Hybrid Architecture of OWL-Ontologies for Relational Data Sources Integration

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ABSTRACT

Data integration is one of the most important tasks in the data warehousing process. The use of ontologies in the mediation process allows semantic and structural integration. In this paper, we propose a new mediation system based on an hybrid architecture of ontologies modelled according to GLAV (Generalized Local As View) model. The hybrid architecture builds a local ontology for each data source and a global ontology viewed as a mediator. The integration model defines how sources, local and global ontologies are mapped. So we propose an ascending method for building ontologies, which facilitates the semantic reconciliation between data sources. Moreover, we use OWL (Ontology Web Language) for defining ontologies and mappings between data sources and ontologies. User queries are expressed in our specific language which handles global ontology concepts and local ontologies properties since we assume that the user is expert in its domain. Queries are decomposed by the rewriting algorithm to obtain a set of equivalent subqueries that are sent to the corresponding sources for execution, and after that recomposed to obtain the final result.

1. INTRODUCTION

In a data warehousing process, data integration is an important phases. Centralized data warehouse is a solution for companies that handle static data. However, when data change, this solution becomes not practical because of the refreshment cost. We think that data integration by mediation can solve this problem and allows to construct a mediation system for building analysis context on-the-fly using data from their real sources.

In this paper, we treat only the first part, which concerns the building of the mediation framework. It consists in creating a mediator based on ontologies. The use of ontologies in the integration by mediation is not recent [3, 4], it allows to implement a structural and semantic integration. There are several architectures based on ontologies in integration systems [1, 2, 16]. approaches with only one ontology as in the case of system *SIMS* [5], approaches with multiple ontologies as in *OBSERVER* [6] and hybrid architecture which associates a local ontology for each data source and a global ontology to link them [7]. The later is interesting because it is flexible for updates and there is no need to define mappings between local ontologies. Several structural models can be applied on this architecture: *GAV* (Global As View) [9, 10, 11], *LAV* (Local As View) [12, 13, 14, 6, 8]. The advantages and disadvantages of these two approaches are opposite [8]. *LAV* is flexible for updates but the construction of query's answers is complex, contrary to the construction of answers in a system adopting an approach *GAV* which simply consists in replacing the predicates of the query global concepts by their definition. *GLAV* (Global-Local As View) [15] is the combination of *GAV* and *LAV*. It inherits the query unfolding property of GAV, maintains independence between data sources and allows to indirectly computing mappings between them. It uses views in local and global levels. The query processing in this model is only feasible when the query is expressed in a language that takes into account global and local levels.

In this context, we propose an ascending method for building ontologies starting from the local ones, then we use these ontologies to build manually the global ontology and define mappings between global and local ontologies (figure 1). We use *OWL* (OntologyWeb Language) to define ontologies and their mappings. Our goal is to use the ontologies terminology to formulate user queries. To reach this goal, we propose a query language based on global ontology concepts and local ontologies properties. The problem of mediator using several ontologies according to the *GLAV* model is the query rewriting and the way how the obtained results are combined. For this end, we propose our query rewriting algorithm, which enables to reformulate user queries to queries comprehensive by the mediator.

Our work lies within the scope of a project of virtual data warehousing of banking data in LCL - Le Crédit Lyonnais (French bank). The purpose of the project is to manage and improve the decision process in LCL in the direct marketing activities domain. It contains many management applications and databases. The banking data are heterogeneous and change much, so the construction of cubes on-the-fly is pertinent. Each cube represents a specific analysis context.

The remainder of this paper is organized as follows. Section 2 presents our mediation system starting by our approach, which allows to create various ontologies applied to the case of the sources of the LCL. Next, we present our query language. After that, we present our query rewriting algorithm and give an example. The architecture and the implementation of our mediator are exposed in section 3. We finish this article by the section 4 which concludes our work and presents the prospects on new generated problems.

2. ONTOLOGY-BASED MEDIATION SYSTEM

The construction of the mediation system is decomposed into three steps:

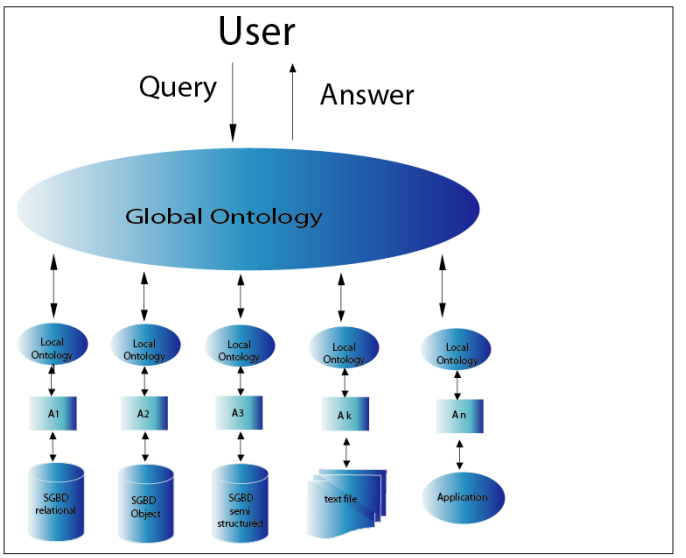
1. definition of local and global ontologies
2. definition of a query language
3. definition of the query rewriting algorithm.

2.1 Ontologies Development Approach

In this section, we present our approach of ontologies construction using the hybrid architecture modelled according to GLAV model. We also use OWL for the ontologies description. In fact, OWL is capable to describe data and metadata in order to make ontologies more powerful for the integration task. OWL is based on RDF (Ressource Description Framework), so it gathers the RDF description power and the mechanism of reasoning. The approach we propose consists in creating ontologies in an ascending way. We start from local ontologies, and extract a global ontology from the local ones in order to facilitate the semantic reconciliation between sources.

- The first phase consists in creating local ontologies. It contains two steps: (1) the analysis of sources; and (2) the definition of ontology concepts. The first step is a complete analysis of each source independently. The analysis consists in searching primitives used in sources, implicit information, its storage, its significance and its relation with other terms. After that, we define concepts which will constitute the ontology hierarchy, their relations and constraints on their use.
- The second phase is the extraction of the global ontology starting from various concepts used in local ontologies. It contains two steps: (1) local ontologies analysis; and (2) selection of all concepts and solving semantic conflicts. The first step is a complete analysis of local ontologies. Note that, ontologies analysis is easier than that of data sources. After concepts selection, the expert solves all kinds of heterogeneity (naming conflicts, confounding conflicts and/or scaling conflicts) to determine global ontology concepts.
- The third phase, which represents the core of the system, consists in defining mappings between the global and local ontologies. The global ontology is built

Figure 1. Ontology-based mediation system



from local ontologies. So, in order to identify the original ontological source of concepts, we use annotations. *OWL* enables the annotation of concepts and properties according to predefined meta data schema.

Our study is limited on relational data sources, where tables are represented by *OWL* classes. Relationships between classes are represented in *OWL* by *owl:ObjectProperty* and *owl:-DatatypeProperty. OWL* properties can represent various attributes and constraints in the relational schema. They also represent attributes by *Datatype*. If the attribute is a primary key constraint, then a functional characteristic will be added. In addition, we use *owl:ObjectProperty* to represent foreign keys attributes. Therefore, we obtain two ontologies representing the two relational data sources. The process of ontologies development must be particularly reliable for the global ontology construction. In fact, this ontology ensures the connection between various local ontologies and contains the knowledge for the query formulation and the data warehouse construction. The LCL has two relational data sources, each one contains two tables. the *OWL* schema is represented in the following table:

2.2 Query Language

The use of the global ontology as a model for query reformulation is not new. It can be more intuitive for the users. Our system allows queries to exploit concepts of the global ontology and properties of local ontologies. A basic user query is in the form:

Concept ^ Property ^ Concept or only Concept.

2.3 Query Rewriting

The *GLAV* Approach corresponds to each concept $Concept_G$ or V_G from the global ontology a concept $Concept_L$ or a view V_L from the local ontology. A query

Table 1. LCL relational tables representation in OWL

Tables	Equivalent OWL
Collaborator	owl:Class rdf:ID="Collaborator"
MarketingDemand	owl:Class rdf:ID="MarketingDemand"
Person	owl:Class rdf:ID="Person"
Profile	owl:Class rdf:ID="Profile"

expressed in terms of global ontology can not be always reformulated in a view from the local ontology only if the query is expressed in terms of the global and the local schemas. For that we propose the preceding query language (see example in section 2.3.2) and the following rewriting algorithm.

2.3.1 Rewriting Algorithm

The user query expressed in our language query will be rewritten by our algorithm to obtain a set of linked subqueries. If a concept in the user query is not linked with the preceding ones, it will be excluded. Semantically, this exclusion tends to make the query coherent. A coherent query is decomposable into subqueries, and of which its results can be recomposed. The query rewriting can be seen as a mapping between the global ontology and local ontologies.

- **Formal Algorithm**: Formally, a based-ontology mediation system *O* is a triplet *(G, S, $M_{G,S}$)* where *G* is the global ontology, *S* is the set of local ontologies and $M_{G,S}$ are mappings between the global ontology *G* and local ontologies *S* in O.
- **Global ontology**: Let C_g be the set of the hierarchic concepts of the global ontology, An_g the set of annotations, and Annotation a function defined from C_g to An_g.
- **Local ontologies**: Let *S* be a set of *n* local ontologies S_1, S_2,..., S_n. We note A_{si} the set of a local ontology concepts. A_s is the union of the A_{si} of the n local ontologies. Local ontologies concepts are linked by a set Rsi of properties defined in $A_{si} * A_{sj}$. Let R_s be the union of all properties sets R_{sj}. Let An_s be the set of annotations and let Wrapping be the function defined from As to An_s which associates to each concept an annotation.
- **Mappings**: the mapping $M_{G,S}$ defines how the concepts of the global ontology *G* and concepts of the local ontology S_i are linked. $M_{G,S}$ is a function from C_g to S_i.
- **Query language**: Queries are expressed in terms of a query language Q_g. In our system, queries are conjunctions of global ontology concepts and local ontologies properties, so we obtain two types of queries:

Algorithm 1 Query rewriting

Entry:
$Q : Userquery$
$G = \{C_{g1}, C_{g2}, ..., C_{gn}\}, S = \{C_{s_1}, C_{s_1}, ..., C_{sn}\}, R = \{r_{s_1}, r_{s_1}, ..., r_{sn}\}$
Result:
$Q_d[k] : The\ set\ of\ k\ queries\ deduced\ from\ Q$
$T[k] : The\ set\ of\ correspondence\ tables\ for\ the\ k\ queries$
$K \leftarrow 1, Q_d[k] \leftarrow Q, NoCorrespondent \leftarrow True$
for all $u \in \{1...Size\ Of\ (Q_d)\}$ **do**
  for all $Q_i\ (i = 1...n) \in Q_d[u]$ **do**
    if $Q_i\ is\ Q_{LAV}$ **then**
      for all $Q_j\ (j = 1...i-1)$ **do**
        Ψ : *the set of subsumed, subsuming or equivalent concepts* C_s *of* Q_i
        Ω : *the set of* C_j *concepts obtained using* C_s *concepts of* Ψ *such as :* $Annotation\ (C_s) = Annotation\ (C_j)$ *and* $C_j \in Q_j$
        for all $C_j \in Q_j$ **do**
          for all $C_h \in \Omega$ **do**
            if $CorrespondConcept(C_j, C_h) \neq \Phi$ **then**
              $HasCorrespondent \leftarrow false$
              $K++$
              $Q_i \leftarrow C_i \cup r_h \cup C_h\{r_h\ is\ the\ role\ which\ links\ C_i\ and\ C_i\}$
              $Q_d[k] \leftarrow Q_d[k] \cup Q_i$
              $T[k] \leftarrow T[k-1]$
              $Addcorrespondence\ (C_j, C_h)\ in\ T[k]$
            end if
          end for
        end for
      end for
      if $NoCorrespondent$ **then**
        $Q \leftarrow Q - Q_i$
      end if
      $Else\{Q_i\ is\ Q_{GAV}\}$
      for all $Q_j(j = 1...(i-1))do$ **do**
        if $CorrespondSubQuery(Q_i, Q_j) \neq \Phi$ **then**
          $add\ the\ correspondence\ (C_i, C_j)\ in\ T[k]$
        else
          $Q \leftarrow (Q - Q_i)$
        end if
      end for
    end if
  end for
end for
$return(Q_d, T)$

1. Either the user uses the global ontology concepts only, in this case we obtain a Q_{LAV} query.
2. Or the user uses the global ontology concepts and the local ontologies properties, and in this case we have a Q_{GAV} query.

- **Query rewriting**: the general idea is that the mediator must obtain a conjunction of Q_{GAV} subqueries and a table of correspondence between the different subqueries. In the case of a query which contains more Q_{LAV} subqueries, it is necessary to reformulate all Q_{LAV} subqueries to Q_{GAV} subqueries to allow the construction of the correspondence table. To rewrite the Q_{LAV} to Q_{GAV} we propose the algorithm (see previous page).

The reasoning mechanism of *OWL*, helps our algorithm to obtain a set of Q_{GAV} and/or Q_{LAV} subqueries, which are equivalent semantically. The goal of the user query rewriting is to eliminate Q_{GAV} subqueries, which have not any relationship with other ones in the same query. *Function2* has as parameters two concepts C_i and C_j and gives, as result the role (if it exists), which links them. *Function1* returns two equivalent concepts or two concepts linked by a role. Our algorithm uses all global ontology concepts and local ontologies roles to provide a set of equivalent subqueries. For each subquery Q_i of the user query Q.

Algorithm 2 Function1: CorrespondSubQuery(Q_i, Q_j)

Entry:
$Q_i, Q_j : TwoSubqueries$, $G = \{C_{g_1}, C_{g_1}, ..., C_{g_n}\}$, $S = \{C_{s_1}, C_{s_1}, ..., C_{s_n}\}$, $R = \{r_{s_1}, r_{s_1}, ..., r_{s_n}\}$
Result:
$(c_i, c_j) :$ *The relationships between* Q_i *and* Q_j
for all $C_k \in Q_i$ **do**
  for all $C_h \in Q_i$ **do**
    if $C_k = C_h$ **then**
      $Return\ (c_k, c_h)$
    else
      if $CorrespondConcept(C_k, C_h)$ **then**
        $Return\ (c_k, c_h)$
      else
        $Return\ \Phi$
      end if
    end if
  end for
end for

- If Q_i is Q_{LAV} subquery, that means it contains only one concept; the algorithm selects concepts C_j into all previous subqueries Q_j of Q. So, we obtain the set of all candidate concepts.
- If the algorithm finds a correspondence between C_i and concepts C_j then, for each concept $C_j \subset \Omega$, it verifies if there is a correspondence between this concept and the concept C_i. If C_i corresponds to C_j then, it will be replaced by C_j. The result is a new rewritten subquery using the corresponding concept.
- If there is no correspondence, the concept C_i is excluded.
- If Q_i is Q_{GAV} subquery, that means it contains two concepts and a role, the algorithm search in previous subqueries of Q, a corresponding subquery. If there is no one, Q_i is excluded.
- The algorithm processes all subqueries into Q. After that it processes new rewritten queries as the initial query.

Algorithm 3 Function2: CorrespondConcept(C_i, C_j)

Entry:
$C_i, C_j : Two\ Q_{GAV}\ Subqueries$, $G = \{C_{g1}, C_{g1}, ..., C_{gn}\}$
$S = \{C_{s1}, C_{s1}, ..., C_{sn}\}$, $R = \{r_{s1}, r_{s1}, ..., r_{sn}\}$
Result:
$(r :$ *The Role, which links* c_i *and* c_j
if $r(C_i, C_j) \in Rorr(C_j, C_i) \in R$ **then**
  $Return\ r$
else
  $Return\ \Phi$
end if

2.3.2 Example

Our approach is validated on LCL relational data sources. The following query concerns all collaborators having an address in .Lyon. and a certain profile:

(Collaborator(x) ^ hasAddress(x; y) ^ Address(y)) ^ (Address(z) ^ hasAsTown(z; "Lyon")) ^
(Profile(p))

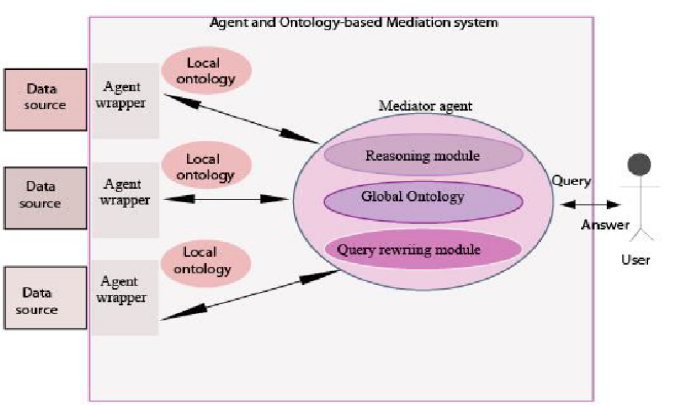
The mediator breaks up it into three subqueries. The two first are sent directly to the sources to be executed because they are linked by the concept Address and thus they can be recomposed by a classic join. However, the third subquery is not linked directly with the two previous subqueries. The mediator must find a link between Profile concept and concepts of the previous subqueries, if there is no link, it excludes this concept. In our example, the mediator must find a link between two concepts .Collaborator. and .Address., which is a property gathering directly these concepts with Profile concept. It can be also a property links Profile concept to another equivalent concept, subsumed or subsuming one of the two previous concepts: *Collaborator* or *Address*. In our case, *Person* concept is the concept subsuming *Collaborator*, and it has a link with *Profile*. The mediator must thus rewrite the third subquery *Profile(p)* into "*Person(r)* ^ *HasProfile(r,p)* ^ *Profile(p)*". It must add in his table of correspondence that *Collaborator* of the first subquery corresponds to *Persone* of the third subquery. It will join its result with the two previous one.

3. IMPLEMENTATION

To validate our approach, we develop a prototype that implements our architecture of mediation. Our system manages data sources independence and their distributivity. It manages also the interaction between global ontology and local ones during the query creation. Our prototype is based on Multi Agents Systems (*MAS*) since they are more adapted for distributed and cooperate environments. Our environment is distinguished from the existing integration systems by mediation by the fact that it enables to express descriptions of sources using the recent recommendation *W3C* for the ontologies description, which is *OWL*. It offers very interesting possibilities of descriptions and reasoning. Our objective is also to combine the power of expression and description of language *OWL* with the aspect communicating and cooperative Systems Multi Agents (*MAS*).

The mediator is an agent that communicates with other agents. It contains the global ontology and the rewriting module. The other agents are the sources agents. The process of query creation or rewriting is done by a dialogue between the agent mediator and the other agents. For the development of this environment, we used a certain number of tools: the ontology editor Protégé2000[1], the framework *JADE*[2] for agents, the framework *Jena*[3] for *OWL*-ontologies handling. Jena is a project of free source code developed by *HP* for the semantic Web. This framework offers us many advantages: it enables to have a uniform access for various ontologies because all information is stored in a *Jena* model. For the reasoning on *OWL*-ontologies, we use the free arguer *Pellet*[4], which allows to reason on the terminological part. Queries interface is presented in the form of a Java Web application based on the framework *Struts*[5].

Figure 2. Based-agent mediator architecture



4. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a new approach of data sources integration based on ontologies in data warehousing environment. Our approach is based on a hybrid architecture, using a global ontology for the mediator and local ontologies for the sources. It is important to create global ontology starting from local ontologies, because this facilitates and improves the resolution of semantic heterogeneity between data sources. We defined a method of ontologies construction, a language which guarantees the correct treatment of queries , by allowing their expression in terms of global and local ontologies. We also proposed a strategy of query rewriting, which ensures the user query coherence, by eliminating concepts not linked with others of the same user query. We applied our approach of ontologies creation on the relational sources of the LCL.

These ontologies are used in our system of integration, and were useful in the phase of creation and rewriting of queries. Various perspectives are considered. Initially, completing the implementation. Then the adaptation of the system to the various sources of information. It will be necessary to automatize the ontologies conception method. To reach this goal, we think to use data mining techniques to generate concepts classes and relationships in a formal way.

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ENDNOTES

1 http://Protégé.standard.org
2 http://jade.tilab.com
3 http://jena.sourceforge.net
4 http://www.mindswap.org/2003/pellet/
5 http://jakarta.apache.org/struts/