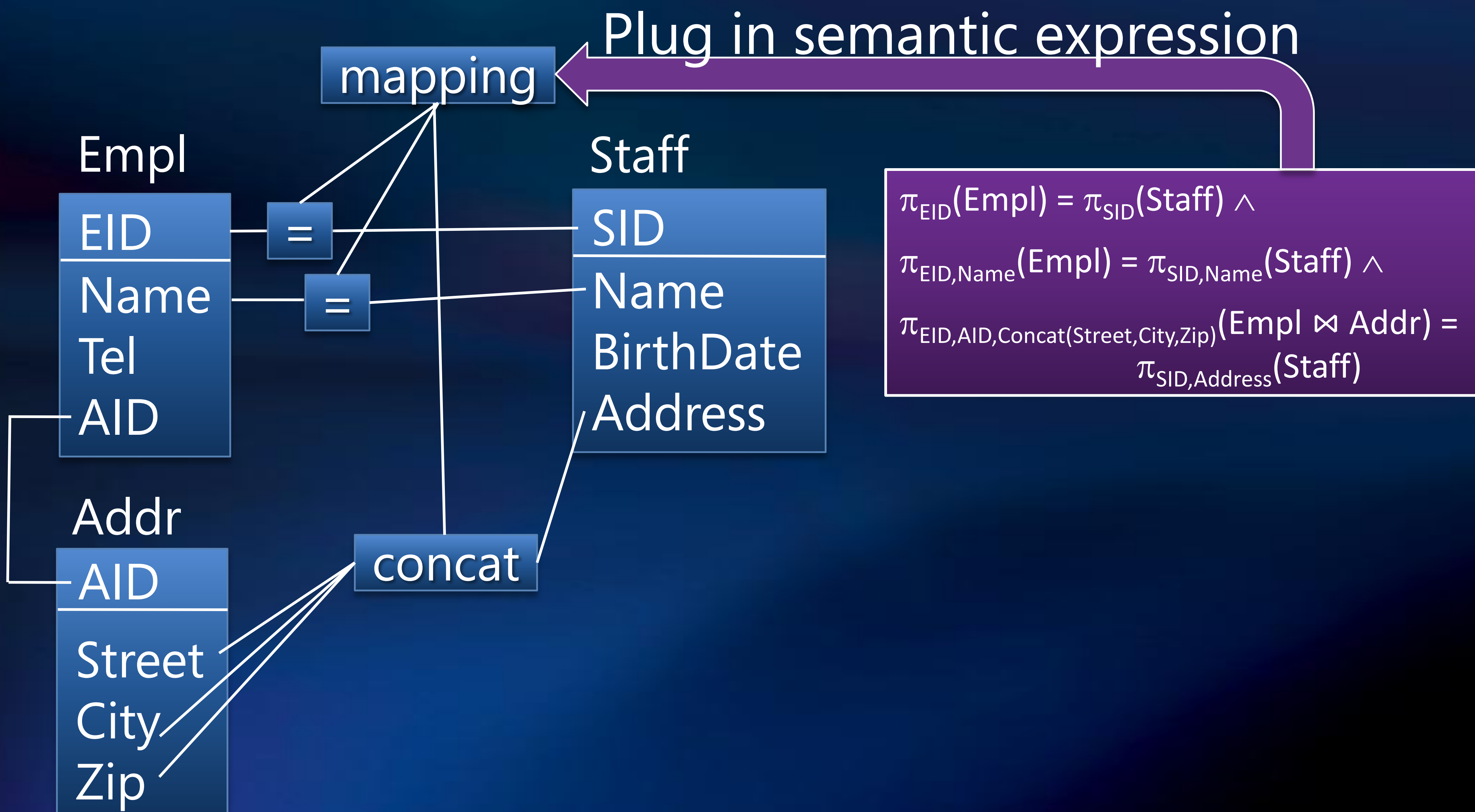
Semantic Mapping

- $\mathbb{I}(S_1)$ are the instances of schema S_1
  - Each d in $\mathbb{I}(S_1)$ is a database (e.g., a set of relations)
- $\mathbb{I}(S_2)$ are the instances of schema S_2
- $\text{map}_{12} \subseteq \mathbb{I}(S_1) \times \mathbb{I}(S_2)$
- Usually, we represent a mapping by an expression
  - $V = R \bowtie S$
  - $R \bowtie S = T \bowtie U$

Example

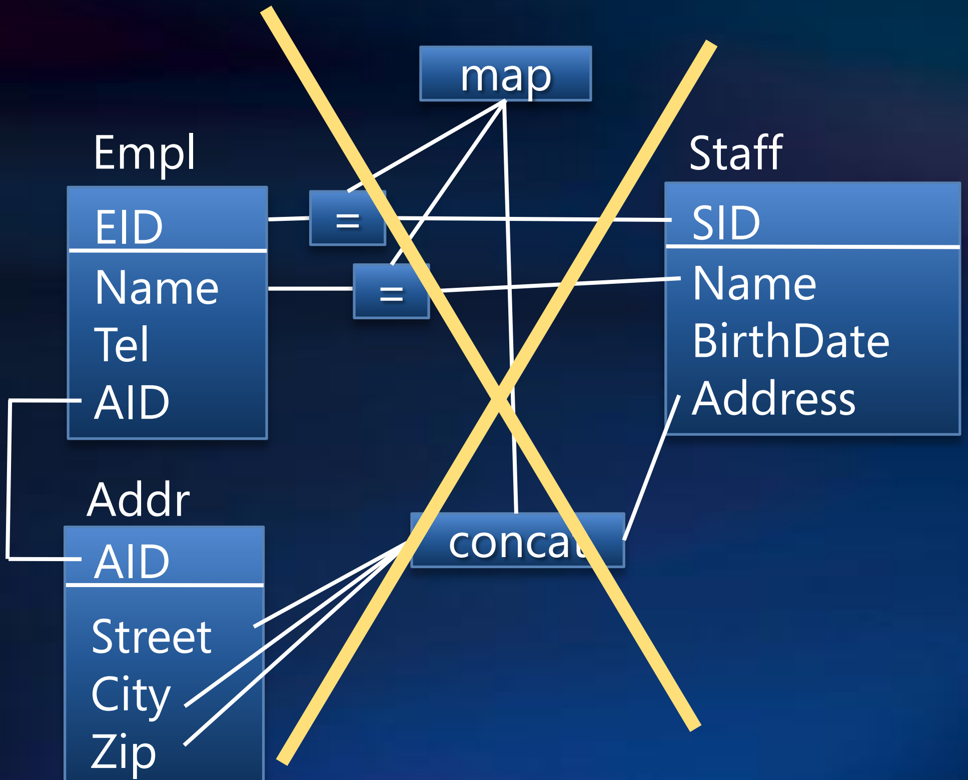
In 2000, mapping is a structure

[Bernstein. CIDR 03]



Example

In 2007, just use the expression



$$\pi_{EID}(Empl) = \pi_{SID}(Staff) \wedge$$

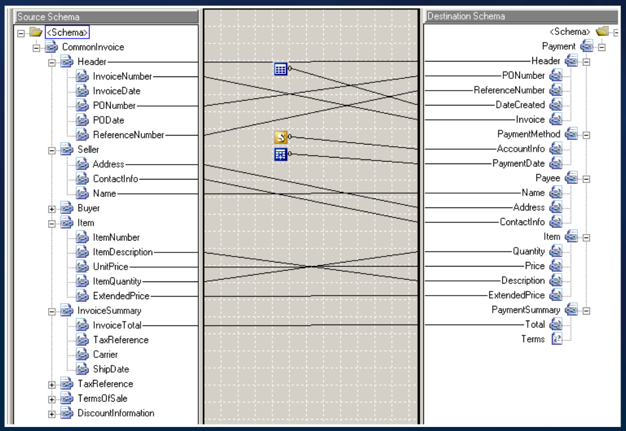
$$\pi_{EID,Name}(Empl) = \pi_{SID,Name}(Staff) \wedge$$

$$\pi_{EID,AID,Concat(Street,City,Zip)}(Empl \bowtie Addr) = \pi_{SID,Address}(Staff)$$

Mappings

[Casanova, Vidal. PODS 83] [Catarci, Lenzerini. J. CoopIS 93]
[Biskup, Convent. SIGMOD 86] [Miller, Haas, Hernandez. VLDB 00]

- Element correspondences
  - First step in aligning schemas
  - For lineage & impact analysis
  - Weak or no formal semantics



- Mapping constraints relate instances of schemas
  - E.g., equality of relational expressions

```
SELECT Id, Name, Dept  =  SELECT Id, Name, Dept
FROM   Employee           FROM HR JOIN Empl ON Id
```

- Transformation is an executable mapping constraint
  - Constructs target instances from source instances
  - E.g., SQL query, XSLT, C# program

Mapping Expressiveness

- What we want: first-order logic with
  - aggregation
  - set and bag semantics
  - regular expressions
  - nested collections and lists
  - rich type constructors
    (e.g., to construct XML fragments),
  - user-defined functions
  - deduplication and other heuristic functions
- What can we handle? … Much less.

Parallel Evolution

Clio Project

- IBM, Univ. of Toronto, U.C. Santa Cruz
- Miller, Haas, Hernandez, Fagin, Ho, Popa, Tan, …

Model Management

- Microsoft, Univ. of Washington, Univ. of Leipzig
- Bernstein, Halevy, Pottinger, Rahm, Madhavan, Melnik, …

Build a design tool for semantic mappings

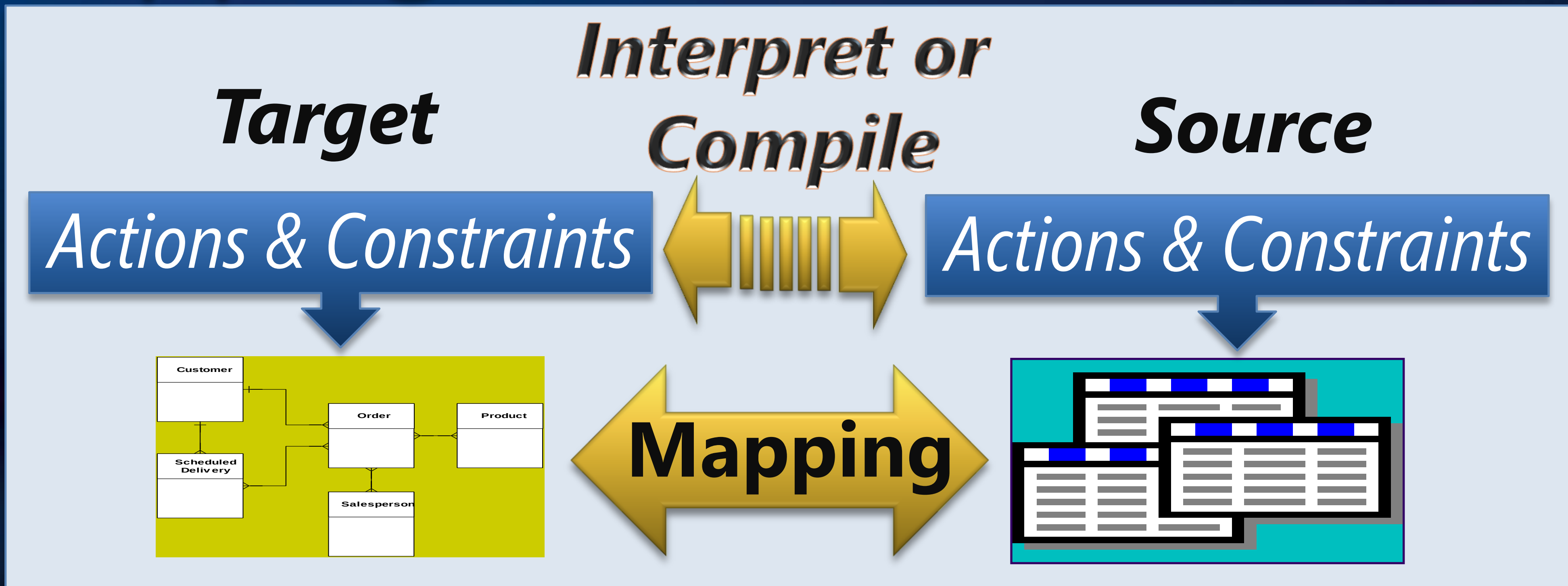
Build model management operations with plug-in semantics

Study model management operations with semantics

What Has Changed?
Include the Runtime

2000 Design-time	2007 Run-time
• Model management is independent of run-time	• Model management is tied to a run-time
• No special run-time functionality	• Run-time functions are sensitive to mapping expressiveness and model mgt capabilities

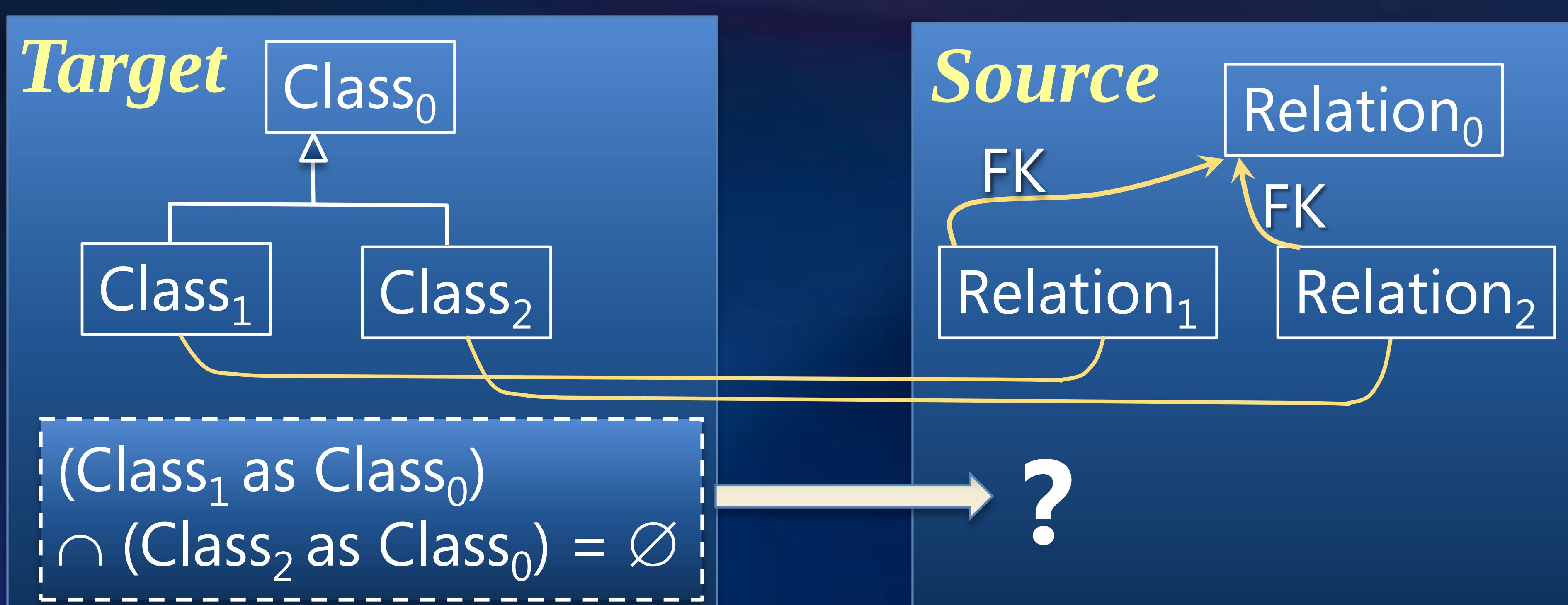
Mapping Runtime



- Queries
- Updates
- Peer-to-peer
- Provenance
- Access Control
- Integrity constraints
- Synch logic
- Business logic
- Debugging
- Errors
- Indexing
- Notifications
- Batch loading
- Data exchange

Mapping Runtime Examples

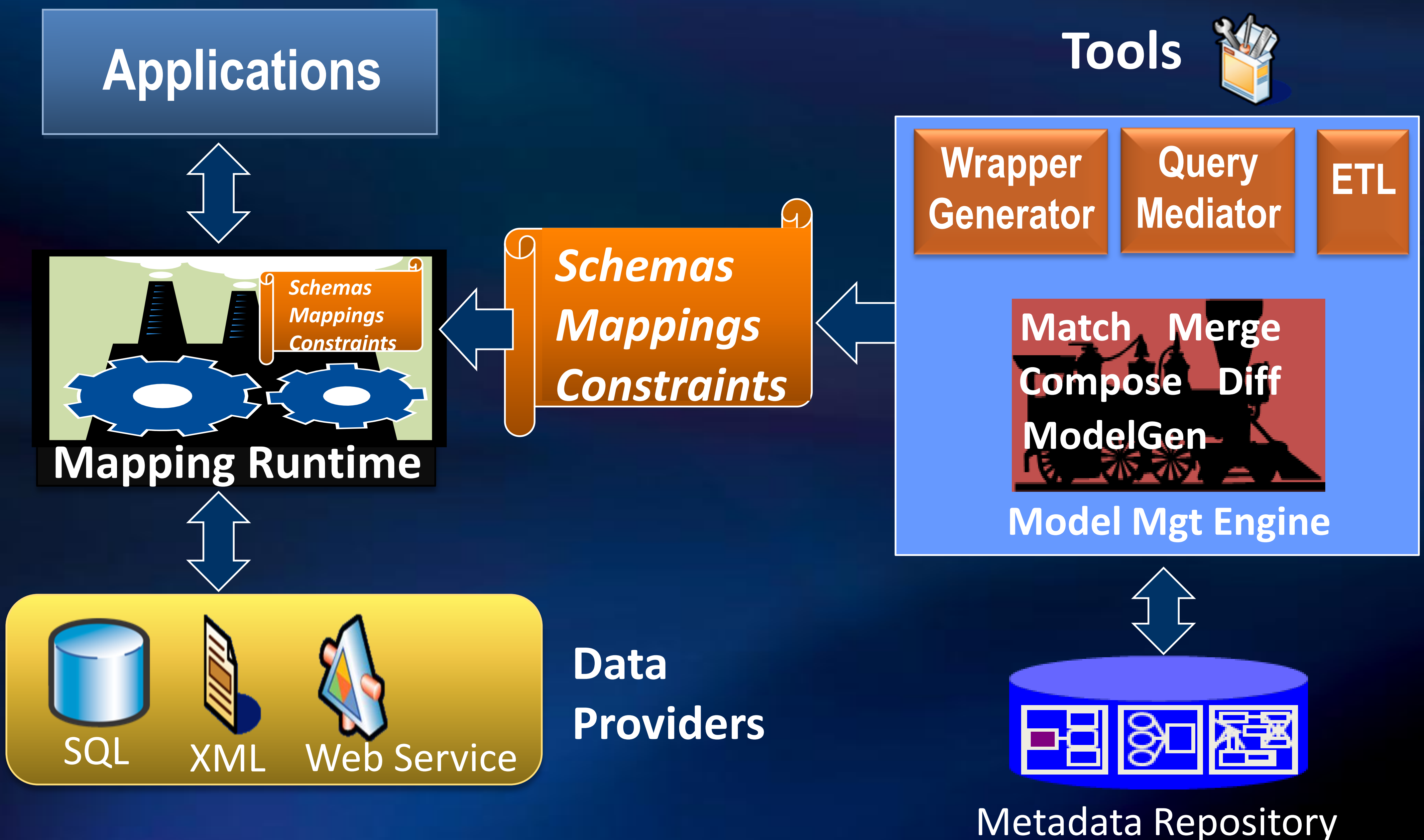
- Integrity constraints
  - Integrity constraints on target T are enforced by a combination of constraints enforced by the source and by the target runtime.
  - Feasibility - some constraints on T may not be expressible in source S.



Mapping Runtime Examples (2)

- Provenance [Cui, Widom, Weiner. TODS 00] [Baghwat, Chiticariu, Tan, Vijayvargia. VLDB J. 05] [Buneman, Chapman, Cheney. SIGMOD 06]
  - User moves data from source S to target T
  - Which source data contributed to a particular target data item?
- Errors
  - A data access via T is translated into an access on S that generates an error
  - The error needs to be passed back through the mapping in a form that is understandable in the context of T.

Model Management 2.0



Scenarios

1. **Create mappings**
   - Match
   - ConstraintGen
   - TransGen
   - ModelGen

2. **Evolve mappings**
   - Compose
   - Diff
   - Merge
   - Inverse

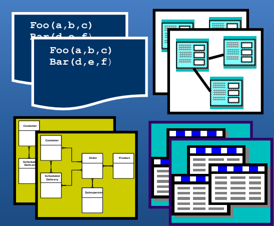
Schema Matching

- Exploit lexical analysis of element names, schema structure, data types, thesauri, value distributions, ontologies, instances, and previous matches
- Past Goal - improved precision & recall
  - Big productivity gains are unlikely
- Better goals
  - Return top-k, not best overall match
  - Avoid the tedium. Manage work.
  - HCI – handle large schemas.
  - User studies – what would improve productivity?

Cast of Thousands

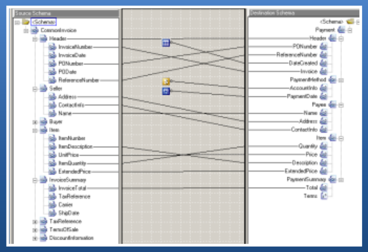
- AnHai Doan
- Alon Halevy
- Pedro Domingos
- Phil Bernstein
- Erhard Rahm
- Sergey Melnik
- Jayant Madhavan
- Jeffrey Naughton
- Jaewoo Kang
- Tova Milo
- Pavel Shvaiko
- Fausto Giunchiglia
- Sonia Bergamaschi
- Silvana Castano
- Bin He
- Kevin Chang
- Namyoun Choi
- Il-Yeol Song
- Hyoil Han
- Domenico Ursino
- Luigi Palopoli
- Dominico Sacca
- Georgio Terracina
- David Embley
- David Jackman
- Li Xu
- Yihong Ding
- Jacob Berlin
- Amihai Motro
- Hong Hai Do
- Fabien Duchateau
- Zohra Mellahsene
- Ela Hunt
- Toralf Kirsten
- Andreas Thor
- Alexander Bilke
- Avigdor Gal
- Michalis Petropoulos
- Christoph Quix
- Chris Clifton
- Arnie Rosenthal
- Wen-Syan Li
- Hector Garcia-Molina
- Sagit Zohar
- Gio Wiederhold
- Anna Zhdanova
- Jerome Euzenat
- Prasenjit Mitra
- Natasha Noy
- Anuj Jaiswal
- Mikalai Yatskevich
- Nuno Silva
- Joao Rocha
- David Aumueller
- Sabine Massmann
- Felix Naumann

Code Generation Scenarios [Miller, Haas, & Hernandez, VLDB 00]

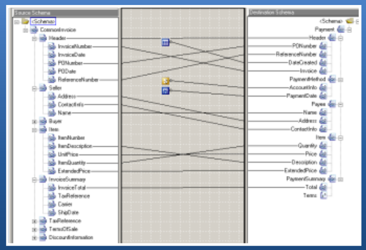


Models

Match



Correspondences



Correspondences

ConstraintGen

Select ord#, prod#, cust#
From Shipped
=
Select ord#, prod#, cust#
From Order Join Item
on ord#

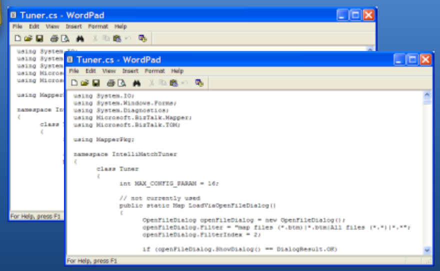
Constraints

?

Select ord#, prod#, cust#
From Shipped
⊆
Select ord#, prod#, cust#
From Order Join Item
on ord#

Constraints

TransGen



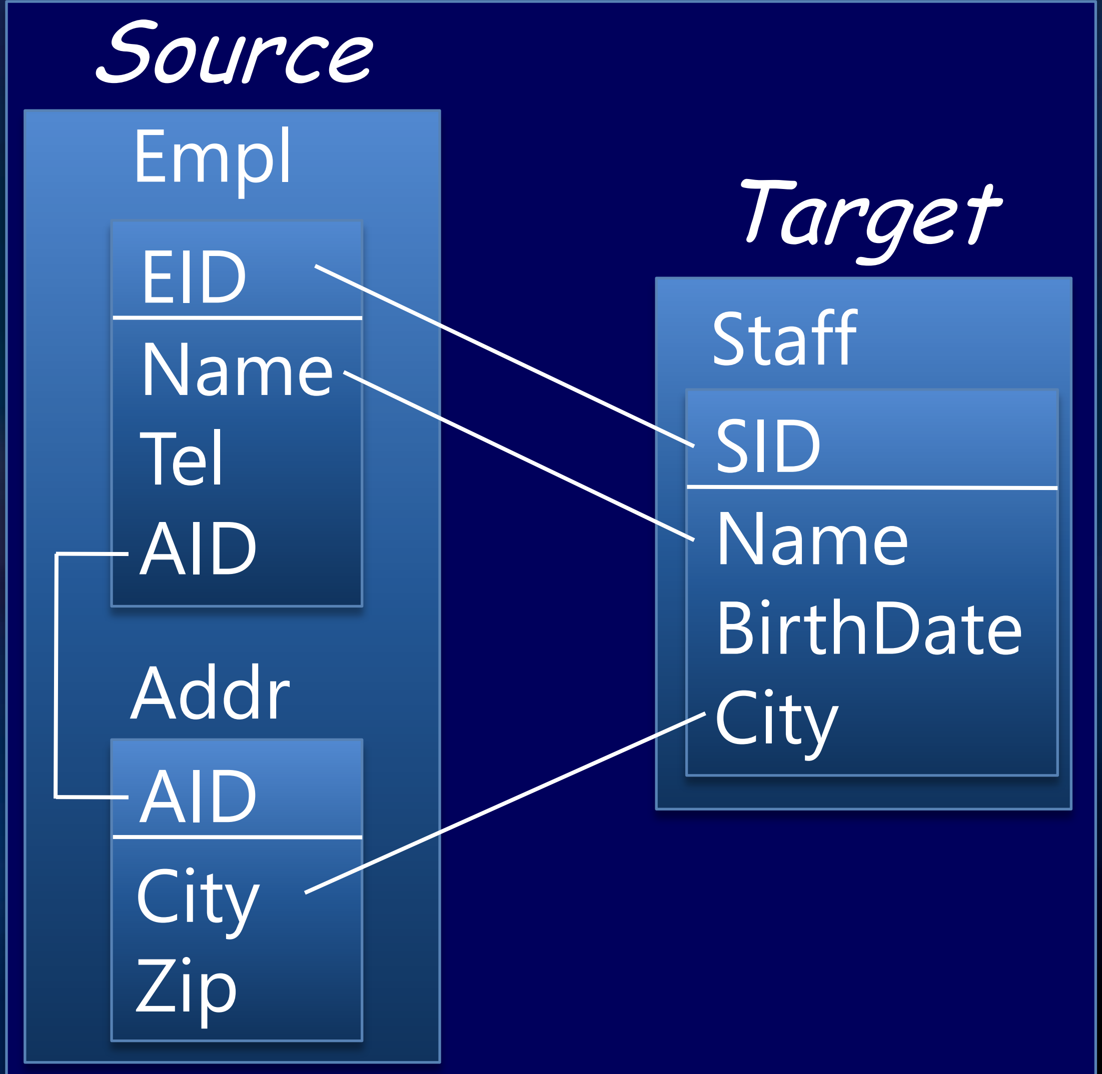
Transformations

Correspondences → Transformations

[Popa, Velegrakis, Miller, Hernandez, Fagin. VLDB 02]
[Velegrakis. PhD thesis 2005]

For a given target element

- Find all source elements linked by correspondences
- Find all ways that source elements are related
- Choose one of them and generate the transformation

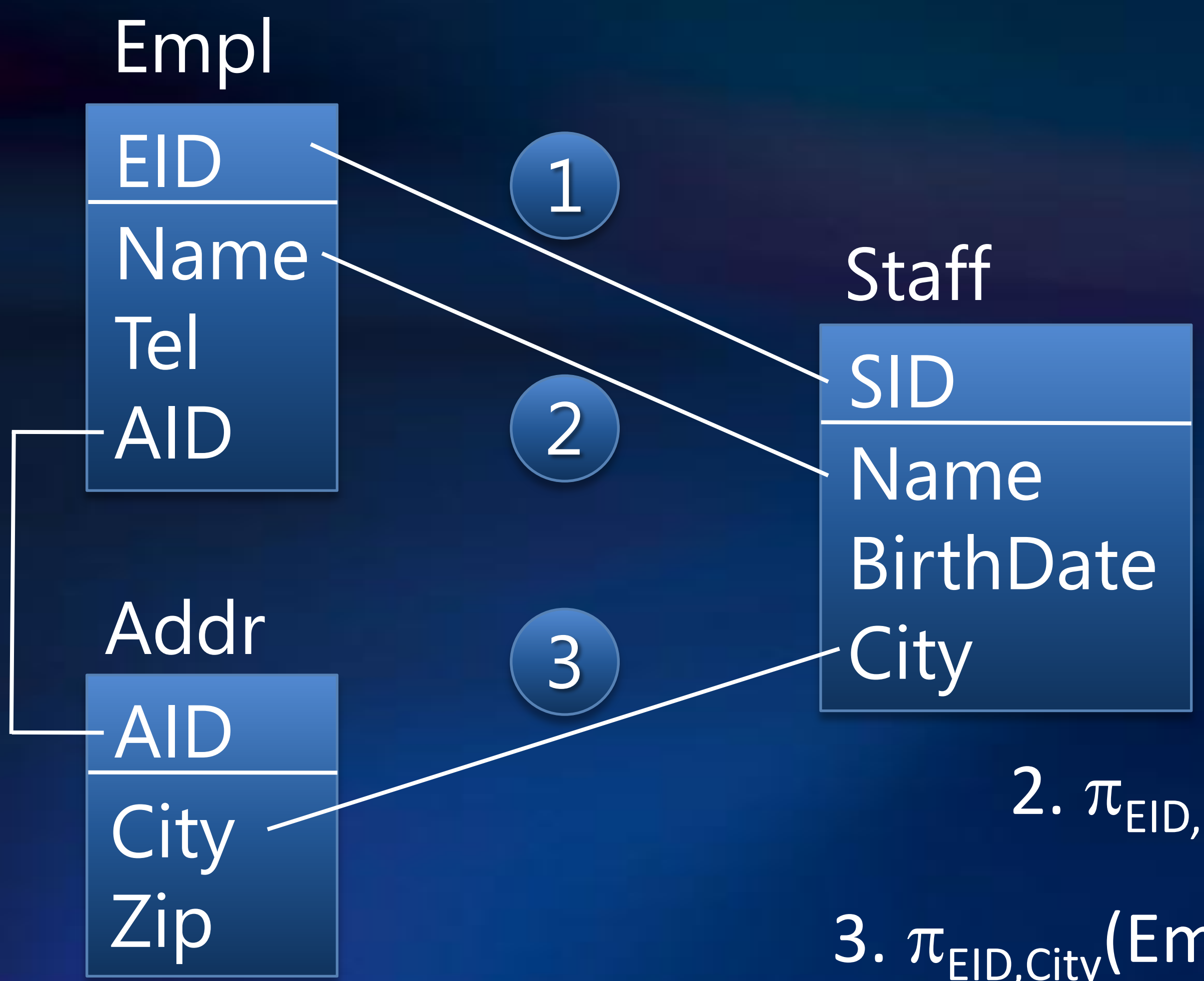


$$\pi_{SID,Name,City}(Staff) = \pi_{EID,Name,City}(Empl \bowtie Addr)$$

Correspondences → Constraints

[Melnik, Bernstein, Halevy, & Rahm, SIGMOD 05]

- Directly interpret correspondences as mapping constraints
- If it's a tree schema and keys correspond

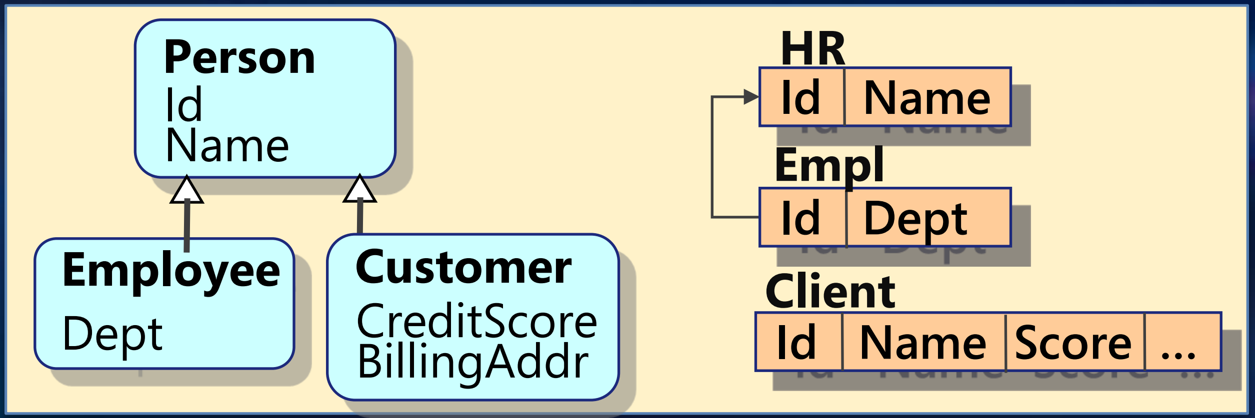


1. $\pi_{EID}(Empl) = \pi_{SID}(Staff)$

2. $\pi_{EID,Name}(Empl) = \pi_{SID,Name}(Staff)$

3. $\pi_{EID,City}(Empl \bowtie Addr) = \pi_{SID,City}(Staff)$

ADO.NET EER-to-SQL



Mapping Constraints

```
SELECT p.Id, p.Name
FROM Persons AS p
WHERE p IS OF (ONLY Person)
  OR p IS OF (ONLY Employee)
```

=

```
SELECT Id, Name
FROM dbo.HR
```

```
SELECT e.Id, e.Dept
FROM Persons AS e
WHERE e IS OF Employee
```

=

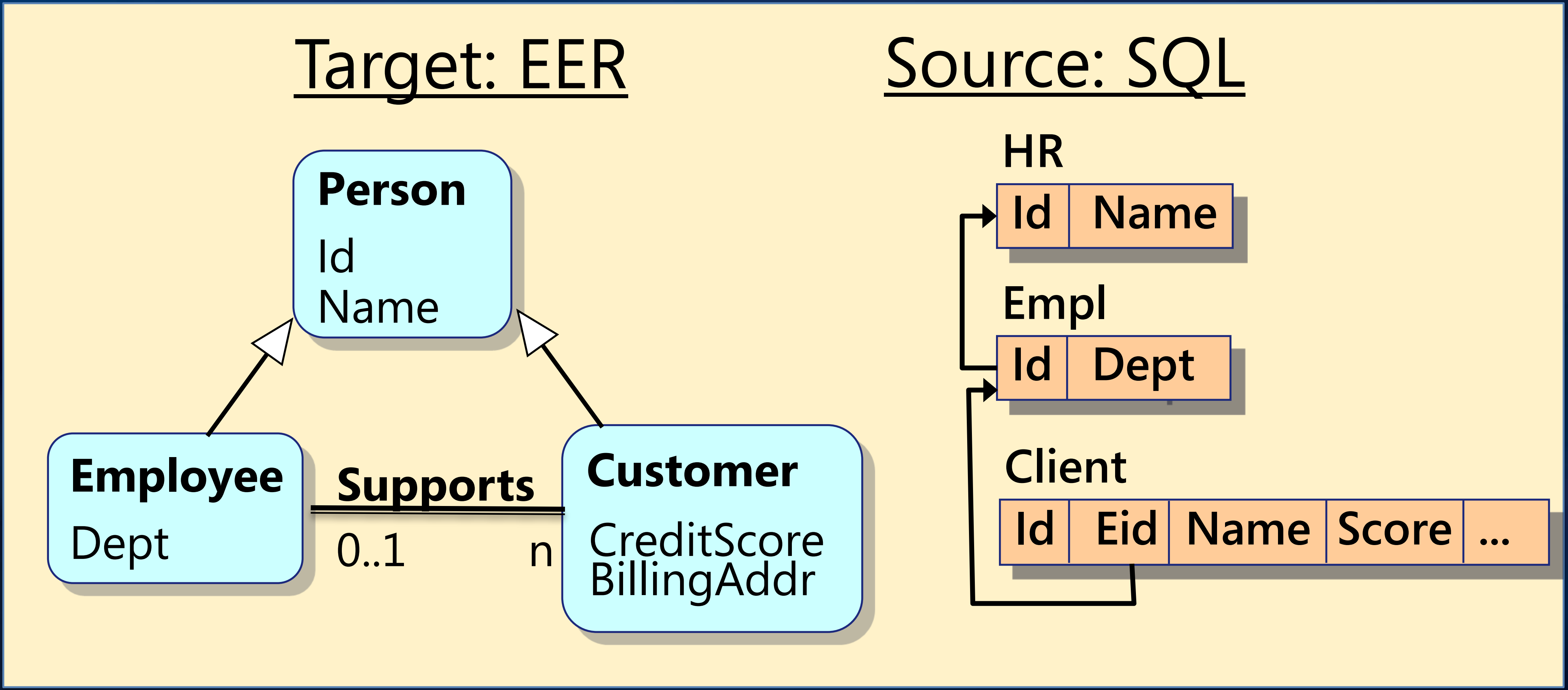
```
SELECT Id, Dept
FROM dbo.Empl
```

```
SELECT c.Id, c.Name,
  c.CreditScore, c.BillingAddr
FROM Persons AS c
WHERE c IS OF Customer
```

=

```
SELECT Id, Name,
          Score, Addr
FROM dbo.Client
```

A Relationship Constraint



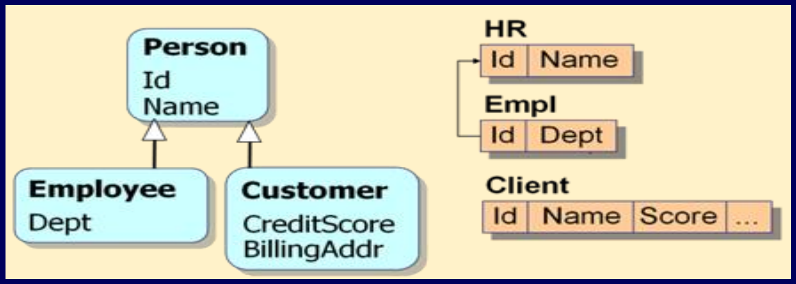

```
SELECT Key(s.Customer).Id,
       Key(s.Employee).Id
FROM Supports s
```

=

```
SELECT Cid, Eid
FROM Client
WHERE Eid IS NOT NULL
```

Constraints → Transformations

[Melnik, Adya, Bernstein, SIGMOD 07]




```
SELECT p.Id, p.Name
FROM Persons AS p
WHERE p IS OF (ONLY Person)
  OR p IS OF (ONLY Employee)
=
SELECT Id, Name
FROM dbo.HR
```

```
SELECT e.Id, e.Dept
FROM Persons AS e
WHERE e IS OF Employee
=
SELECT Id, Dept
FROM dbo.Empl
```

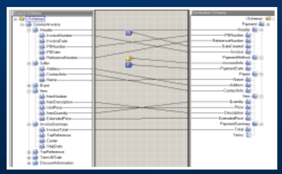
```
SELECT c.Id, c.Name,
  c.CreditScore, c.BillingAddr
FROM Persons AS c
WHERE c IS OF Customer
=
SELECT Id, Name,
       Score, Addr
FROM dbo.Client
```

```
SELECT VALUE
    CASE
      WHEN (T5._from2 AND NOT(T5._from1))  THEN Person(T5.Person_Id,
T5.Person_Name)
      WHEN (T5._from1 AND T5._from2)
        THEN Employee(T5.Person_Id, T5.Person_Name, T5.Employee_Dept)
        ELSE Customer(T5.Person_Id, T5.Person_Name, T5.Customer_CreditScore,
            T5.Customer_BillingAddr)
    END
  FROM (  (SELECT T1.Person_Id, T1.Person_Name, T2.Employee_Dept,
                CAST(NULL AS SqlServer.int) AS Customer_CreditScore,
                CAST(NULL AS SqlServer.nvarchar) AS Customer_BillingAddr, False AS
                 _from0,
                (T2._from1 AND T2._from1 IS NOT NULL) AS _from1,  T1._from2
          FROM ( SELECT  T.Id AS Person_Id, T.Name AS Person_Name, True AS
                 _from2
                FROM HR AS T) AS T1
                LEFT OUTER JOIN (
                  SELECT  T.Id AS Person_Id,  T.Dept AS Employee_Dept, True AS
                   _from1
                  FROM dbo.Empl AS T) AS T2
                ON T1.Person_Id = T2.Person_Id )
          UNION ALL (
                SELECT  T.Id AS Person_Id,  T.Name AS Person_Name,
                       CAST(NULL AS SqlServer.nvarchar) AS Employee_Dept,
                       T.Score AS Customer_CreditScore,  T.Addr AS
Customer_BillingAddr,
                       True AS _from0,  False AS _from1,  False AS _from2
                FROM Client AS T)
        ) AS T5
```

Constraints → Transformations (2)

- Difficulty depends on
  - Whether the constraints are functions
  - The transformation language (e.g., SQL, XSLT)
  - Expressiveness of constraints
  - Optimization required

ADO.NET O/R Mapping [Melnik, Adya, Bernstein SIGMOD 07]



Correspondences

Select ord#, prod#, cust#
From Shipped
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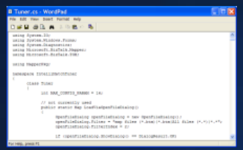
Select ord#, prod#, cust#
From Order Join Item
on ord#

Constraints



Transformations

- Declarative mapping language
  - Allows non-expert users to specify complex mappings
  - Formal semantics
- Bidirectional views
  - Uniform, efficient runtime
  - Simplifies dev & test
- Updates via view maintenance
  - Arbitrary updates
  - Uses view maintenance technology

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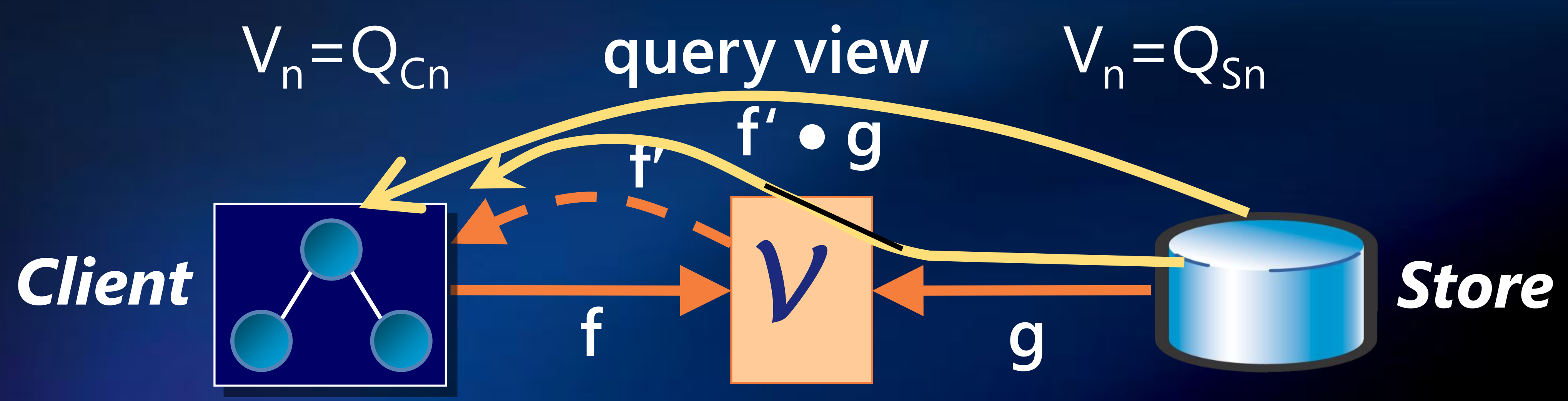
Compiling Constraints

- Mapping: $\{Q_{C1}=Q_{S1}, \ldots, Q_{Cn}=Q_{Sn}\}$
- E.g., f: SELECT p.Id, p.Name FROM **Persons** p = g: SELECT Id, Name FROM ClientInfo

- f: $V_1=Q_{C1} \cup$
  $V_2=Q_{C2} \cup$
  …
  $V_n=Q_{Cn}$

- g: $V_1=Q_{S1} \cup$
  $V_2=Q_{S2} \cup$
  …
  $V_n=Q_{Sn}$



Composition

$$\underbrace{S_1 \stackrel{map_{12}}{\rule{2cm}{0.4pt}} S_2 \stackrel{map_{23}}{\rule{2cm}{0.4pt}} S_3}_{map_{12} \,\bullet\, map_{23}}$$

$\mathbb{I}(S_1)$ are the instances of schema S_1

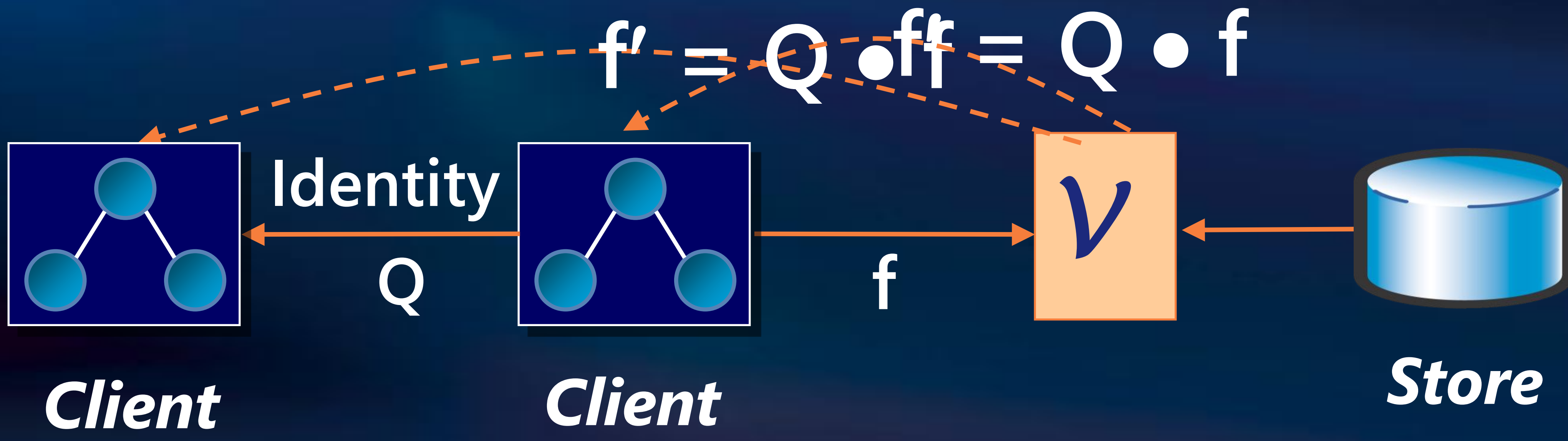
$map_{12} \subseteq \mathbb{I}(S_1) \times \mathbb{I}(S_2)$ $\qquad$ $map_{13} \subseteq \mathbb{I}(S_2) \times \mathbb{I}(S_3)$

$$map_{13} = \{<d_1 \in \mathbb{I}(S_1), d_3 \in \mathbb{I}(S_3)> \mid \\ \exists\, d_2 \in \mathbb{I}(S_2)\ (<d_1, d_2> \in map_{12}) \\ \wedge\ (<d_2, d_3> \in map_{23})\ \}$$

Well known examples

- View unfolding $S_1 \xrightarrow{v} S_2 \xrightarrow{q} S_3$
- Answering queries using views $S_1 \xleftarrow{v} S_2 \xrightarrow{q} S_3$

Computing f' from f



- Use query rewriting to compute f′ from f
- This is mapping composition.

Scenarios

1. **Create mappings**
   - ✓ Match
   - ✓ ConstraintGen
   - ✓ TransGen
   - **ModelGen**

2. **Evolve mappings**
   - Compose
   - Diff
   - Merge
   - Inverse

ModelGen: Schema Translation

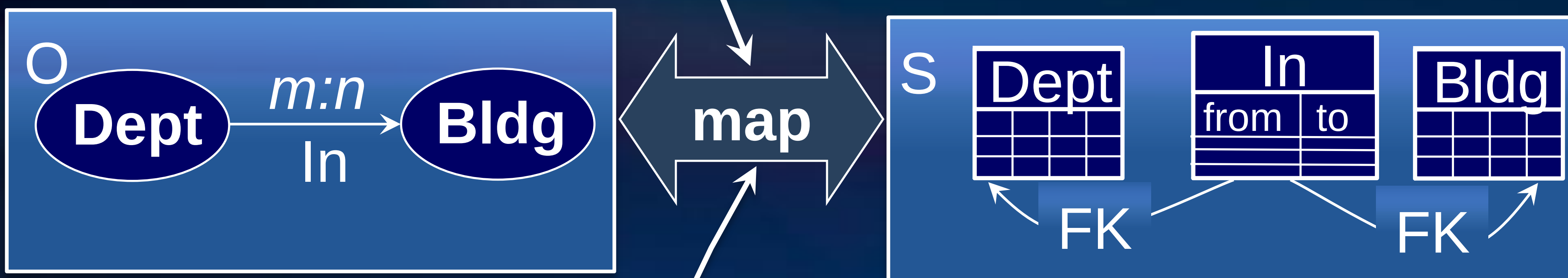
Input
- source model
- target metamodel

Output
- target model
- constraints

[Atzeni, Torlone. EDBT 96]
[Bernstein, Melnik, Mork. VLDB 05]
[Atzeni, Cappellari, Bernstein. EDBT 06]

OO schema

SQL schema

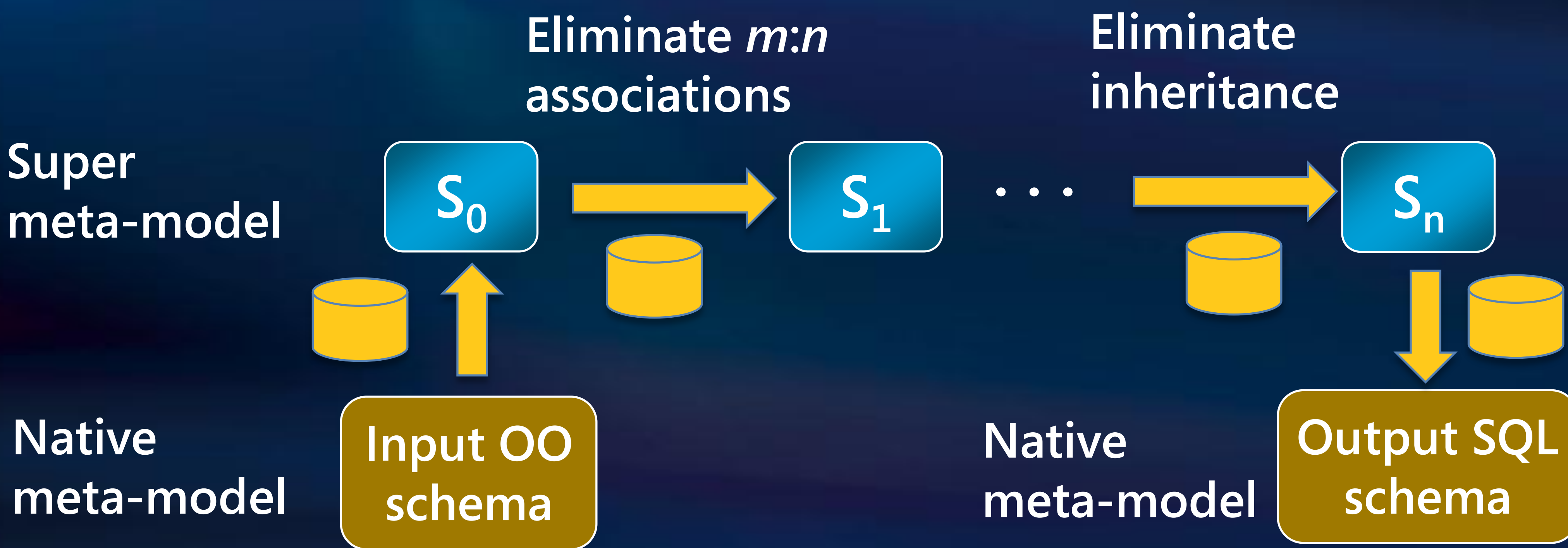


O.Dept(d) ⇔ S.Dept(d.key)
O.Bldg(b) ⇔ S.Bldg(b.key)
O.In(d,b) ⇔ S.In(d.key, b.key)

- There are several credible prototypes
  - Don't know of products, yet

Implementing ModelGen

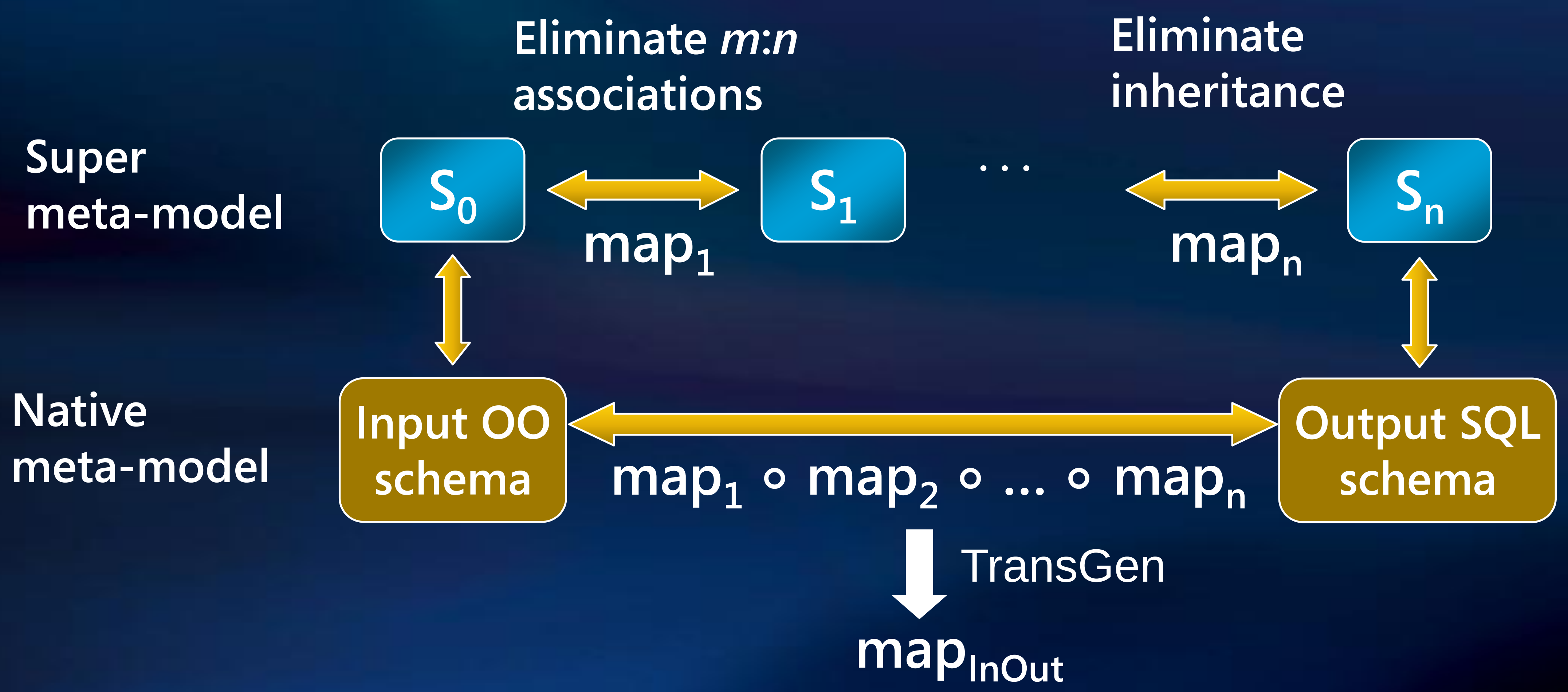
[Atzeni, Torlone]
[Papotti, Torlone]
[Atzeni, Cappellari]



- Data is transferred to super-metamodel DB
- Data is transformed within super-metamodel DB
- Data is transferred to output schema's database

Obtaining Mappings From ModelGen

[Bernstein, Melnik, Mork VLDB'05, ER'07]



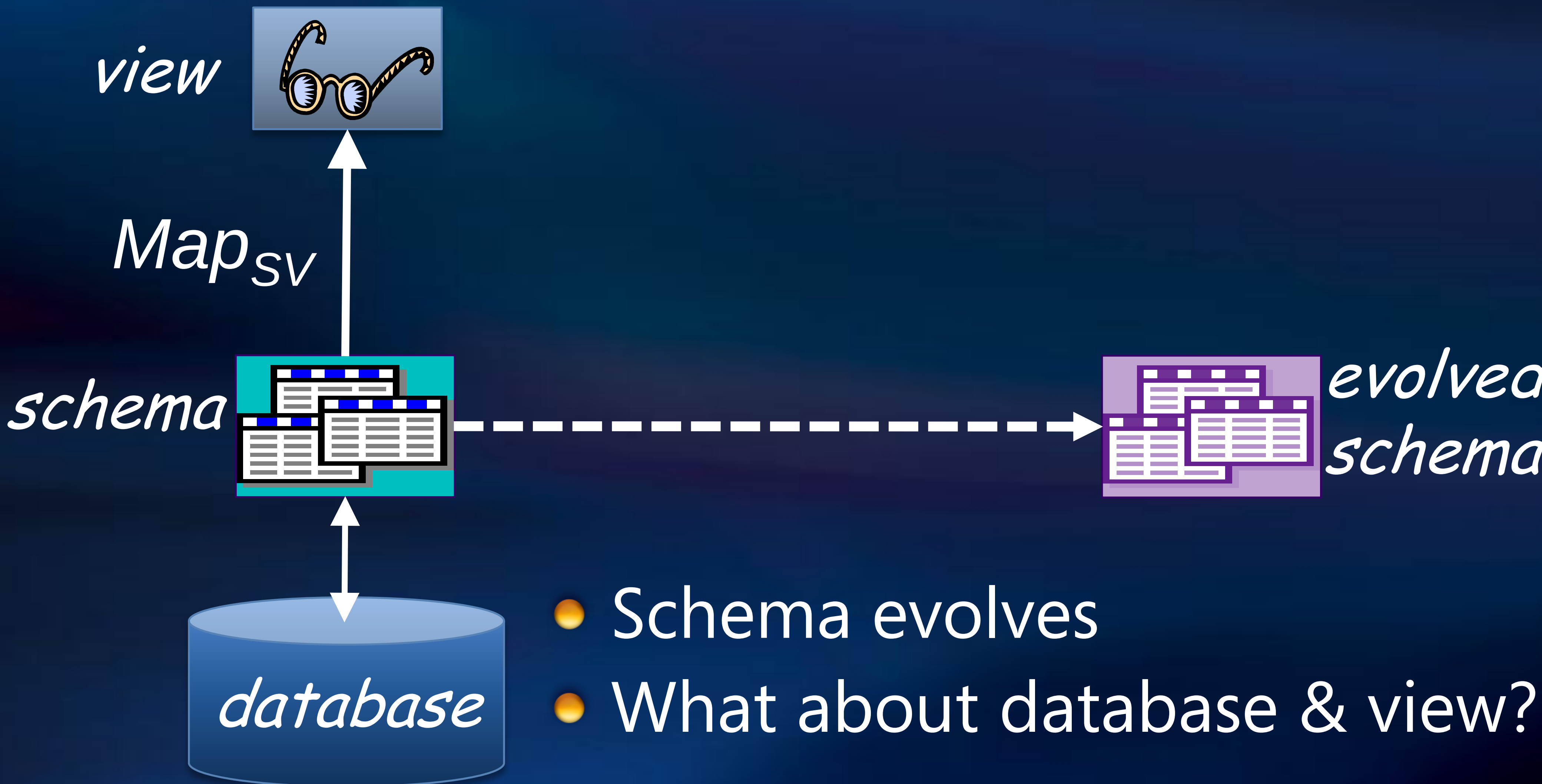
- Leverages Compose operator
- Each map_i roundtrips data

Scenarios

1. Create mappings
- ✓ Match
- ✓ ConstraintGen
- ✓ TransGen
- ✓ ModelGen

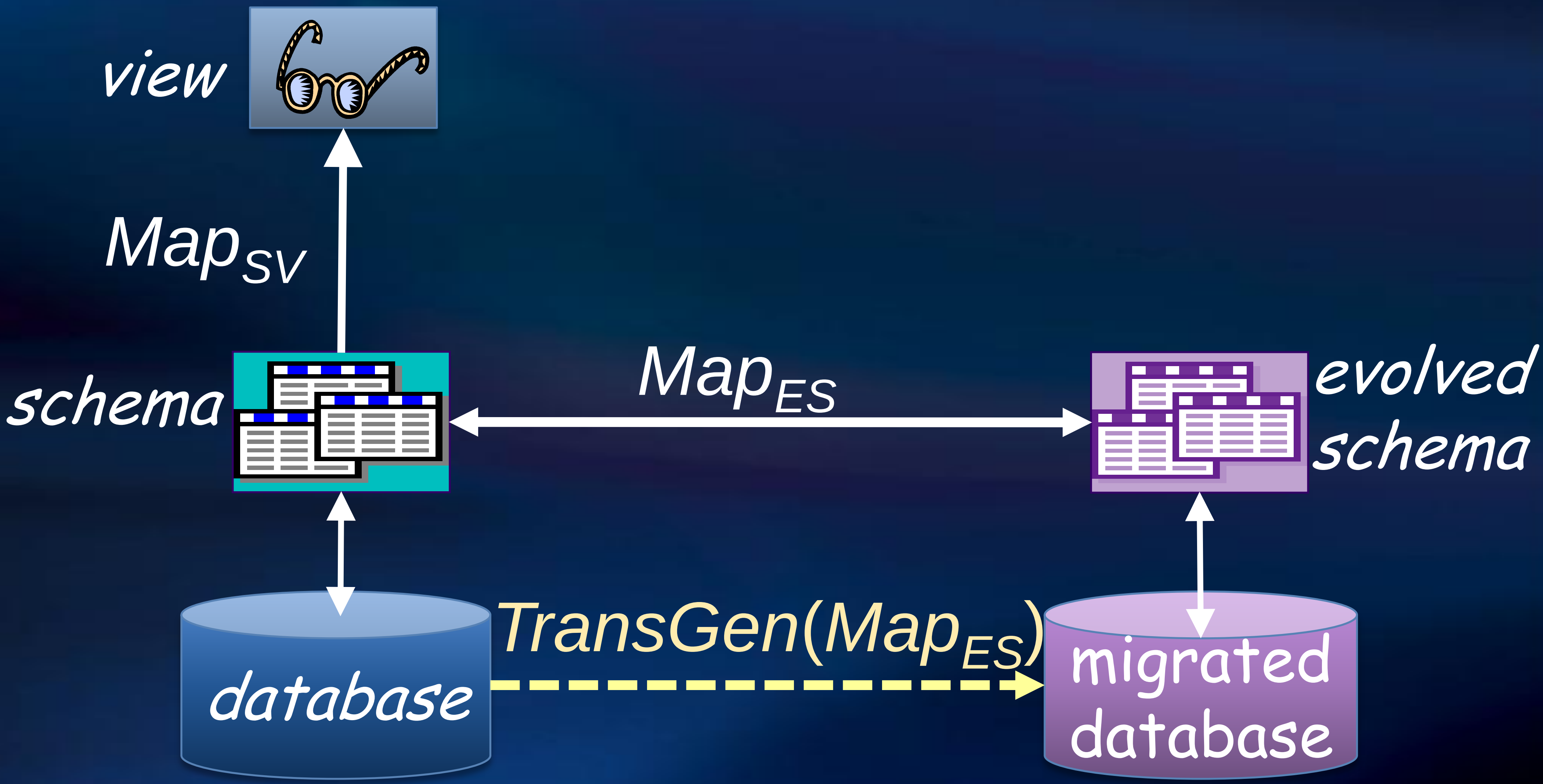
2. Evolve mappings
- Compose
- Diff
- Merge
- Inverse

Schema Evolution [Rahm, Bernstein. SIGMOD Rec. Dec 06]



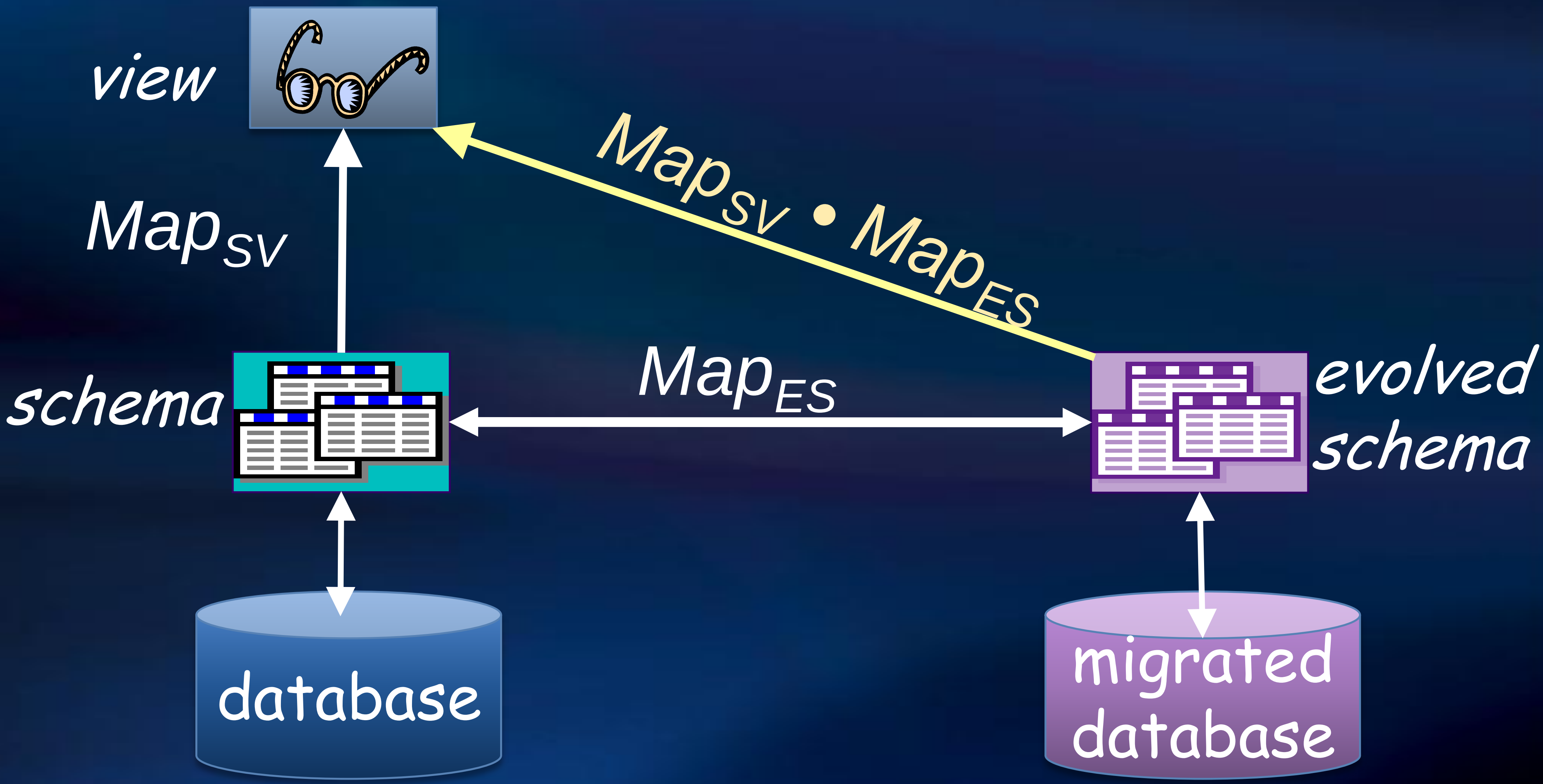
- Schema evolves
- What about database & view?

Data Migration



1. Create mapping: *schema* ⇔ *evolved schema*
2. Generate a transformation

View Migration



- Compose Map_{SV} and Map_{ES} to connect *view* to *evolved schema*

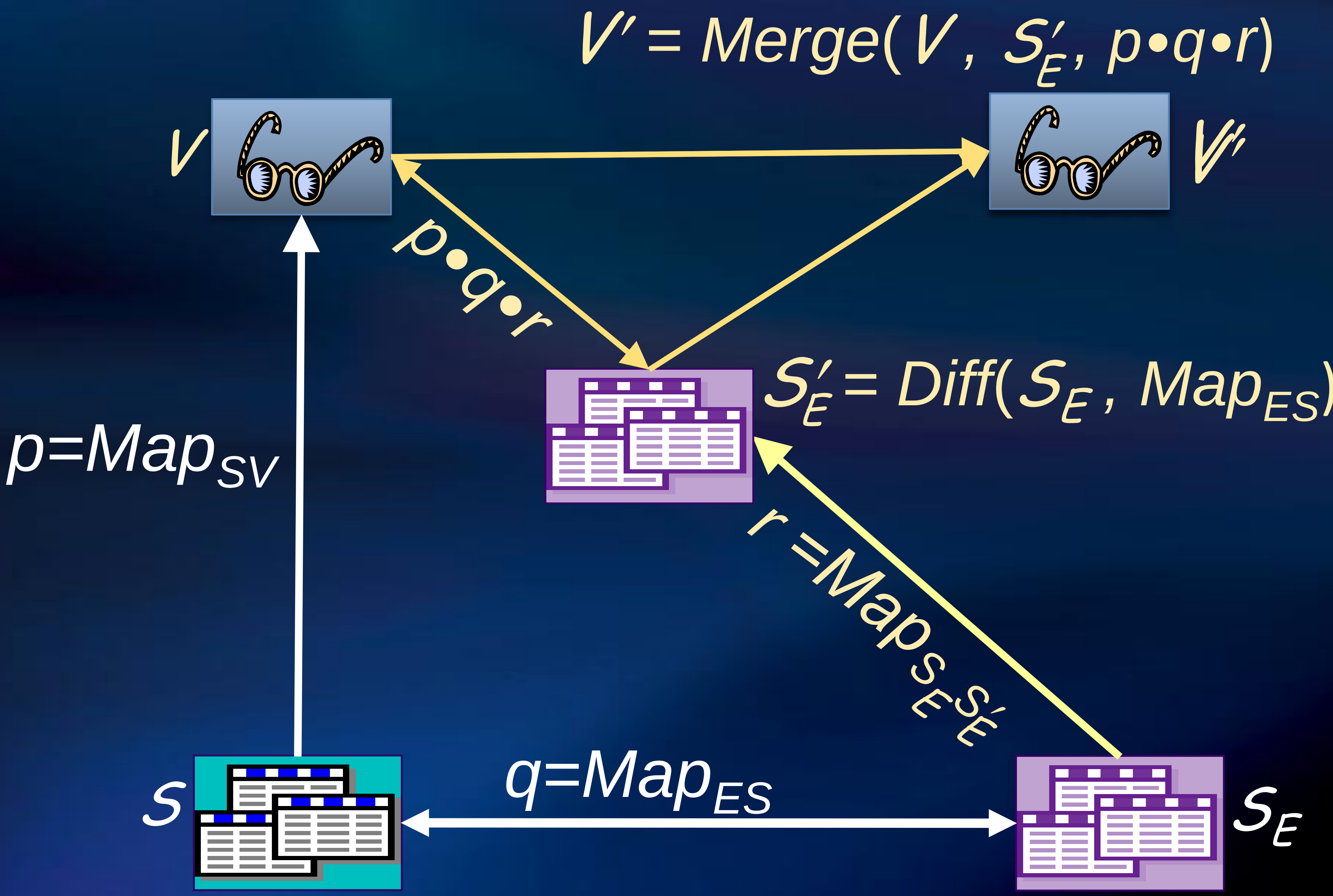
Composition

[Fagin, Kolaitis, Popa, Tan. TODS 05]
[Nash, Bernstein, Melnik. TODS 07]
[Yu, Popa. VLDB 05]
[Bernstein, Green, Melnik, Nash. VLDB 06]

$$\underbrace{S_1 \xrightarrow{map_{12}} S_2 \xrightarrow{map_{23}} S_3}_{map_{12} \bullet map_{23}}$$

- Some natural 1st-order mapping languages are not closed under composition
  - Sometimes, it's undecidable whether the composition is expressible in the input language
  - Can settle for a partial solution over 1st-order mappings
- Or you can use a 2nd-order mapping language that's closed under composition
  - There's a composition algorithm to compute it
- Some prototype implementations reported
  - Practical applications needed

Augment View with S_E's new data



Extract & Diff

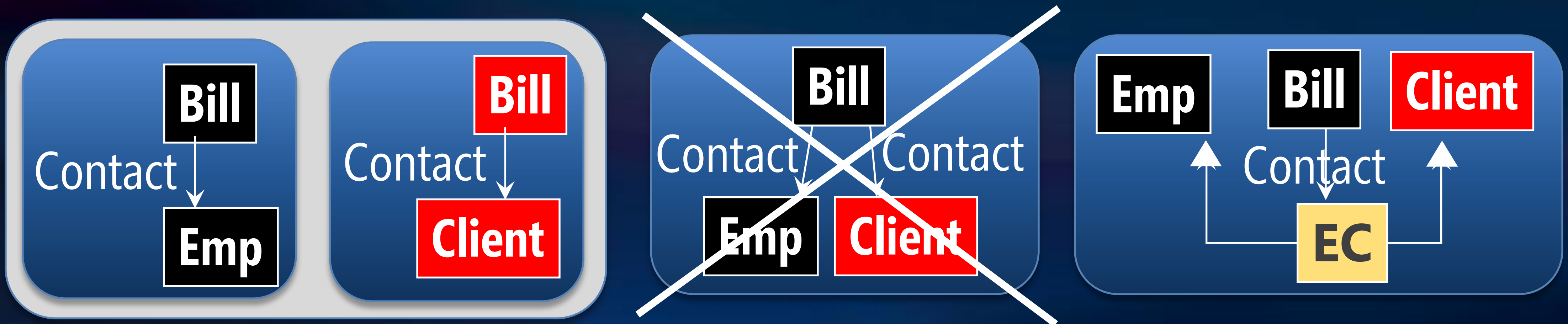
$S'' \xrightarrow{map_{S''\text{-}S'}} S' \xrightarrow{map_{S'\text{-}S}} S$

- $[S'', map_{S''\text{-}S'}] = \text{Extract}(S', map_{S'\text{-}S})$
  - S'' is a maximal sub-schema of S' that can be populated with data from S via $map_{S'\text{-}S}$
  - Related to the materialized view selection problem: S'' is the minimal view needed to populate S
- $\text{Diff}(S', map_{S'\text{-}S})$ is the complement of Extract
  - It's the view complement problem [Bancillon & Spyratos, TODS 81]
  - An algorithm for select-project-join-union views is in [Lechtenbörger, Vossen. TODS 03]

Merge

[Casanova, Vidal. PODS 83]
[Biskup, Convent. SIGMOD 86]
[Buneman, Davidson, Kosky. EDBT 92]
[Spaccapietra, Parent. TKDE 94]
[Pottinger, Bernstein. VLDB 03]

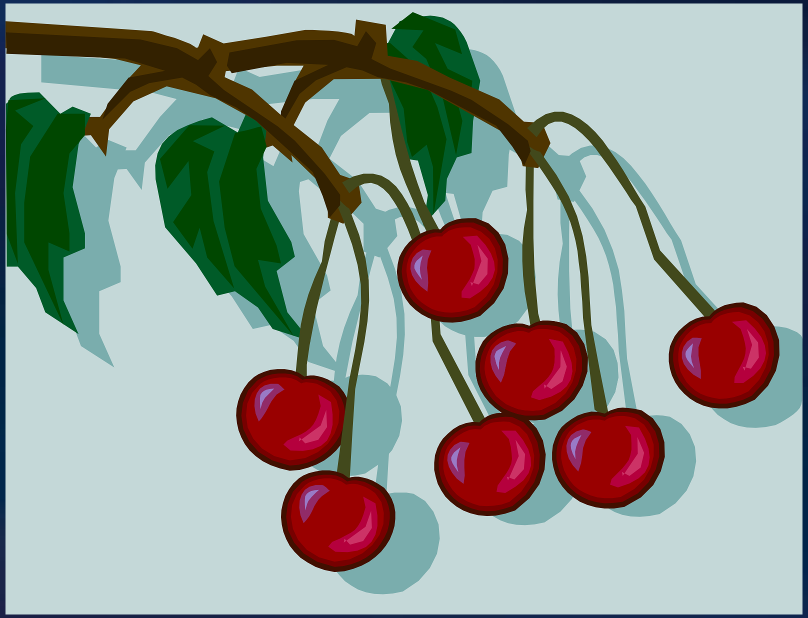
- Take disjoint union of schemas and constraints and then optimize
- Merge algorithms for structural mappings



- Extension: input map is a first-class model
- Nothing known for semantic mappings

Low Hanging Fruit

- More surveys
  - Solutions to data programability problems
  - Products that address these problems (e.g. runtimes)
- More case studies
  - Using published solutions and products to solve mapping problems

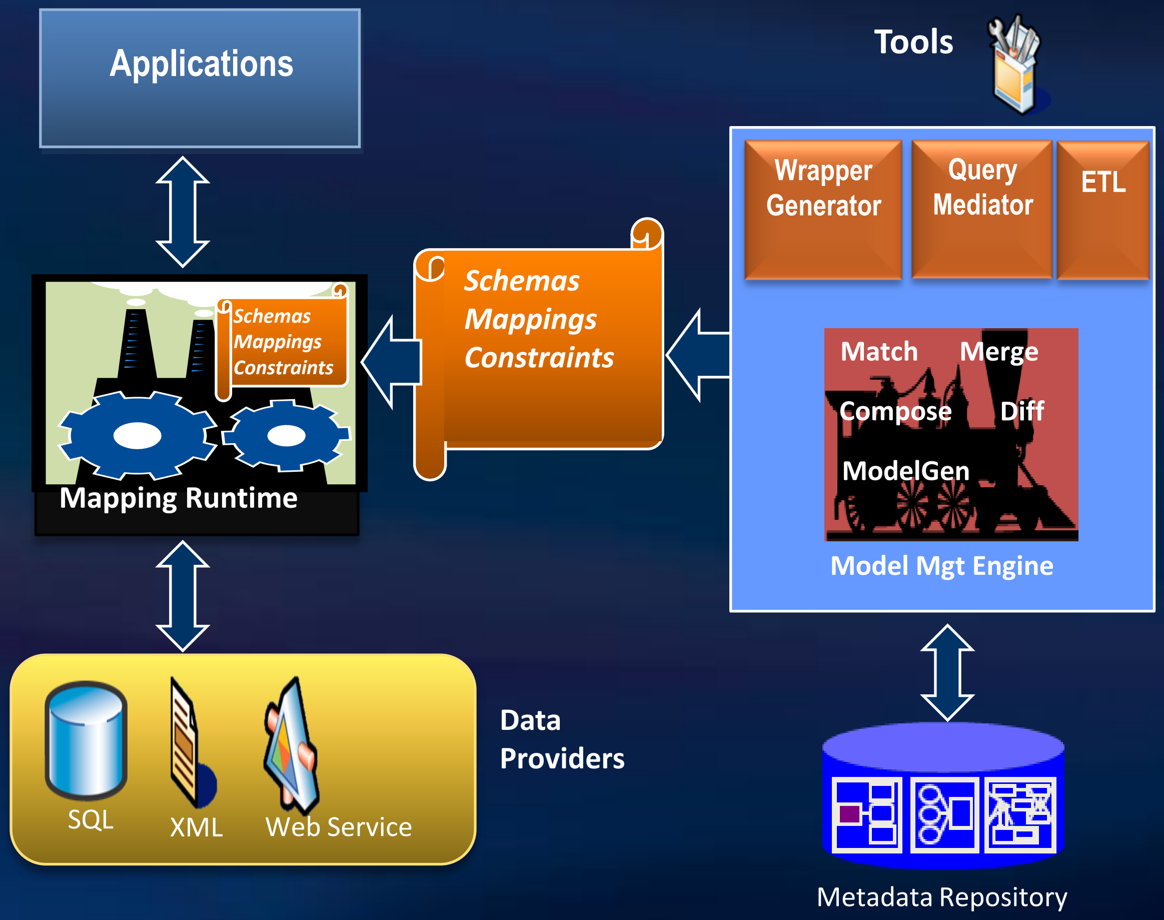


Other Challenges

- Semantics and algorithms of operators with more expressive mappings
- Translating behavior on target via mapping to behavior on source

Model Management System

- Is it still a goal to build a MMS?
- Or is it just a set of techniques to be applied?



Summary

- There's a big market looking for solutions
- Limited known about run-time scenarios
  - Mostly just for queries
  - Some updates, provenance, integrity constraints
  - Much work needed for synch logic, errors, indexing, notifications, batch loading, ….
- There's progress on many operators
  - But it's incomplete
  - For mappings with limited expressiveness
  - Little known about merge, diff, extract

References

- P. Bernstein, S. Melnik, “Model Management 2.0: Manipulating Richer Mappings,” *SIGMOD 2007*
- S. Melnik, A. Adya, P. Bernstein, “Compiling Mappings to Bridge Applications and Databases, *SIGMOD 2007*

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