Using ontologies for P2P data sharing and ETL design

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Outline

- **Data sharing in PDMS**
- Ontology-based ETL design

Peer Data Management Systems

- P2P networks
  - massive sharing of structured or unstructured data
- Structured vs. unstructured overlays
  - Structured
    - data is indexed and stored at peers with pre-specified characteristics, e.g. peer id
    - peers are connected to specific peers
  - Unstructured
    - no pre-specified connection of peers and storage/indexing of data

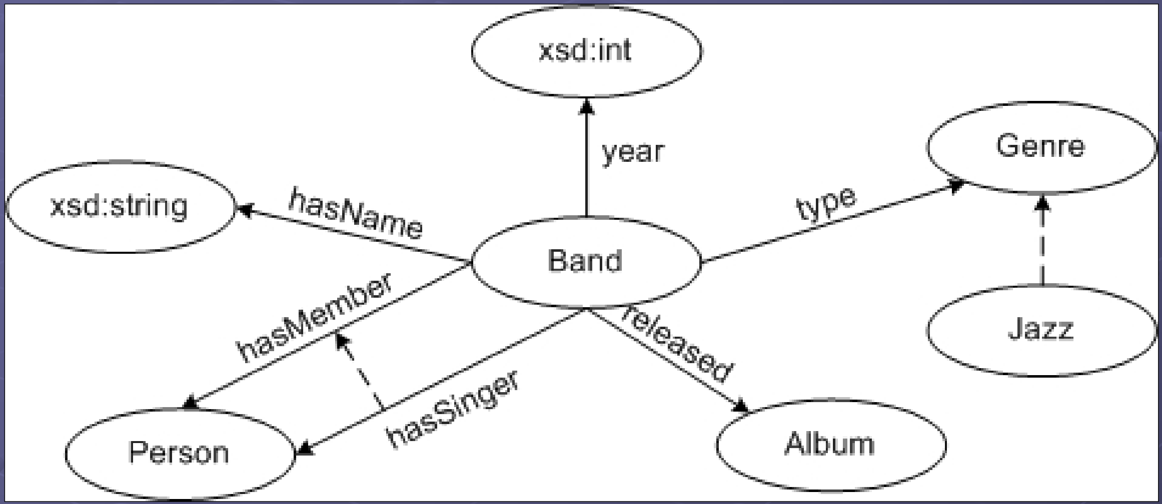
Problem description

- An unstructured PDMS
  - local relational database
  - pairwise mappings of the forms GAV/LAV/GLAV
  - SPJ queries
    - expressed on the local schema
    - reformulated according to the mappings
- An OWL ontology describing the application domain

Problem description (cont'd)

- Semantic peer $\mathrm{P} = (\mathrm{R}, \mathrm{O}, \mathrm{A})$
  - R: local database schema
  - O: the domain ontology
  - A: semantic annotation
- Two issues
  - Semantic similarity between peer schemas
  - Semantic similarity between reformulated queries

Sample ontology and peer schemas



- P_1 : bands (name, members, year)
- P_2 : bands (name, singer, year)
- M_{P_1, P_2} : bands (name, members, year) :- bands (name, singer, year)

Semantic annotations

- P_1 : bands having at least one album
- P_2 : bands that play Jazz music, were formed before the year 2000, and have released at least 3 albums

- $Band\_P_1 \equiv Band \sqcap \geq_1 released$
- $Band\_P_2 \equiv Band \sqcap \forall type.Jazz \sqcap \geq_3 released$

  $\sqcap \forall year.(\leq 2000)$

Comparison of peer schemas

- Express the degree of relevance between the interests of peers (subset, superset, overlap, etc.)
- Semantic similarity is assessed by comparing the classes annotating the peer schemas
- The similarity function needs to be asymmetric

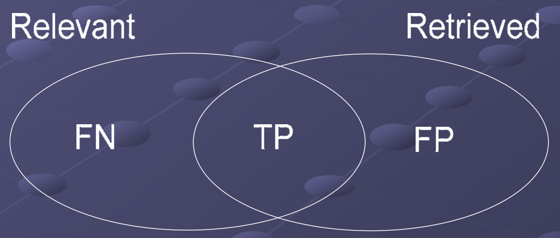
Recall and Precision

- Use notions *recall* and *precision* from Information Retrieval

$$recall = \frac{|relevant \cap retrieved|}{|relevant|}$$

$$precision = \frac{|relevant \cap retrieved|}{|retrieved|}$$

$$F_\alpha = \frac{(1+\alpha)\cdot precision \cdot recall}{\alpha \cdot precision + recall}$$



TP: True Positive

FP: False Positive

FN: False Negative

Adapting recall and precision

- We adapt the notions of recall and precision as follows:

$$recall(C_1,\ C_2) = \frac{\left|\{x \mid x \in (C_1 \sqcap C_2)\}\right|}{\left|\{x \mid x \in C_1\}\right|}$$

$$precision(C_1,\ C_2) = \frac{\left|\{x \mid x \in (C_1 \sqcap C_2)\}\right|}{\left|\{x \mid x \in C_2\}\right|}$$

Relationship	*equivalent*	*subset*	*superset*	*overlap*	*disjoint*
Recall	1	1	<1	<1	0
Precision	1	<1	1	<1	0

Semantic similarity

- Similarity is assessed by the semantic information provided by the ontology
  - class hierarchy
  - properties
    - property hierarchy
    - value and cardinality restrictions

Calculating recall and precision

- Based on the class hierarchy
  - ratio of common ancestors
    - similarity increases with the hierarchy depth

$$recall_C(C_1,\ C_2)\ =\ \frac{|\,A(C_1)\ \cap\ A(C_2)\,|}{|\,A(C_2)\,|}$$

$$precision_C(C_1,\ C_2)\ =\ \frac{|\,A(C_1)\ \cap\ A(C_2)\,|}{|\,A(C_1)\,|}$$

Calculating recall and precision (cont'd)

- Based on the properties of classes
  - property hierarchy

$$recall(p_1, p_2) = \frac{|A(p_1) \cap A(p_2)|}{|A(p_2)|}$$

$$precision(p_1, p_2) = \frac{|A(p_1) \cap A(p_2)|}{|A(p_1)|}$$

Calculating recall and precision (cont'd)

- Based on the properties of classes (cont'd)
  - property restrictions
    - value restrictions on object properties: $\forall$ type.Jazz
    - value restrictions on datatype properties: $\forall$ year.($\leq$ 2000)
    - cardinality restrictions: $\geq_3$ released

$case$	$recall(R_1, R_2)$	$precision(R_1, R_2)$
$R_1 \equiv R_2$	1	1
$R_1 \subseteq R_2$	1	0.5
$R_1 \supseteq R_2$	0.5	1
$R_1 \cap R_2 \neq \varnothing$	0.5	0.5
$R_1 \cap R_2 = \varnothing$	0	0

Calculating recall and precision (cont'd)

- Based on the properties of classes (cont'd)
  - combining property hierarchy and restrictions

$$recall(p_1, p_2) = \frac{|A(p_1) \cap A(p_2)|}{|A(p_2)|} \cdot \prod_{R(p_2)} recall(R_i'(p_1), R_i(p_2))$$

$$precision(p_1, p_2) = \frac{|A(p_1) \cap A(p_2)|}{|A(p_1)|} \cdot \prod_{R(p_1)} precision(R_i(p_1), R_i'(p_2))$$

Calculating recall and precision (cont'd)

- Based on the properties of classes (cont'd)

$$recall(C_1,\ C_2) = \frac{\sum_{P(C_2)} recall(p'(C_1), p(C_2))}{|P(C_2)|}$$

$$precision(C_1,\ C_2) = \frac{\sum_{P(C_1)} precision(p(C_1), p'(C_2))}{|P(C_1)|}$$

Calculating recall and precision (cont'd)

- Extending to sets of classes

$$recall(C_1, C_2) = \frac{\sum_{C_i \in C_1} recall(C_i, C_i')}{|C_1|}$$

$$precision(C_1, C_2) = \frac{\sum_{C_i \in C_2} precision(C_i', C_i)}{|C_2|}$$

Query reformulation

- A query Q_o is forwarded from peer P_i to peer P_j, and is reformulated as Q_r
  - some attributes may not be rewritten
  - some attributes may be rewritten approximately
  - some conditions may be lost
  - some conditions may be inserted

Extending the similarity measure

- Rewritten attributes
  - t was rewritten to t´
    - recall(t , t´) = recall(p_t , $p_{t´}$)
    - precision(t , t´) = precision(p_t , $p_{t´}$)
  - t was not rewritten
    - recall = 0
    - precision is not affected

Extending the similarity measure (cont'd)

- Rewritten conditions
  1. A query Q_o is issued at peer P_i
  2. C_{Q_o} ← the set of classes annotating the relations in Q_o
  3. $C_{Q_{o,e}}$ ← the classes in C_{Q_o} enhanced with additional value restrictions, according to the conditions specified in Q_o
  4. Q_o is forwarded to peer P_j and is rewritten as Q_r
  5. $C_{Q_{r,e}}$ ← apply steps 2 and 3 for Q_r

Example

- Q_o: SELECT name, members, year FROM bands WHERE year ≥ 1980 AND year < 1990
- $C_{Q_{o,e}}$: $Band\_P_1 \equiv Band \sqcap \geq_1 released \sqcap \forall\, year.([1980, 1990))$
- Q_r: SELECT name, singer, year FROM bands WHERE year ≥ 1980 AND year < 1990
- $C_{Q_{r,e}}$: $Band\_P_2 \equiv Band \sqcap \forall\, type.Jazz \sqcap \geq_3 released \sqcap \forall\, year.([1980, 1990))$

Similarity measure for rewritten queries

- Combine results for attributes and conditions

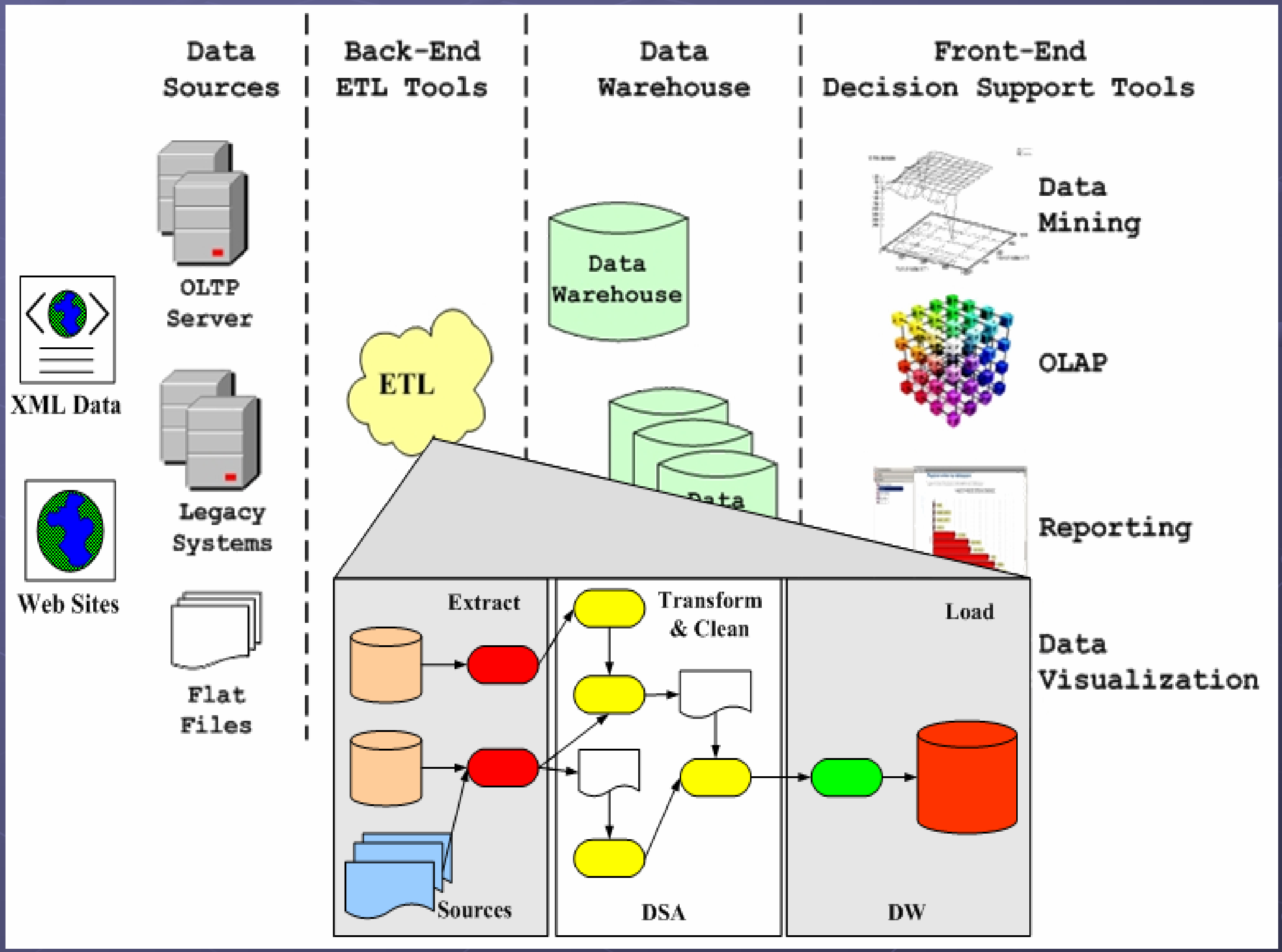
$$recall(C_{Q_{o,e}}, C_{Q_{r,e}}, Q_o, Q_r) = \frac{\sum_{t \in S(Q_o)} recall(p_t, p_{t'})}{|S(Q_o)|} \cdot recall(C_{Q_{o,e}}, C_{Q_{r,e}})$$

$$precision(C_{Q_{o,e}}, C_{Q_{r,e}}, Q_o, Q_r) = \frac{\sum_{t \in S(Q_r)} precision(p_{t'}, p_t)}{|S(Q_r)|} \cdot precision(C_{Q_{o,e}}, C_{Q_{r,e}})$$

Outline

- Data sharing in PDMS
- **Ontology-based ETL design**

Extract-Transform-Load (ETL)



Problem description

- The problem of heterogeneity in data sources
  - structural heterogeneity
    - data stored under different schemata
  - semantic heterogeneity
    - different naming conventions
      - e.g., homonyms, synonyms
    - different representation formats
      - e.g., units of measurement, currencies, encodings
    - different ranges of values
- Two main goals
  - specify inter-schema mappings
  - identify appropriate transformations

Overview

- Construct a suitable application ontology
- Annotate the datastores
  - establish mappings between the datastore schemas and the ontology
- Apply reasoning techniques to
  - select relevant sources
  - to identify required transformations

Reference example

Source schema	Target schema
emp	**employee**
fname	**name**
lname	**project**
prj	**salary**
salary	**city**
address	**street**

at least one

EUR

at least two

USD, above basic

The application ontology

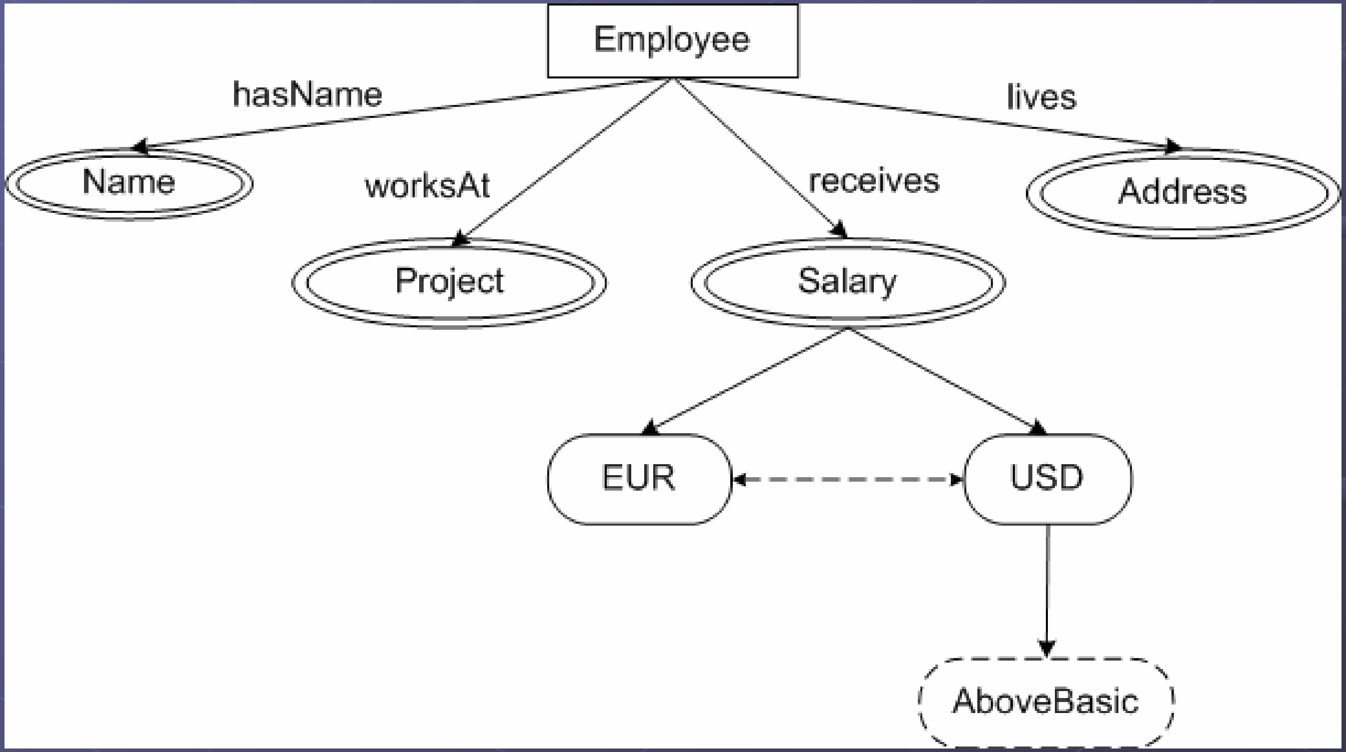
- A suitable application ontology is constructed to model
  - the concepts of the domain
  - the relationships between those concepts
  - the attributes characterizing each concept
  - the different representation formats or (ranges of) values for each attribute
- A graph representation specified for the ontology
  - graph nodes → classes
  - graph edges → properties
  - visual notation
    - different symbols used for each type of class or property

Ontology graph notation

	Type	Represents	Symbol
Nodes	concept-node	a class $c \in C_C$	C
	aggregation-node	a class $c \in C_G$	C
	type-node	a class $c \in C_{TP}$	C
	format-node	a class $c \in C_{TF}$	C
	range-node	a class $c \in C_{TR}$	C
	aggregated-node	a class $c \in C_{TG}$	C
Edges	property-edge	a property $p \in P_P$	– p →
	convertsTo-edge	property `convertsTo`	- - →
	aggregates-edge	property `aggregates`	●→
	groups-edge	property groups	○→
	subclass-edge	class hierarchy	→
	disjoint-edge	disjointness of classes	←X→

Reference example (cont'd)

- The application ontology graph

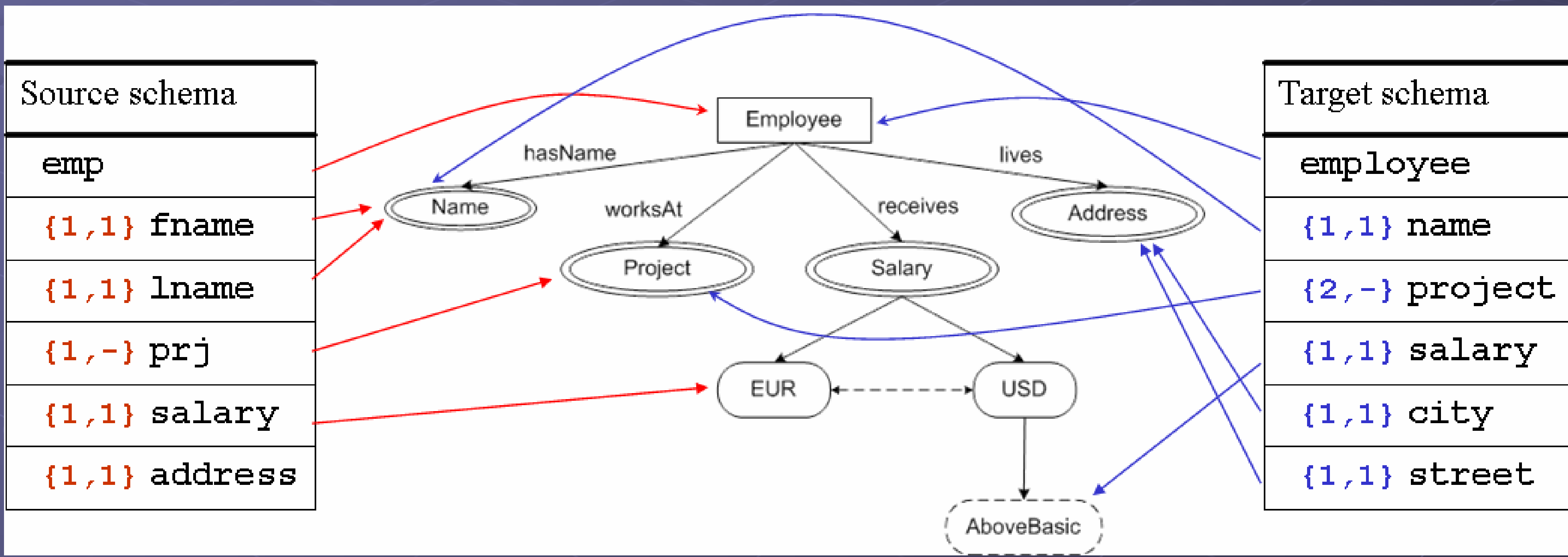


Datastore Annotation

- Semantic annotation → correspondences between the datastore schema and the ontology
- Relations are mapped to concept-nodes
- Attributes are mapped to nodes of the following types:
  - type-node
  - format-node
  - range-node
  - aggregated-node
- Defined classes are created to express the semantics of the schema elements

Reference example (cont'd)

- Datastore mappings



Reference example (cont'd)

- Datastore definitions
  - $\mathtt{S.Emp} \equiv \mathtt{Employee} \sqcap \forall \mathtt{hasName.Name} \sqcap =_1\mathtt{hasName} \sqcap \forall \mathtt{worksAt.Project} \sqcap \geq_1\mathtt{worksAt} \sqcap \forall \mathtt{receives.EUR} \sqcap =_1\mathtt{receives} \sqcap \forall \mathtt{lives.Address} \sqcap =_1\mathtt{lives}$
  - $\mathtt{T.Employee} \equiv \mathtt{Employee} \sqcap \forall \mathtt{hasName.Name} \sqcap =_1\mathtt{hasName} \sqcap \forall \mathtt{worksAt.Project} \sqcap \geq_2\mathtt{worksAt} \sqcap \forall \mathtt{receives.AboveBasic} \sqcap =_1\mathtt{receives} \sqcap \forall \mathtt{lives.Address} \sqcap =_1\mathtt{lives}$

ETL Transformations

- Generic types of ETL transformations

Operation	Description
RETRIEVE(n)	Retrieves recordsets from the underlying provider node n
EXTRACT(c)	Extracts, from incoming recordsets, the part denoted by c
MERGE	Merges recordsets from two or more provider nodes
FILTER(c)	Filters incoming recordsets, allowing only records with values of the template type specified by c
CONVERT(c_1, c_2)	Converts incoming recordsets from the template type denoted by c_1 to the template type denoted by c_2
AGGREGATE(f_g, g_1, …, g_n)	Aggregates incoming recordsets over the attributes g_1, …, g_n applying the aggregate function denoted by f_g.
MINCARD(p,min)	Filters out incoming recordsets having cardinality less than min on property p
MAXCARD(p,max)	Filters out incoming recordsets having cardinality more than max on property p
UNION	Unites recordsets from two or more sources
JOIN	Joins incoming recordsets
STORE	Stores incoming recordsets to a target datastore

Generating ETL transformations

- Two main steps
  - select relevant sources to populate a target element
  - identify required data transformations
- Based on the use of a reasoner to infer subsumption relationships between the defined classes representing the datastores

Generating ETL transformations

- Selecting relevant sources
  - a source node n_S, mapped to class c_S
  - a target node n_T, mapped to class c_T
  - n_S is provider for n_T, if
    - c_S and c_T have a common superclass
      - ensures that the integrated data records refer to the same kind of entity in the domain
    - c_S and c_T are not disjoint
      - prevents integration between datastores with conflicting constraints

Generating ETL transformations

- Identifying data transformations (I)
  - a RETRIEVE operation for each provider node
  - a MERGE operation to combine data from several provider nodes
  - an EXTRACT operation to extract a portion of data from a provider node

Generating ETL transformations

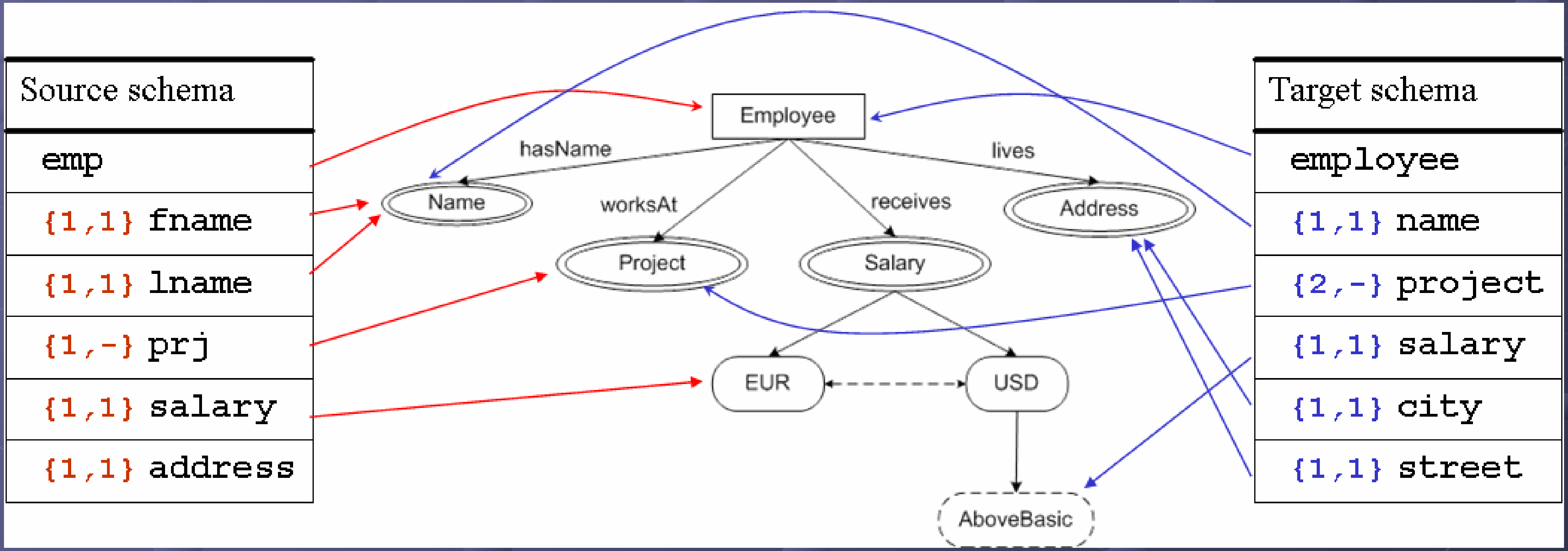
- Identifying data transformations (II)
  - if $C_S \equiv C_T$ or $C_S \sqsubset C_T$, no transformations are required
  - if $C_T \sqsubset C_S$, AGGREGATE, FILTER and/or MINCARD/MAXCARD operations are required
    - choice of specific operation(s) is based on parsing the class definitions and analyzing the value and cardinality restrictions found
  - else, as previous plus CONVERT operations

Generating ETL transformations

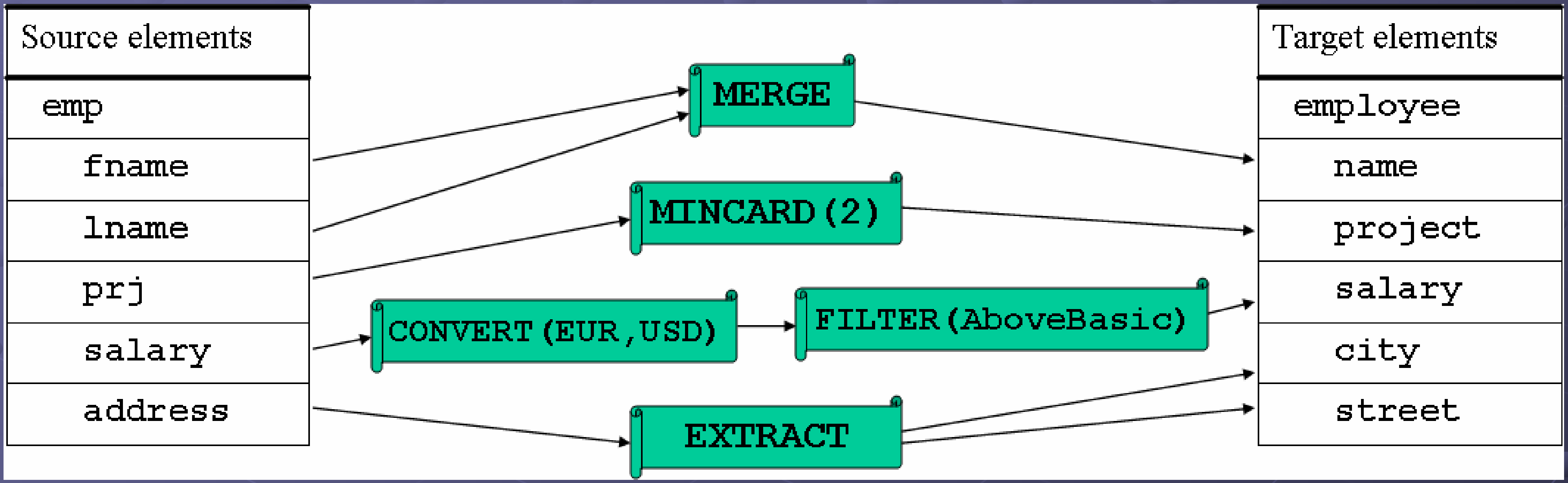
- Identifying data transformations (III)
  - a JOIN operation to combine recordsets from nodes, whose corresponding classes are related by a property
  - a UNION operation to combine recordsets from nodes, whose corresponding classes have a common superclass
  - a STORE operation to denote loading of data to the target datastore

Reference example (cont'd)

- Datastore mappings



Reference example (cont'd)



Current and Future Work

- PDMS
  - route queries in the network
  - apply the approach to social network applications
- ETL
  - NLG techniques for textual representation of datastore descriptions and ETL operations
  - impact of schema evolution
- Semantic Web services
  - service ranking
  - QoS aspects

Thank You