# Fuzzy Constraint-based Schema Matching Formulation

Alsayed Algergawy, Eike Schallehn, Gunter Saake
{alshahat|eike|saake}@ovgu.de

Department of Computer Science
University of Magdeburg
Magdeburg, Germany

The First Workshop in Advanced Deep Web 2008
ADW2008

# Road Map

1. **Motivations**
2. Preliminaries
3. Schema Graphs
4. Schema Matching as an FCOP
5. Summary and Future Work

# Motivations

- *Schema matching* is defined as the task of identifying the semantic correspondences from heterogeneous data sources
- Current Approaches
  - Lack of formulation
  - Discovering simple mappings
  - Matching Performance
  - Matching Scalability
  - Uncertainty

# Motivations

- *Schema matching* is defined as the task of identifying the semantic correspondences from heterogeneous data sources
- Current Approaches
  - Lack of formulation
  - Discovering simple mappings
  - Matching Performance
  - Matching Scalability
  - Uncertainty
- *Therefore, we need a formalization framework that enables us to cope with:*
  - Discovering complex mappings as well as simple mappings
  - Trading-off between two performance aspects—matching effectiveness and matching efficiency
  - Dealing with schema matching uncertainty

# Road Map

1. Motivations

2. **Preliminaries**

3. Schema Graphs

4. Schema Matching as an FCOP

5. Summary and Future Work

# Preliminaries

- Our fuzzy constraint optimization framework is based on:
    - Rooted labeled graphs
    - Constraint programming

# Rooted Labeled Graphs

- Schemas to ba matched can be modeled as rooted labeled graphs called schema graphs SG

$$G = (N_G, E_G, Lab_G, src, tar, l)$$

  - $N_G = \{n_{root}, n_2, ..., n_n\} \Rrightarrow$ a finite set of nodes

# Rooted Labeled Graphs

- Schemas to ba matched can be modeled as rooted labeled graphs called schema graphs SG

$$G = (N_G, E_G, Lab_G, src, tar, l)$$

  - $N_G = \{n_{root}, n_2, ..., n_n\} \Rrightarrow$ a finite set of nodes
  - $E_G = \{(n_i, n_j) | n_i, n_j \in N_G\} \Rrightarrow$ a finite set of edges,

# Rooted Labeled Graphs

- Schemas to ba matched can be modeled as rooted labeled graphs called schema graphs SG

$$G = (N_G, E_G, Lab_G, src, tar, l)$$

  - $N_G = \{n_{root}, n_2, ..., n_n\}$ ⇛ a finite set of nodes
  - $E_G = \{(n_i, n_j) | n_i, n_j \in N_G\}$ ⇛ a finite set of edges,
  - $Lab_G$ ={ $Lab_{NG}$, $Lab_{EG}$ } ⇛ a finite set of node labels $Lab_{NG}$, and a finite set of edge labels $Lab_{EG}$

# Rooted Labeled Graphs

- Schemas to ba matched can be modeled as rooted labeled graphs called schema graphs SG

$$G = (N_G, E_G, Lab_G, src, tar, l)$$

- $N_G = \{n_{root}, n_2, ..., n_n\} \Rrightarrow$ a finite set of nodes
- $E_G = \{(n_i, n_j) | n_i, n_j \in N_G\} \Rrightarrow$ a finite set of edges,
- $Lab_G$ ={ $Lab_{NG}$, $Lab_{EG}$ } $\Rrightarrow$ a finite set of node labels $Lab_{NG}$, and a finite set of edge labels $Lab_{EG}$
- $src$ and $tar$: $E_G \mapsto N_G \Rrightarrow$ two mappings source and target,

# Rooted Labeled Graphs

- Schemas to ba matched can be modeled as rooted labeled graphs called schema graphs SG

$$G = (N_G, E_G, Lab_G, src, tar, l)$$

  - $N_G = \{n_{root}, n_2, ..., n_n\}$ $\Rrightarrow$ a finite set of nodes
  - $E_G = \{(n_i, n_j) | n_i, n_j \in N_G\}$ $\Rrightarrow$ a finite set of edges,
  - $Lab_G$ ={ $Lab_{NG}$, $Lab_{EG}$ } $\Rrightarrow$ a finite set of node labels $Lab_{NG}$, and a finite set of edge labels $Lab_{EG}$
  - $src$ and $tar$: $E_G \mapsto N_G$ $\Rrightarrow$ two mappings source and target,
  - $l : N_G \cup E_G \mapsto Lab_G$ $\Rrightarrow$ a mapping label assigning

# Constraint Programming I

- A lot of problems in computer science, most notably in AI, can be interpreted as special cases of constraint programming.
- Semantic schema matching is an intelligent process
- Therefore, constraint programming is a suitable framework for interpreting and understanding the schema matching problem

# Constraint Programming I

- A lot of problems in computer science, most notably in AI, can be interpreted as special cases of constraint programming.
- Semantic schema matching is an intelligent process
- Therefore, constraint programming is a suitable framework for interpreting and understanding the schema matching problem
- Types of constraint problems
  - Constraint Satisfaction Problem *CSP*
  - Constraint Optimization Problem *COP*
  - Fuzzy Constraint Optimization Problem *FCOP*

# Constraint Programming II

- *CSP P* is a 3-tuple,

$$P = (X, D, C)$$

  - $X$ is a finite set of variables
  - $D$ is a collection of finite domains
  - $C$ is a set of constraints

# Constraint Programming II

- *CSP P* is a 3-tuple,

$$P = (X, D, C)$$

  - $X$ is a finite set of variables
  - $D$ is a collection of finite domains
  - $C$ is a set of constraints
- Constraint

$$C_s \subseteq D_1 \times ... \times D_r \rightarrow \{0, 1\}$$
$$S = \{x_1, x_2, ...x_r\}$$

# Constraint Programming II

- *CSP P* is a 3-tuple,

$$P = (X, D, C)$$

  - $X$ is a finite set of variables
  - $D$ is a collection of finite domains
  - $C$ is a set of constraints
- Constraint

$$C_s \subseteq D_1 \times ... \times D_r \rightarrow \{0, 1\}$$
$$S = \{x_1, x_2, ...x_r\}$$

- Solution of a CSP
  An assignment $\Lambda$ is a solution of a *CSP* if it satisfies all the constraints of the problem.

# Constraint Programming III

- *COP* COP Q is a 2-tuple, $Q = (P, g)$
  - $P$ is a CSP
  - $g$ is an objective function

# Constraint Programming III

- *COP* COP Q is a 2-tuple, $Q = (P, g)$
  - $P$ is a CSP
  - $g$ is an objective function
- While powerful, both *CSP* and *COP* present some limitations
  - ALL constraints are mandatory (*CRISP CONSTRAINTS*)

# Constraint Programming III

- *COP* COP Q is a 2-tuple, $Q = (P, g)$
  - $P$ is a CSP
  - $g$ is an objective function
- While powerful, both *CSP* and *COP* present some limitations
  - ALL constraints are mandatory (*CRISP CONSTRAINTS*)
- Fuzzy Constraints: A fuzzy constraint $C_\mu$ is represented by the fuzzy relation $R_f$, defined by

$$\mu_R : \prod_{x_i \in var(C)} D_i \rightarrow [0, 1]$$

# Constraint Programming III

- *COP* COP Q is a 2-tuple, $Q = (P, g)$
  - $P$ is a CSP
  - $g$ is an objective function
- While powerful, both *CSP* and *COP* present some limitations
  - ALL constraints are mandatory (*CRISP CONSTRAINTS*)
- Fuzzy Constraints: A fuzzy constraint $C_\mu$ is represented by the fuzzy relation $R_f$, defined by

$$\mu_R : \prod_{x_i \in var(C)} D_i \rightarrow [0, 1]$$

- Fuzzy Constraint Optimization Problem FCOP $Q_\mu$ is a 4-tuple

$$Q_\mu = (X, D, C\mu, g)$$

# Road Map


1. Motivations

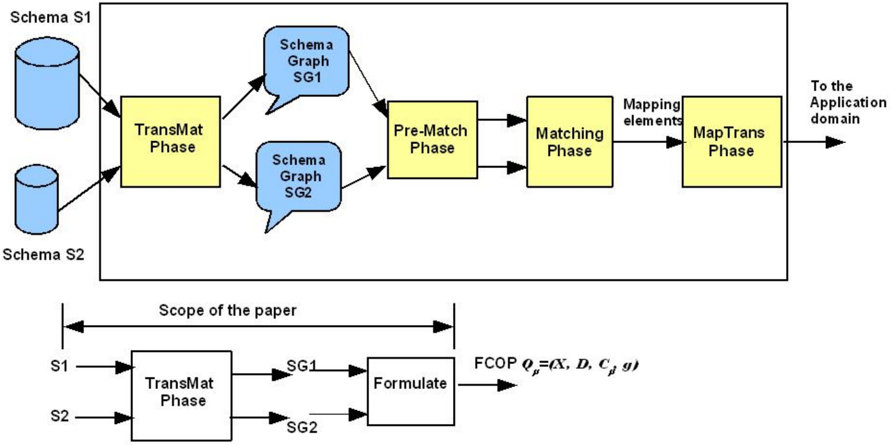
2. Preliminaries

3. Schema Graphs

4. Schema Matching as an FCOP

5. Summary and Future Work

# A Unified Schema Matching Framework



# Transformation Rules

- Every *prepared matching object* in a schema such as schema, relations, elements, attributes etc. is represented by *a node* in the schema graph
- The *features* of the prepared matching object are represented by *node labels* $Lab_{NG}$
- The *relationship* between two prepared matching objects is represented by *an edge* of the schema graph
- The *features* of the relationship between prepared objects are represented by *edge labels* $Lab_{EG}$

# Schema Graph Example I

## Relational Schema

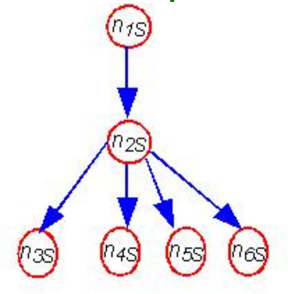
```
Schema S
   create table Personnel(
   Pno int primary key,
   Pname string,
   Dept string,
   Born date);
```

# Schema Graph Example I

## Relational Schema

```
Schema S
   create table Personnel(
   Pno int primary key,
   Pname string,
   Dept string,
   Born date);
```

## Schema Graph




Schema Graph SG1

# Schema Graph Example II

## Relational Schema

```
Schema T
   create table Employee(
   EmpNo int primary key,
   EmpName varchar(20),
   DeptNo int REFERENCES Department,
   Salary int,
   BirthDate date);

  create table Department(
  DeptNo int primary key,
  DeptName varchar(30));
```

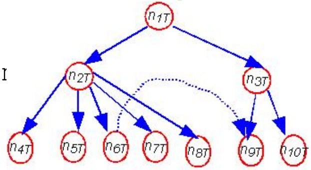
# Schema Graph Example II

## Relational Schema

```
Schema T
   create table Employee(
   EmpNo int primary key,
   EmpName varchar(20),
   DeptNo int REFERENCES Departı
   Salary int,
   BirthDate date);

  create table Department(
  DeptNo int primary key,
  DeptName varchar(30));
```

## Schema Graph




Schema Graph SG2

# Road Map


1. Motivations

2. Preliminaries

3. Schema Graphs

**4. Schema Matching as an FCOP**

5. Summary and Future Work

# Schema Matching as Graph Matching I

- The schema matching problem is converted into graph matching
  - Graph Morphism; $N_1 \neq N_2$ (schema matching)
  - Graph Homomorphism; $N_1 = N_2$

# Schema Matching as Graph Matching I

- The schema matching problem is converted into graph matching
  - Graph Morphism; $N_1 \neq N_2$ (schema matching)
  - Graph Homomorphism; $N_1 = N_2$
- Graph Morphism

$$\phi : SG1 \rightarrow SG2$$

$SG1 = (N_{GS}, E_{GS}, Lab_{GS}, src_S, tar_S, l_S)$
$SG2 = (N_{GT}, E_{GT}, Lab_{GT}, src_T, tar_T, l_T)$
$\phi = (\phi_N, \phi_E)$ such that $\phi_N : N_{GS} \rightarrow N_{GT}$, $\phi_E : E_{GS} \rightarrow E_{GT}$

# Schema Matching as Graph Matching I

- The schema matching problem is converted into graph matching
  - Graph Morphism; $N_1 \neq N_2$ (schema matching)
  - Graph Homomorphism; $N_1 = N_2$
- Graph Morphism

$$\phi : SG1 \rightarrow SG2$$

$SG1 = (N_{GS}, E_{GS}, Lab_{GS}, src_S, tar_S, l_S)$
$SG2 = (N_{GT}, E_{GT}, Lab_{GT}, src_T, tar_T, l_T)$
$\phi = (\phi_N, \phi_E)$ such that $\phi_N : N_{GS} \rightarrow N_{GT}$, $\phi_E : E_{GS} \rightarrow E_{GT}$

1. $\forall n \in N_{GS} \exists l_S(n) = l_T(\phi_N(n))$ *(node label preserving)*
2. $\forall e \in E_{GS} \exists l_S(e) = l_T(\phi_E(e))$ *(edge label preserving)*
3. $\forall e \in E_{GS} \exists$ a path $p' \in N_{GT} \times E_{GT}$ such that $p' = \phi_E(e)$ and $\phi_N(src_S(e)) = src_T(\phi_E(e)) \wedge \phi_N(tar_S(e)) = tar_T(\phi_E(e))$. *(graph structure preserving)*

# Schema Matching as Graph Matching II

- Graph matching is considered to be one of the most complex problems in computer science. Its complexity is due to two major problems:-
  - The time complexity
  - The fact that all of the algorithms for graph matching found so far can only be applied to two graphs at a time.

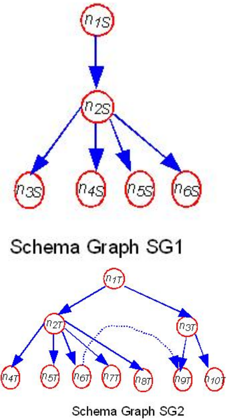
# Schema Matching as Graph Matching II

- Graph matching is considered to be one of the most complex problems in computer science. Its complexity is due to two major problems:-
  - The time complexity
  - The fact that all of the algorithms for graph matching found so far can only be applied to two graphs at a time.
- *To tackle these challenges, as well as the mentioned motivations, we decide to extend graph matching into an FCOP*

# Graph Matching as an FCOP

- Graph matching → an FCOP using the following rules:
  - take the *objects of one schema graph* to be matched as the *CPs set of variables*,
  - take the *objects of the other schema graph* to be matched as the *variables domain*
  - find a proper translation of the *conditions that apply to a schema matching* into a *set of constraints*, and
  - form the *objective functions* to be optimized.

# Schema Matching as an FCOP: Example



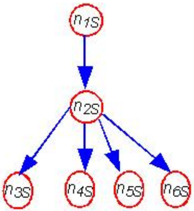

- The set of variables X:

$$X = X_N \cup X_E$$

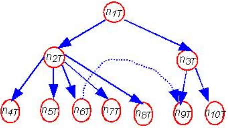
$$= \{x_{n1}, x_{n2}, x_{n3}, x_{n4}, x_{n5}, x_{n6}\} \cup \{x_{e12}, x_{e23}, x_{e24}, x_{e25}, x_{e26}\}$$

$$= \{x_{n1}, x_{n2}, x_{n3}, x_{n4}, x_{n5}, x_{n6}, x_{e12}, x_{e23}, x_{e24}, x_{e25}, x_{e26}\}$$

# Schema Matching as an FCOP: Example




Schema Graph SG1




Schema Graph SG2

- The set of variables X:

$$X = X_N \cup X_E$$

$$= \{x_{n1}, x_{n2}, x_{n3}, x_{n4}, x_{n5}, x_{n6}\} \cup \{x_{e12}, x_{e23}, x_{e24}, x_{e25}, x_{e26}\}$$

$$= \{x_{n1}, x_{n2}, x_{n3}, x_{n4}, x_{n5}, x_{n6}, x_{e12}, x_{e23}, x_{e24}, x_{e25}, x_{e26}\}$$

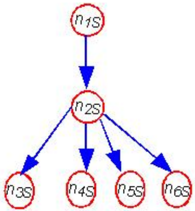
- The set of domain D:

$$D = N_{GT} \cup E_{GT}$$

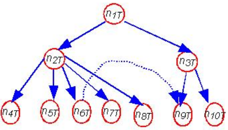
$$= \{D_{n1}, D_{n2}, D_{n3}, D_{n4}, D_{n5}, D_{n6}\} \cup \{D_{e12}, D_{e23}, D_{e24}, D_{e25}, D_{e26}$$

$$= \{D_{n1}, D_{n2}, D_{n3}, D_{n4}, D_{n5}, D_{n6}, D_{e12}, D_{e23}, D_{e24}, D_{e25}, D_{e26}\}$$

# Schema Matching as an FCOP: Example




Schema Graph SG1




Schema Graph SG2

- The set of variables X:

$$X = X_N \cup X_E$$
$$= \{x_{n1}, x_{n2}, x_{n3}, x_{n4}, x_{n5}, x_{n6}\} \cup \{x_{e12}, x_{e23}, x_{e24}, x_{e25}, x_{e26}\}$$
$$= \{x_{n1}, x_{n2}, x_{n3}, x_{n4}, x_{n5}, x_{n6}, x_{e12}, x_{e23}, x_{e24}, x_{e25}, x_{e26}\}$$

- The set of domain D:

$$D = N_{GT} \cup E_{GT}$$

$$= \{D_{n1}, D_{n2}, D_{n3}, D_{n4}, D_{n5}, D_{n6}\} \cup \{D_{e12}, D_{e23}, D_{e24}, D_{e25}, D_{e26}$$
$$= \{D_{n1}, D_{n2}, D_{n3}, D_{n4}, D_{n5}, D_{n6}, D_{e12}, D_{e23}, D_{e24}, D_{e25}, D_{e26}\}$$

$$D_{n1} = D_{n2} = D_{n3} = D_{n4} = D_{n5} = D_{n6} = \{n_{1T}, n_{2T}, n_{3T}, n_{4T}, n_{5T}, n_{6T}, n_{7T}, n_{8T}, n_{9T}, n_{10T}\}$$

# Constraint Construction

- Syntactic constraints
  - Domain Constraint

$$C^{dom}_{\mu(x_{ni})} = \{d_i \in D_{Ni}\}$$
$$C^{dom}_{\mu(x_{ei})} = \{d_i \in D_{Ei}\}$$

  - Structural Constraints
    - Parent Constraint

$$C^{parent}_{\mu(x_{ni},x_{nj})} = \{(d_i, d_j) \in D_N \times D_N | \exists\ e\ (d_i, d_j)\ s.t.\ src(e)=d_i\ \}$$

    - Child Constraint

$$C^{child}_{\mu(x_{ni},x_{nj})} = \{(d_i, d_j) \in D_N \times D_N | \exists\ e\ (d_i, d_j)\ s.t.\ tar(e)=d_j\ \}$$

# Constraint Construction

- Syntactic constraints
  - Domain Constraint

$$C^{dom}_{\mu(x_{ni})} = \{d_i \in D_{Ni}\}$$
$$C^{dom}_{\mu(x_{ei})} = \{d_i \in D_{Ei}\}$$

  - Structural Constraints
    - Parent Constraint

$$C^{parent}_{\mu(x_{ni},x_{nj})} = \{(d_i, d_j) \in D_N \times D_N | \exists\ e\ (d_i, d_j)\ s.t.\ src(e){=}d_i\ \}$$

    - Child Constraint

$$C^{child}_{\mu(x_{ni},x_{nj})} = \{(d_i, d_j) \in D_N \times D_N | \exists\ e\ (d_i, d_j)\ s.t.\ tar(e){=}d_j\ \}$$

- Semantic constraints
  - Labeled Constraints

$$C^{Lab}_{\mu(x_i)} = \{d_j \in D_N | \ lsim(l_S(x_i),l_T(d_j)) \geq t\ \}$$
$$C^{Lab}_{\mu(x_i)} = \{d_j \in D_E | \ lsim(l_S(x_i),l_T(d_j)) \geq t\}$$

# Objective Function Construction

- is the function associated with the optimization process
- constitutes the implementation of the problem to be solved.
- The input parameters are the object parameters
- The output is the objective value representing the evaluation/quality of the individual

$$g = min|max(\sum_{setofconstraint} f_{cost} + \sum_{setofassignment} f_{energy})$$

# Road Map

1. Motivations

2. Preliminaries

3. Schema Graphs

4. Schema Matching as an FCOP

5. **Summary and Future Work**

# Summary and Future Work

- Building a conceptual connection between the schema matching problem and fuzzy constraint optimization problem
- Developing a formal framework for the SMP, which
  - generic framework; model and domain independent
  - able to handle uncertainty
  - able to cope with complex mappings
- Benefits behind formulation:
  - Increase our understanding of the problem
  - Help mapping of the problem into another well-known problem
  - Open a path to adopt of different existing algorithms
  - Guide the initial design of the schema matching prototype
- Future work?? Implementation, evaluation, and comparison with other mainstream systems

Thank You

Thank You

Questions??