Upgrading Databases to Ontologies

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Outline

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Ontologies and Enterprises

**Ontology:**
- Formal representation of a conceptualization [Gruber]
- Roughly, an abstract formal model of a complex domain
- Recognized to be a fundamental tool for KRR

The strong need of knowledge-based technologies is perceived by industries today
- Ontologies start to be exploited

**Enterprise ontologies**
- Terms and definitions relevant to business enterprises
- Clean conceptual view of the enterprise knowledge
- Improve sharing and manipulation
- Simplify information retrieval and knowledge discovery

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Motivation

- **Enterprise ontologies are not widely used, why?**
  - Two major obstacles:
    1. Specification of real-world ontologies is an hard task
    2. Often relevant information stored in relational DB
  - Indeed, developing by scratch would be time consuming and expensive
    - Knowledge engineers + domain experts
  - Ontology must incorporate large amount of data from Enterprise Information Systems
    - mainly regarding instances
    - avoid import: exploit fresh data + legacy system support
    - data from several autonomous systems
      → well known inconsistency problems
      [argw-etal-95,lenz-02,bert-etal-05]
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“Lifting” databases to ontologies (1)

- Combine an ontology representation language, with Large (already existent) databases
  - *High Expressive power + deal with large amount of data*
- **Deal with inconsistency:**
  - *Data Integration techniques*
- Analyze the schema and recognize entities and relationships
  - Create an ontology specification
  - Obtain a clean view of the enterprise knowledge
- Exploit database data for specifying concept instances
  - Data should be kept at the sources
  - Legacy systems might still work on it
  - Take only *consistent information*
“Lifting” databases to ontologies (2)

- **OntoDLP**
  - Ontology representation language
  - **rule based:** Disjunctive Logic Programming - ASP

+ **Virtual classes and virtual relations**
  - Link data about instances to the ontology
  - Seamless combination of ontologies and DB [lenz-02] (GAV approach)
  - Data are kept to the original sources!

+ **Consistent Query Answering (CQA)**
  [lenz-02,bert-etal-05,chom-marcin-05]
  - By rewriting queries in DLP
  - Minimal Change Integrity Maintenance [chom-marcin-05]
OntoDLP \[\text{ricca-etal-08}\]

- **OntoDLP** = DLP +
  - Ontology specification constructs
    - Classes, (Multiple) Inheritance, Relations, ...
    - Data-Types (integer, string, date ...)
  - Consistency control features
    - Strong typing, user defined axioms
  - Rules
    - Support DLP with many linguistic enhancements
      - Lists and Sets, Aggregate and Plug-in functions, Complex Terms, Named notation
    - Modular Programming: Reasoning modules
Example: Reasoning on Ontology

Example

class employee(name:string, salary:int).
class project(numeEmp:int, bud:int, numSk:int, maxSal:int).

module (team_building) {
inTeam(E,P) v outTeam(E,P) :- E:employee(), P:project().
:- P:project(numEmp:N), not #countE: inTeam(emp:E)=N.
:- P:project(numSk:S), not #count{Sk: E:employee(sk:Sk), inTeam(E,P)}≥S.
:- P:project(budt:B), not #sum{Sa,E: E:employee(sal:Sa), inTeam(E,P)}≤B.
:- P:project(maxSal:M),
   not #max{Sa: E:employee(sal:Sa), inTeam(E,P)}≤M.
}

X:person(age:18, father:employee(skill:"Java Programmer")), inTeam(X, _)?
OntoDLV Main Features

- **Advanced Platform for Ontology Management**
  - Specification, Browsing, Querying, Reasoning
  - Based on OntoDLP
    - Ontology + Disjunctive Logic Programming - ASP
    - High computational power
      - Solve complex problems in a fully declarative way
  - Built on DLV the state-of-the-art DLP System [leone-et al-06]
  - Application Programming Interface (API)
  - OWL Interoperability

- **Able to deal with data-intensive applications**
  - Persistency on DBMS
  - exploits DLV$^{DB}$ (DLV working on mass memory)
Virtual Class and Virtual Relation

Virtual Class and Virtual Relations

- Usual schema specification
- Instances are specified by means of mapping rules
  - exploits Sourced Atoms (logical notation)
  - Exploit SQL Atoms (SQL notation)

Sources are specified directly in OntoDLP

- built-in class dbSource
- several databases and ...any other kind of sources

Example

class dbSource(uri:string, user:string, psw:string).

db1:dbSource(uri:"http://mydb.mysite.com:3306", user:"me", psw:"myPsw").
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```
Virtual Class Specification

Example

```
virtual class branch(name : string, city : string, assets : integer )
{
  f(BN) : branch(BN, BC, A) :- branch@db1(branch-name : BN, branch-city : BC, assets : A).
}
```

- **Sourced Atoms**
  - Attribute types must match the table schema
  - Attributes can be filled in by constants or variables
- **Functional Object Identifiers** (impedance mismatch)
  - Values vs instances
    - exploit function symbols
  - Each virtual class should use a fresh function symbol
    - distinct oids for distinct classes
Virtual Class with multiple sources

Example

**virtual class** `branch(name : string, city : string, assets : integer )`
{
  f(BN) : branch(BN, BC, A) :- branch@db1(branch-name : BN, branch-city : BC, assets :A).

  f(BN) : branch(BN, BC, A) :- localBranch@db2(bName : BN, bCity : BC, aS : A, group:_).
}

- **Multiple sources**
  - Just write several "mapping" rules
  - Select the information you need

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**Example**

```sql
virtual class branch(name : string, city : string, assets : integer )
{
    f(BN):branch(BN, BC, A) :- [db1, "SELECT branch-name AS BN, branch-city AS BC, assets AS A FROM branch "].
}
```
Virtual Entities in OntoDLV

- **Off-line Mode**
  - Extract data from DBMS
  - Store instances in the Persistency Manager
  - Useful for migrating the database

- **On-line Mode**
  - Keep information in the original database
  - Queries are performed directly at the sources
  - Unfolding (query predicates are substituted with the corresponding query at the sources)

- **Evaluation in mass memory**
  - exploit DLV$^{DB}$
  - restricted to stratified and non disjunctive programs
Data Integration Features

- **Virtual Classes and Virtual Relations**
  - instances are virtually populated
  - rules act as a mapping
  - in presence of multiple source databases
    - typical Data Integration scenario
    - Global As View (GAV) [lenz-02,bert-etal-05]

- **Inconsistency Problems**
  - Integrity constraint may be violated
    1. Repair manually
       - Consistency Checking
    2. Single out as much consistent information as possible
       - Consistent Query Answering (CQA)
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Consistent Query Answering

**Minimal Change Integrity Maintenance** [chom-marc-05]
- Complete sources assumption
  - Common in Data Warehousing
  - Closed World Assumption
- Integrity restoration by *tuple deletion*
  - Constraints: Arbitrary denial, inclusion dependencies
  - Decidable setting: $\Pi_2^D$ in the general case [chom-marc-05]
    → implemented by rewriting in DLP

**Definition**

Given a schema $\Sigma$ and a set $A$ of integrity constraints, let $\mathcal{O}$ and $\mathcal{O}'$ be two ontology instances, $\mathcal{O}'$ is a *repair* [chom-marc-05] of $\mathcal{O}$ w.r.t. $A$, if
- $\mathcal{O}'$ satisfies all the constrains in $A$; and
- the instances in $\mathcal{O}'$ are a maximal subset of the instances in $\mathcal{O}$.

Given a query $Q$, the consistent answers to $Q$ are those tuples that are true in every repair.
Consistent Query Answering

- **Minimal Change Integrity Maintenance** [chom-marc-05]
  - *Complete sources assumption*
    - Common in Data Warehousing
    - Closed World Assumption
  - Integrity restoration by *tuple deletion*
    - Constraints: Arbitrary denial, inclusion dependencies
    - Decidable setting: $\Pi^2_2$ in the general case [chom-marc-05]
      → implemented by rewriting in DLP

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Given a query $Q$, the consistent answers to $Q$ are those tuples that are true in every *repair*. 
CQA by Rewriting

Given \( \mathcal{O} \), \( Q \), \( A \) build program \( \Pi_{cqa} \) and a query \( Q_{cqa} \) s.t. \( \Pi_{cqa} \models_c Q_{cqa} \)

\((Q \text{ is consistently true in } \mathcal{O} \text{ w.r.t. } A \iff Q_{cqa} \text{ is true in every answer set of } \Pi_{cqa})\)

**Run** \( Q_{cqa} \) **on** \( \Pi_{cqa} \) **in mass memory with DLV\(^{DB} \)**

**Example**

Given two relations \( m(\text{code}) \), and \( e(\text{code, name}) \) and \( \text{code}(X) :\neq e(X, \_). \)

\[
\begin{align*}
\&\quad :- e(X, Y), e(X, Z), Y \leftrightarrow Z. & \text{(denial: code is key)} \\
\&\quad :- m(X), \text{not } \text{code}(X) & \text{(inclusion } m[\text{code}] \subseteq e[\text{code}])
\end{align*}
\]

**become:**

\[
\begin{align*}
\bar{e}(X, Y) \lor \bar{e}(X, Z) :&= e(X, Y), e(X, Z), Y \leftrightarrow Z. \\
\bar{e}'(X, Y) :&= e(X, Y), \text{not } \bar{e}(X, Y).
\end{align*}
\]

\[
\begin{align*}
\text{code}^*(X) :&= \bar{e}'(X, \_). \\
\text{m}'(M) :&= m(M), \text{not } \text{code}^*(M).
\end{align*}
\]
CQA by Rewriting

Given $\mathcal{O}$, $Q$, $A$ build program $\Pi_{cqa}$ and a query $Q_{cqa}$ s.t. $\Pi_{cqa} \models_c Q_{cqa}$

$(Q$ is consistently true in $\mathcal{O}$ w.r.t. $A$ iff $Q_{cqa}$ is true in every answer set of $\Pi_{cqa})$

**Run** $Q_{cqa}$ **on** $\Pi_{cqa}$ **in mass memory with** DLV$^{DB}$

### Example

Given two relations $m(code)$, and $e(code,name)$ and $code(X) :- e(X,\_)$.

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\begin{align*}
\langle & e(X, Y), e(X, Z), Y \leftrightarrow Z. \ (denial: \ code \ is \ key) \\
\langle & m(X), \text{not} \ code(X) \ (inclusion \ m[code] \subseteq e[code]) \\

\text{become:} & \hspace{0.5cm} e^\neg(X, Y) \lor e^\neg(X, Z) :- e(X, Y), e(X, Z), Y \leftrightarrow Z. \\
\langle & e'(X, Y) :- e(X, Y), \text{not} \ e^\neg(X, Y). \\
\langle & code^\neg(X) :- e'(X, \_). \\
\langle & m^\neg(M) :- m(M), \text{not} \ code^\neg(M). 
\end{align*}
\]
Conclusion

"Lifting" databases to OntoDLV Ontologies:
- Define an ontology, and specify instances by logic rules
  - Ontological view of the enterprise knowledge
  - Powerful rule-based reasoning mechanisms
- Virtual classes and virtual relations
  → Data is kept at the sources
  → Queries are performed at the source
- Consistent Query Answering:
  → Deal with inconsistencies

Ongoing work:
- Different input sources: XML, RDF, ...
- CQA on user constraints