AN ONTOLOGY MAPPING ARCHITECTURE TO FACILITATE SEMANTIC INTEGRATION

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Abstract: Mapping between ontologies is the major bottleneck in semantic integration. In this paper, we present MCMA, a mediator-centric mapping architecture that facilitates the integration between ontologies of interrelated companies. In MCMA, different ontologies are mapped through some middle concepts and the Mapping Service acts as a bridge to connect them. As a mediator, the provider of Mapping Service is interested in a specific area and offers some common ontologies for participators to reuse. On the assumption that each individual ontology may reuse or make reference to common definitions, some mapping relations can be defined conveniently. Based on these basic mapping relations, the Mapping Service infers more middle-concept oriented mapping relations and organizes them in a layered manner. We present the idea of combining heuristics or machine-learning techniques with common ontology approach in the mapping discovery.

1 INTRODUCTION

Heterogeneity is the main problem in the integration of information systems. Diversified technologies have been suggested for improving the inter-operability between heterogeneous systems. Ontologies, which capture the semantics of information from various sources and giving them a concise, uniform and declarative description (Fensel, 2001), can make the data more sharable and machine-understandable. Some researches show that ontologies are the most likely candidates for solving the interoperability problems, and there have been works (e.g. cui, 2002) of using ontologies to facilitate B2B integration.

Though there are many works in developing common ontologies, the pervasive adoption of common ontologies seems unlikely (Hameed, 2004). When various ontologies are developed, different representations and terminologies for the same concepts emerge and new interoperability problems come up (Su, 2004). In order to reconcile different ontologies, it is necessary to establish the mapping between ontologies.

The ontology mapping is well studied in recent years. In terms of the mapping architecture, the common ontology approach or its variant (Hameed, 2004) seems appropriate for some applications, such as B2B integration. However, it is questionable that a cluster of individuals would completely agree to one or several common ontologies. In fact, the more potential vision is that business partners may reuse some definitions of common ontologies to develop their ontologies, and they can extend the common ontologies with concepts and properties specific to their applications. In such a scenario, the individual ontologies don't absolutely conform to the common ontologies, thus the common ontologies don't have sufficient power to map all the individual ontologies, and parts of the individual ontologies should be mapped directly. Unfortunately, the individual ontologies usually don't know each other. They need some support in the mapping discovery and process.

In this paper, a Mediator-Centric Mapping Architecture (MCMA) is introduced. The initial

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purpose of MCMA is to facilitate the integration of some inter-related companies, such as the companies related to certain industry. In MCMA, there is a Mapping Service acting as a mediator to reconcile different ontologies. It is based on the following premise: The provider of Mapping Service is interested in a specific area and offers some common ontologies for participators to reuse. The common ontologies here are just some reference modules capturing shared understandings of the specific area. They don't act as centralized standards and don't restrict the participators' information descriptions. The participators can make some extension or modification according to existing data source or particular business knowledge while developing their individual ontologies..

On the assumption that each individual ontology may reuse common definitions more or less, there are some obvious mappings between individual ontologies and the common ontologies. And it seems feasible for the Mapping Service to infer more direct mappings between individual ontologies. In order to keep the middle-concept oriented mapping mode, the inferred direct mappings are transformed to middle-concept oriented relations.

Content of this paper is structured as following. Section 2 surveys some related works and provides a background to our research. Section 3 presents MCMA, the mediator-centric mapping architecture. Section 4 describes how the Mapping Service infers direct mappings between ontologies and transforms them to virtual mapping relations. Section 5 discusses some features of MCMA. Finally, the paper ends with a conclusion.

2 BACKGROUND

Mapping between ontologies is the major bottleneck in semantic integration. In a decentralized view, every business partner may adopt different ontologies to represent domain knowledge. Building direct mapping for each pair of ontologies is cumbersome or even impossible. Silva argues that common ontology approach (Silva, 2002) can reduce the number of mappings. Using this approach, individual ontologies are mapped through a common ontology. Thus they are relatively independent of each other. In the work of Hameed (Hameed, 2004), a more manageable, scalable variant of common ontology approach is introduced. In the variant, each individual ontology maps to the common ontology for its cluster, and the common ontologies are mapped to allow the exchange of information and knowledge between the clusters.

Though the common ontology approach and its variant seem potential, we usually do not have the luck that all ontologies can be mapped through common ontologies since reaching a consensus is not easy. If parts of ontologies can't be mapped through common ontologies, they should be mapped directly. Usually, heuristics or machine-learning techniques are used in the process of inferring direct mappings between ontologies. For example, GLUE (Doan, 2002) applies multiple learners to exploit information in concept instances and taxonomic structure of ontologies. It uses a probabilistic model to combine the results of learners. In another probabilistic framework (Pan, 2005), ontologies are firstly translated into Bayesian networks, and the concept mapping is realized as evidential reasoning between the two BNs by Jeffrey's rule.

There are also some researches that try to develop methods for improving the quality of existing mappings. OMEN (Mitra, 2005) is an example that improving existing ontology matches based on a probabilistic inference. OMEN uses a Bayesian Net to represent the influences between potential concept mappings across ontologies, and uses the mapping to infer mappings between related concepts. This mapping strategy is also described as "Taxonomy context based strategy" (Tang, 2005).

Our work is enlightened by above research works. We are concentrating to design an ontology-based integration framework for some interrelated companies. Since these companies are related to a specific industry or domain, it seems that the ontology reusing (Ding, 2002) is an applicable mechanism to simplify the ontology developing and improve the similarity between different ontologies. In our integration framework (Wang, 2005), some common ontology modules are provided for registered companies to reuse. Due to the reusing, parts of individual ontologies can be mapped through common ontologies. However, since the particular business context can be involved, there are some concepts that have no correspondence in the common ontologies existing in various individual ontologies. Motivated by the analysis above, we design MCMA, an ontology mapping architecture that combines Heuristics and Machine-learning techniques with common ontology approach to discovery mappings. In our work, some related researches are adopted and extended to meet the application scenario.

3 MEDIATOR-CENTRIC MAPPING ARCHITECTURE

Figure 1 shows the overview of Mediator-Centric Mapping Architecture (MCMA). In MCMA, there is a central Mapping Service that serves as a mediator to facilitate the mappings between individual ontologies. Different ontologies are mapped through some middle concepts and there are mapping relations that relate concepts in individual ontologies to middle concepts. The middle concepts are not limited to the concepts that are described in the common ontologies, they can be virtual concepts defined by the Mapping Service. The Mapping Service is responsible for building and updating the mapping relations, as well as bridging the individual ontologies according to the mapping relations.

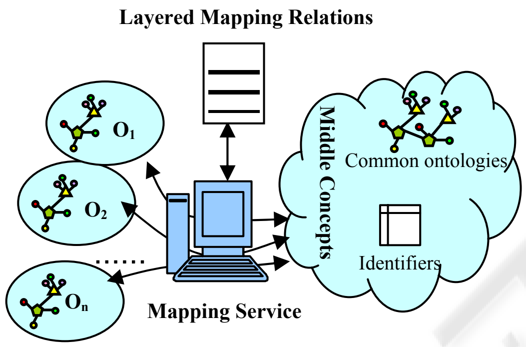

Figure 1: Mediator-Centric Mapping Architecture.

3.1 Mapping through Middle Concepts

Different ontologies in MCMA are mapped through middle concepts. The mapping relations serve as the main evidence for the Mapping Mediation Service to find the matching pairs between individual ontologies. A mapping relation is defined as:

$$MR\{O\_ID, SC, TC, P, TR_1, TR_2\}$$

- *O_ID* identifies an individual ontology.
- *SC* is a concept in the ontology *O_ID.*
- *TC* is the corresponding concept of SC, it may be either a real concept that is defined in a common ontology module, or just a virtual concept that is defined to link related concepts.
- The value of *P* (from 0 to 1) implies the possibility of the matching.
- TR_1 represents the transformation function that converts *SC* to *TC*, while TR_2 represents the transformation function that converts *TC* to *SC*. TR_1 and TR_2 can be omitted. It means that there is no transformation function needed or no transformation function available.

For instance, MR $\{O_1$, product_price, price_USD, 1} means *product_price* in O_1 is just the same as *Price_USD* in common ontology modules. In the case such as data integration, the Mapping Service can use the mapping relations to build the mappings between ontologies. According to the mapping relations with the middle concepts, similar concepts in different ontologies could be mapped to each other. For example, if there are MR $\{O_1, c_1, c, 1\}$ and MR $\{O_2, c_2, c, 1\}$ found, the concept c_1 in the ontology O_1 can be mapped to the concept c_2 in the ontology O_2, and vice versa.

3.2 Layered Mapping Relations

In MCMA, some mapping relations are defined or validated by human intervention, while some are inferred by machine. Layered mapping relations reflect the depth of mapping inference and the certainty of the mapping relations.

As mentioned previously, MCMA is based on the premise that most individual ontologies are inter-related and each ontology makes reference to common ontologies more or less. So it is convenient for the participators to define some obvious mapping relations while developing their ontologies. These mapping relations can be built in a semi-automated fashion and submitted to the Mapping Service to serve as the *basic mapping relations*, the inner layer of the layered structure.

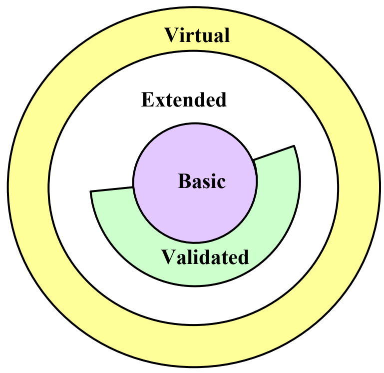

Figure 2: Layered Structure of Mapping Relations.

The basic mapping relations are not enough in the process of bridging individual ontologies. There are two reasons: (1) the basic relations are defined by human intervention, so it is probable that some mappings between individual ontologies and common ontologies are ignored. (2) In the individual ontologies, there exist some concepts that have no obvious correspondences in common ontologies.

These concepts can't be mapped through common ontologies. Therefore, in order to reconcile different ontologies, the Mapping Service should do the mapping inference. Since there have been basic mapping relations, taxonomy context based strategy (Tang, 2005) seems appropriate.

Mapping inference in MCMA consists of two phases. At first, the Mapping Service infers more mapping relations between individual ontologies and common ontologies on the basis of basic mapping relations. The inference task is disassembled to a series of sub-tasks. A sub-task is responsible for inferring more mappings between two ontologies, a common ontology and an individual ontology that have been partly mapped. A sub-task is done by a relatively independent sub-service of the Mapping Service, Direct Mapping Enhancer. The mapping relations infered from this phase are termed as *extended mapping relations,* which locate in the middle layer of the layered structure. In this layer, the *validated relations* are distinguished from the other relations. They represent some of the extended relations that are validated by the owners of participated ontologies.

Secondly, According to the previous two layers of mapping relations, the Mapping Service infers more mappings between individual ontologies. In order to be consistent with the middle-concept oriented mapping mode, the inferred mappings are transformed to *virtual mapping relations*, in which concepts are mapped through *virtual concepts*, some identifiers defined by the Mapping Service. The virtual mapping relations form the outer layer of the layered structure. The inference of virtual relations is more difficult, and we will discuss the inference of virtual mapping relations in section 4.

3.3 The Management of Mapping Relations

The Mapping Service and related participators operate in a highly dynamic environment. It is improper to regard the MCMA as a static architecture. New ontology may join, or an existing ontology may drop out. Furthermore, all the ontologies, including individual ontologies and common ontologies, may evolve constantly. Thus the Mapping Service should manage the change of the Mapping Relations.

In the layered structure of mapping relations, a layer depends on the layers under it. Accordingly the change of a layer may cause the modification of the layer above it. For example, if the basic mapping relations are changed, the Mapping Service should rebuild the extended mapping relations and the virtual mapping relations.

Most changes are introduced by the variation of ontologies. When a participator's ontology is modified, the participator should propagate the changes to the Mapping Service and the Mapping Service should revise the mapping relations that involve the changed ontology. The situation is more complex when changes occur in a common ontology. The Mapping Service should notify all the participators who make reference to the changed common ontology and the participators should make modification to the basic relations that involve their ontologies. If some participators couldn't do the modification, the Mapping Service would delete the relations that seem doubtful due to the variation of common ontologies. Obviously, the modification of common ontologies can cause the updating work very hard, so it is recommended that only stable concepts be defined in the common ontologies.

4 BUILDING VIRTUAL MAPPING RELATIONS

The virtual mapping relations are inferred on the basis of the basic mapping relations and the extended mapping relations. The major steps are described as follows: Firstly, according to the existing mapping relations, the Mapping Service builds primary mappings for each pair of ontologies. Secondly, according to the primary mappings and the semantic relations between concepts, the Mapping Service infers more direct mapping relations between individual ontologies. Finally, the inferred relations are transformed to the virtual relations that are middle-concepts oriented. In this section, we will discuss how new mappings are inferred and transformed to the virtual relations. In order to reduce the complexity of mapping inference, we ignore the transformation between concepts while doing the inference. So a mapping relation is denoted as MR {O_ID, SC, TC, P} in the inference.

4.1 Direct Mapping Inference

According to the basic mapping relations and the extended mapping relations, the Mapping Service can build some primary mappings for each pair of individual ontologies. Once the Mapping Service has built the primary mappings for each pair of ontologies, the next step is to infer more direct mappings between them.

Except the primary mapping relations between ontologies, the semantic relations between concepts are used to infer new mapping relations. A semantic relation is defined as:

SR {O_ID, C1, C2, R}

- *O_ID* identifies an ontology. If the *O_ID* is omitted, it means that the semantic relation is about the concepts in common ontologies.
- Both *C1* and *C2* are concepts in the ontology *O_ID*.
- R refers to the semantic relationship between C1 and C2, such as *Is_a*, *Part_of*, *Disjoint_with* and *Overlap_to*.

Therefore, based on the primary mapping relations and semantic mapping relations, the Direct Mapping Enhancer infers more direct mappings between two ontologies. These new mappings cluster to form the set of Direct Mappings (DM), which serve as the key evidence to build the virtual mapping relations.

Threshold is given to decide whether the direct mapping inference for a pair of ontologies can be carried out. Only if the primary mappings between two ontologies are above the threshold (i.e. more than 20% of the concepts have been mapped), the Mapping Service does the mapping inference for them. Once a pair of ontologies has passed the inferability examination, a sub-service, the so-called "Direct Mapping Enhancer" is invoked to infer more mapping relations between them. Figure 3 shows the mapping inference algorithm.

Input:
PM={MR_1,MR_2,….,MR_m},
MR_i represents an existing mapping relation.
SR={ SR_1, SR_2, ….,SR_i…., SR_n}
SR_i represents the set of the semantic relations of O_i
Step:
For each middle concept c that appears in PM do
  While there are {O_i, c_k, c, p_k}∈PM
      and {O_j, c_l, c, p_l}∈PM do
    Add concept pair (c_k, c_l , p_k*p_l) → $M_{i,j}$
    Delete {O_i, c_k, c, p_k} and {O_j, c_l, c, p_l} from PM
  End While
End For
For i=1,….n-1 do
 For j=i+1 ….n do
   the number of concepts pairs in $M_{i,j}$ → num1
   the maximum number of concepts
      in O_i,O_j→ num2
  If num1/num2>= threshold then
    (1) Invoke "direct mapping enhancer", infer
      more mappings between O_i,O_j on the basis
      of $M_{i,j}$, SR_i and SR_j;
    (2) The set of new mappings between
      O_i,O_j→$NM_{i,j}$
    (3) For each (c_k, c_l, p)∈$NM_{i,j}$ do
        If p> a given threshold Then
          Add { O_i, c_k, O_j, c_l, p}→ DM
      End For
  End If
 End For
End For
Output: DM, the set of new direct mappings

Figure 3: The Mapping Inference Algorithm.

In MCMA, the Direct Mapping Enhancer is a relatively independent sub-service that infers more mappings between two partly mapped ontologies. In this paper, we mainly concern the middle-concept oriented mapping architecture. So we don't discuss the algorithm of Direct Mapping Enhancer in detail. In principle, it can be any related techniques adopt from the current and future researches, and it can be updated whenever necessary. Currently we mainly adopt some ideas from OMEN (Mitra, 2005). And we find that the result of mapping inference is ideal if two ontologies have the similar structure. However, if there is structure discrepancy between two ontologies, the inference work is hard and the result is still not satisfactory enough. We are trying to improve the algorithm of Direct Mapping Enhancer to get more ideal mapping result.

4.2 Transforming Direct Mappings to Virtual Mapping Relations

Once the Mapping Service has inferred more direct mappings between ontologies, the next step is to generate new mapping relations according to the inferred direct mappings. In order to be consistent with the middle-concept oriented mapping mechanism of MCMA, the Mapping Service should transform the inferred direct mappings to the virtual mapping relations. Some identifiers are introduced to serve as the middle concepts when building the virtual mapping relations. The following summarizes the transformation algorithm:

Input: DM, the set of inferred direct mappings.
Output: VMR, the set of virtual mapping relations.
Step:(1) In terms of DM, calculate the total-probability of mappings for every concept that appears in DM. Let P={ p(O_1, c_1), p(O_1, c_2)…p(O_i, c_k)…}be a set of total-probability, and p(O_i, c_k) represents the total-probability of the concept c_k in ontology O_i. For each { O_i, c, O_j, c', p}∈DM, do p(O_i, c)= p(O_i, c) +p and p(O_j, c')= p(O_j, c')+p.

(2) Select the maximum value p(O_{max}, c_{max}) from P. Then a new identifier *id* is defined to replace the However, the Mapping Service does not infer mappings for every pair of ontologies. Before

inferring new mappings, the Mapping Service exams the infer-ability for each pair of ontologies. A concept c_{max} in O_{max} **.** Add { O_{max}, c_{max}, id,1}to VMR and invoke the recursive function *FindSimilar(*O_{max}, c_{max}, *id*) to find concepts that is similar *to* c_{max} and do the transformation work.

(3) Do (2) until DM=ф

```
FindSimilar (O_rep, c_rep, id)
{   while there exist mapping relations that
                          involve (O_rep, c_rep) in DM, do
      {  select a mapping relation { O_i, c, O_rep, c_rep, p}
                    or { O_rep, c_rep, O_i, c, p} from DM;
          add virtual relation{ O_i, c, id, p} to VMR;
          delete the selected relation from DM;
          if(p==1) FindSimilar (O_i, c, id);
       }
}
```

Figure 4: The Recursive Function—FindSimilar.

The total-probability of a concept indicates how probably the concept maps to the other concepts in the DM. It seems suitable to select a concept with larger total-probability to act as the middle concept.

The main purpose of the Function *FindSimilar* is to find the concepts that can be matched to the identifier *id* as much as possible from the direct mapping set *DM.* The recursive process restrain the situation that more than one identifier are created to replace the completely same concepts which are defined in different ontologies.

5 DISCUSSIONS

The main purpose of MCMA is to facilitate the integration of some interrelated companies. Our early research focuses on the following question: Does the MCMA seem promising in the application scenario? To answer this question, we have investigated some companies that are related with the ironware industry. As expected, despite the terms and information models are diversified, there are still shared understandings among these companies. Accordingly, though these companies can't absolutely conform to one or several common ontologies, they can benefit from the reusing of some shared ontologies while developing their individual ontologies(Wang, 2005).

Therefore, we think it is the more convincible architecture that companies can freely reuse contents of common ontologies to develop their individual ontologies. The common ontologies are shared modules capturing relevant concepts and knowledge that most companies expected. They may be stored in a library. The related companies can select desired modules on it's own account and custom-modulate to meet their needs while developing individual ontologies. In such a scenario, only parts of individual ontologies can be mapped through common ontologies. So the common ontology approach (Silva, 2002) seems not competent here.

MCMA is designed for the integration scenario above. In MCMA, the Mapping Service can discover more potential mappings by combining the mapping inference technologies with the common ontology approach. As we have mentioned before, the main feature of MCMA is mapping ontologies through middle-concepts. While transforming the inferred direct mappings to the middle-concept oriented relations, virtual concepts are introduced to link concepts between ontologies.

The primary reason of using virtual concepts to replace the actual concepts is to reduce the dependency between ontologies. For example, supposing there are direct mappings {O_1,c_1,O_2, c_2,1}, {O_1,c_1,O_3,c_3,0.7}, and {O_1,c_1,O_4,c_4,0.8}in DM, and id_1 is defined to replace concept c_1 , the virtual relations MR{O_1,c_1,id_1,1}, MR{O_2,c_2,id_1,1}, MR{O_3, c_3,id_1,0.7} and MR{O_4,c_4, id_1, 0.8} would be appended to the VRM. Thus the concept c_1, c_2, c_3 and c_4 can be mapped to each other through id_1. If the ontology O_1 drops out from the mapping architecture, what needed is deleting MR{O_1,c_1, id_1,1} from the VMR. The concept c_2, c_3 and c_4 can still be mapped through id_1.

From the above example, we also notice that more concepts can be matched with each other after the direct mappings are transformed to virtual mapping relations. In the above example, either c_2 or c_4 can be mapped to c_1 according to the direct mappings in DM, but there is no direct mapping relation between c_2 and c_4. In other words, c_2 and c_4 can't be mapped to each other in the direct mapping mode. However, while the direct mappings are transformed to the middle concept oriented mapping relations, $c_1$and c_2 can be mapped through the virtual concept id_1.

In our experiment, we find a mapping problem that caused by reduplicate and inconsistent virtual mapping relations. In the previous example, c_3 and c_4 can be mapped through id_1. Supposing that there is also a direct mapping relation {O_3,c_3,O_4,c_4,0.75} in DM, and two virtual mapping relations MR{O_3,c_3,id_3,1}and MR{O_4,c_4, id_3, 0.75} are appended to the VRM during the transformation, c_3 and c_4 would be mapped through id_3. It seems trouble when the Mapping Service tries to match c_3 and c_4 since they can be mapped through id_1 or id_3 with different mapping probabilities. We called this phenomenon "mapping inconsistency".

The inconsistency would not happen while the Mapping Service was building the exact mapping for ontologies. In this situation, only certain mapping relations (the possibility value p=1) are selected to build the mappings. However, if the mapping process is carried out in the situation that precision of information is not very important, such as information searching, the mapping inconsistency may occur since some uncertain mapping relations would be selected to build the mappings. Fortunately, in this situation, we mainly concern the maximum possibility that two concepts would be matched. Thus inconsistency of the mapping relations doesn't impede the Mapping Service to discover the matching possibility of two concepts.

MCMA seems suitable for our integration scenario. Since all the individual ontologies in MCMA are mapped through middle concepts, they are relatively independent of each other. Furthermore, The middle-concept oriented approach makes it convenient to map one concept in certain ontology to multiple concepts in other ontologies. So MCMA is especially suitable for the situation that 1:n mapping is necessary, such as information searching.

Since ontologies may evolve constantly, the update of mapping relations in MCMA is crucial. In our work, we assume that the Mapping Service can get notified if there is any change happening, and it would rebuild the mapping relations when necessary. Furthermore, if there are changes happening in the common ontologies, the changes can propagate to the related participators, who would modify the basic mapping relations.

6 CONCLUSIONS

In this paper, we have presented MCMA, an ontology mapping architecture that facilitates semantic integration for some inter-related companies. Obviously, MCMA is enlightened by the common ontology approach (Silva, 2002). But it is somewhat different from the usual common ontology approach. In MCMA, the mapping relations, that serve as the main evidence for the Mapping Service to bridge individual ontologies, are arranged in a layered manner. Thanks to the reusing, the basic mapping relations, the first layer of the layered structure, can be defined conveniently by participators. And mapping relations of other layers can be inferred on the basis of the basic relations. From the inference of virtual mapping relations, we see the probability of combining heuristics or machine-learning techniques with common ontology approach in the mapping discovery.

Though MCMA is middle-concept oriented architecture, the direct mapping inference is a crucial step in the building of layered relations. In future, we plan to improve algorithms of the direct mapping inference. Besides, future work also includes developing an integrated mechanism of managing and updating the layered mapping relations.

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