A FRAMEWORK FOR MANAGING MULTIPLE ONTOLOGIES: THE FUNCTION-ORIENTED PERSPECTIVE

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Abstract: Ontologies are now ubiquitous in Semantic Web and knowledge representation areas. Managing multiple ontologies is a challenging issue including comparing existing ontologies, reusing ontologies, maintaining different versions, and so on. However, most previous multiple ontologies management work focused on ontologies maintenance, evolutions, and versioning. They ignored the very important point: exploiting the functions of multiple ontologies provide. This paper proposed a new framework for managing multiple ontologies based on the function-oriented perspective, and its goal is to bring multiple ontologies together to provide more powerful capabilities for the practical applications. The new multiple ontologies management architecture is more feasible and robust in the dynamic and distributed Semantic Web environment.

1 INTRODUCTION

The Semantic Web (Berners-Lee, 2001) envisions a world-wide distribute architecture where data and computational resources will easily interoperate based on semantic marking up of web resources using ontologies. Ontology is a formal, explicit specification of a shared conceptualization (Gruber, 1993), and is also the core of knowledge representation in the Semantic Web. The Semantic Web researches have improved the popularity of ontologies greatly. Although large amount of endeavors have been done for the ontology building that produced many methodologies, tools and criteria for helping the ontology development (Noy, 2001, Corcho, 2003, Ding, 2002), we had to accept the fact that developing ontologies is a labour intensive work. Today, researchers have already accepted such a common viewpoint that due to one cannot expect a single ontology to describe the vast amounts of data on the web, We believe the Semantic Web should be built on many small ontologies (Roussset, 2004, Mena, 2000). We can easily obtain various ontologies through many ways, such as from the web ontology library (DAML Ontology Library) or someone's papers. Frequently, using multiple existing ontologies not only can avoid or reduce the work for building new ontologies, but also can describing the wider knowledge and satisfying the requirements of a varied community of users.

Due to the intrinsic syntactic and semantic heterogeneities between different ontologies, managing multiple ontologies will face many challenges and problems (Noy, Musen, et al., 2004, Ding, 2001, Wendt, 2002). Obviously, we should develop the ontology maintenance methods (Stojanovic, 2003) and tools (Noy, 2004) for multiple ontologies management. Similar to the single ontology, multiple ontologies' evolutions and versioning could be considered in the management too. However, these aspects are not the ultimate goal for managing multiple ontologies, and we believe the real target of managing multiple ontologies is exploiting their powerful function for the practical applications. To bring multiple ontologies together, several ontology management frameworks have been proposed (Noy, Musen, et al., 2004, Cui, 2000, Maedche, 2003, Maedche, 2002, Das, 2001). However, these work focused on the multiple ontologies maintenance or ontology evolutions. Few work discussed the methods of managing multiple ontologies for providing more powerful ability for the applications such as semantic querying across multiple ontologies and extracting reasonable sub-ontologies from the multiple ontologies according the users' requirements.

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This paper presents a new framework to deal with the multiple ontologies management, and our idea is based on the multiple ontologies' functions. To provide more powerful ability for the practical applications, we design the five-layer multiple ontologies management architecture, and investigate the problems of normalizing multiple ontologies, expressing the complex relations between ontologies using bridge ontology, and how to provide functions for different practical requirements.

The rest of this paper is organized as follows. Section 2 argues the reasons of using multiple ontologies, and proposes the multiple ontologies management tasks we focus here. Section 3 presents the framework of managing multiple ontologies and describes the detail of each layer in the framework. Section 4 discusses the related work of managing multiple ontologies. Finally, conclusions are presented in Section 5.

2 MULTIPLE ONTOLOGIES MANAGEMENT TASKS

In this section, we will discuss the reason of managing multiple ontologies and argue the advantages of using multiple ontologies through comparing the multiple ontologies with single ontology. Then we analyze the deficiencies of former multiple ontologies management work and provide the tasks we want to realize through managing multiple ontologies.

2.1 Multiple Ontologies Versus Single Ontology

Why we want to manage multiple ontologies? What are the advantages of using them? In order to answer these questions, we begin with the comparison between single ontology and multiple ontologies shown as in Table 1. There are seven criterions listed in the table. First is the knowledge expressive range. Except for few large-scale ontologies, most single ontology can only express limited and specific domain, but the multiple ontologies can express broader and even the knowledge of crossing domains. The reasoning range is similar to the first criterion that multiple ontologies can reason on the wider range than single ontology could. As far as the usability, singe ontology is easy to use, but multiple ontologies are difficult to use for the reason of the user should know the relations between ontologies in advance. As for the acquirability, it is not easy to find a suitable ontology to meet the requirement of specific domain because each ontology may have some shortages for represent the knowledge of current domain, for example it maybe too 'big' for the needs. So in most time, the users have to build a new one. But it is easy to find multiple ontologies to overcome this problem, and we just use the suitable part in each ontology to combine to satisfy the requirements. The fifth criterion is about the heterogeneous problem. Single ontology has not this kind of problem, but it is a serious problem must be considered in multiple ontologies. How to deal with the heterogeneity is the key problem in our multiple ontologies management. As far as the ontology engineering, single ontology includes building new ontology or extending the existing ontologies, and multiple ontology need ontology mapping or merging. They both are laborious work and lack of automatic method to support. The last criterion is flexibility. It is obvious that multiple ontologies are more flexible than single ontology, and fit the distributed and dynamic Semantic Web environment.

From the comparison discussed above, both the single ontology and the multiple ones have their advantages and disadvantages. But for the fact that more and more small ontologies are popular and the difficulties of building and maintaining big ontology, it is necessary to face to employ multiple ontologies. Therefore, we need some feasible methods to manage multiple ontologies and avoid their disadvantages.

Table 1: Multiple ontologies versus single ontology

Criterion	Single ontology	Multiple ontologies
Expressive range	Limited and specific domain	Wider and cross domain
Reasoning range	Narrow	Wider
Usability	Easy to use	Difficult to use
Acquirability	Difficult to find suitable ontology for specific domain	Easy to find multiple ontologies for specific domain
Heterogeneity	No	Yes
Ontology engineering	Building new ontology; Extending existing ontology	Ontology mapping/alignment and merging/integration
Flexibility	No	Yes

2.2 The Goals of Managing Multiple Ontologies

There are two main advantages of using multiple ontologies. First, using multiple ontologies may realize the ontology reuse. Secondly, the multiple ontologies are more robust in the dynamic Semantic Web environment, which is important to the Semantic Web applications. To achieve these merits, we need an efficient management to deal with the problems of using multiple ontologies to reconcile multiple ontologies. The motivation of this paper is finding a flexible and low-cost approach to manage multiple ontologies to meet the tasks of representing crossing domain knowledge in the dynamic Semantic Web. Different from the previous work, we focus on how to exploit the powerful ability of multiple ontologies provide, and we call this is function-oriented perspective. The following is some goals we want to reach.

Query and retrieve across multiple ontologies Use the mappings defined between ontologies to support query to one ontology posed in terms of another ontology. We should manage the useful and complex relations between ontologies for the querying rewrite in these applications.

Reason across multiple ontologies Use the relationships defined between ontologies to support inference across several ontologies.

Extract sub-ontology from multiple ontologies Analyze dependencies and allow users to extract sets of concepts and relations as a sub-ontology.

Interoperability of shared ontologies Specify transformation rules between different ontologies and versions of the same ontology; Align and map between ontologies; Translate ontologies from one form to another.

3 MULTIPLE ONTOLOGY MANAGEMENT FRAMEWORK

In this section, we will present the architecture of managing multiple ontologies. And then we investigate each functional component in the framework.

3.1 Architecture

Several frameworks were proposed to manage multiple ontologies. In the function, these work mainly focus on the ontology evolution and maintenance. In the architecture, they just have two-layer architecture that is ontology repository and ontology application. There are some disadvantages in these frameworks. First, the two-layer architecture is too simple to manage multiple ontologies, and we need a more systematic architecture. Second, the functions provide by the multiple ontologies are embedded in the practical applications, and that cause many repeated work.

Our idea of solving these problems is based on two aspects. Firstly, we separate the inter-relationships among ontologies from multi-ontologies with bridge ontology, and try to provide the unified extraction for relationships among ontologies. After this step, each ontology is still independent, but we have collected the various relationships among multiple ontologies. It is a

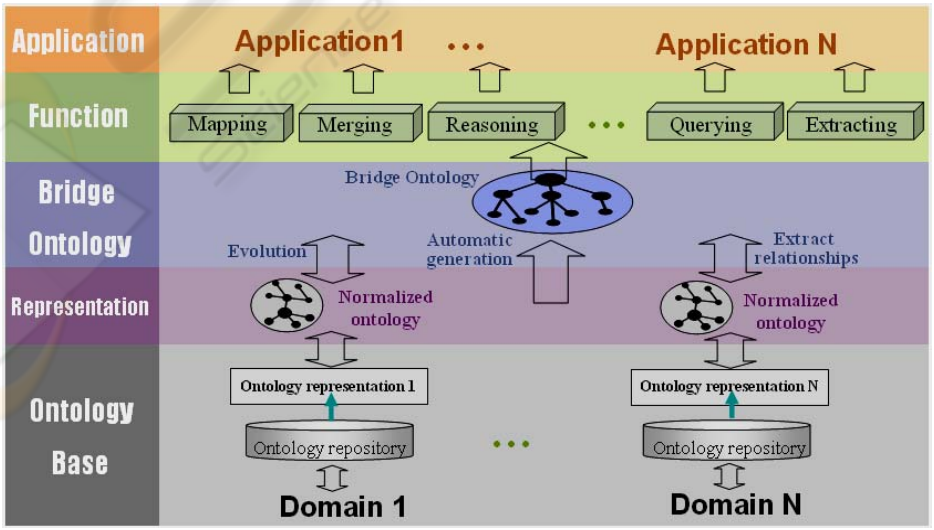

Figure 1: The architecture of managing multiple ontologies.

flexible way for the dynamic web environment. Secondly, we separate multi-ontologies functions from applications to provide unified functions for practical applications, and also provide substitute methods for unnecessary ontology engineering work such as alignment and integration.

Based on these ideas, we design a five-layer architecture for managing multiple ontologies. The framework is composed of the ontology base, ontology representation, bridge ontology to express the relations between ontologies, unified functions provided by multiple ontologies, and the practical applications.

3.2 Ontology Base

We can obtain ontologies from different ways. Each ontology may be built by different people in different period, so they may be in different model and ontology language. Some of them are built in RDF(S), some are built in OWL. These ontologies are our source ontologies, and we use the ontology base to store them.

It is necessary to store all available ontologies in the ontology base. Choosing ontologies is based on the users' requirements. For example, if the users are interested in university and company, we could only store many the two kinds of ontologies in the ontology repository.

3.3 Ontology Representation

There are many different Ontology languages on the Web, such as OWL, DAML+OIL and Ontolingua. They are different in syntax and structure, and based on different logic foundations. Besides the different in syntax, ontology languages may be based on different logic system, such as Frame Logic, Description Logic (DL) and N3. Due to different representation using different logic model and language, their expressing abilities are different too. Therefore, the analyzing, extracting and integrating methods of them are different. Translating ontologies into a unified internal representation, i.e. a unified Ontology model, is necessary.

Generally, an ontology can be seen as a quadruple $O = (C, R, X, \Delta)$, where Δ is the set of individuals; C is the set of concepts, which are subsets of Δ; R is the set of relations, which are subsets of $\Delta \times \Delta$; X is the set of axioms. This definition is very broad and general. This definition is too general and is hard to operate the ontologies in such representation.

In our framework, the information about individuals is not concerned. We focus on the concepts and relations. They are both fundamental elements in most Ontology languages. It makes the extraction difficult. We consider concepts to be the only fundamental element, and organize them into a hierarchy. Relations are divided into attributes (datatype properties in OWL) and other relations (object properties in OWL). Attributes are special relations that between individuals and literals. Both attributes and relations are depending on the concepts that they linked; they are not the fundamental element in Ontology. (The meaning of these elements in Ontology can be found in OWL standards of W3C)

Definition 1. We consider an ontology as a eight-tuple:

$O = (C, A^C, R, A^R, S(C), E(C), H, X)$

where C is the set of concepts; A^c is the set of attributes about concept $c \in C$; R is the set of relations; A^r is the set of attributes about relation $r \in R$; $S(c)$ and $E(c)$ are the sets of relations that can start and end with concept $c \in C$; H represents the concept hierarchy; and X is the set of axioms.

The concept hierarchy is the set of two-tuples of concepts that have subsumption relations. It organizes all the concepts into a well-formed hierarchy.

Relations need to depend on certain concepts. However, each relation associate to pairs of concepts; the number of pairs that is the square number of concepts may be too large to handle. An alternate plan is to describe the starting and ending of relations respectively. $S(c)$ is the set of relations $\{r \mid r \in R \wedge \exists a,b(a \in c \wedge (a,b) \in r)\}$; $E(c)$ is the set of relations $\{r \mid r \in R \wedge \exists a,b(b \in c \wedge (a,b) \in r)\}$, where a, b are individuals. An obvious fact is that $c_1 \subseteq c_2 \rightarrow S(c_1) \subseteq S(c_2) \wedge E(c_1) \subseteq E(c_2)$; the redundancy can be cleared based on this during implementing.

Attributes are specific relations depending on only one certain concept or relation; for example, person name is a string attribute of person. Axioms are restrictions about the concepts, relations and attributes. Each axiom is of course depending on the elements which it put the restrictions.

Visualization of this model is realizable. It can be viewed as a tree-like concept hierarchy with concepts as the nodes and relations between the nodes; attributes are contained in certain concepts and relations.

This model of Ontology is expressive enough to represent ontologies in most Ontology languages. It is possible to translate ontologies in other languages into this model and vice versa.

3.4 Bridge Ontology

The multiple ontologies we need are often overlapped and have relationships between them. However, we do not expect to involve the difficulties of ontology integration. The complete integration will lost the flexibility of multiple ontologies in the dynamic web. Here, we try to generate the relations between ontologies to reach the functions provide by multiple ontologies. We use a similar but more powerful method to ontology mapping, and it is bridge ontology (Wang, 2004). Bridge ontology can describe more refined relations between ontologies. The bridge ontology is a peculiar ontology, and has the ability of expressing the complex relations between multiple ontologies. It can be created and maintained conveniently, and is effective in the applications based on multiple ontologies. In bridge ontology, 12 kinds of relations between ontologies are presented such as different between concepts, complex is-a relationships between concepts, and composed relations between relations of different ontologies.

First, we generate the relations between ontologies based on the requirement of applications. We call these relations as semantic bridges. The generation process of bridge ontology has semi-automatic method to support. And all semantic bridges are managed by bridge ontology. After the generation of bridge relations, some semantic redundancies and conflicts could arise. The problem also can be solved by the algorithms in (Xu, 2004).

After the relations are generated, we just focus on the management of these relations. Due to the process of generating relationships is automatic or semi-automatic, so we can delete ontology or add new ontology into the current multiple ontologies. Now, the ontologies in the multiple ontologies are independent but their inter-relations are extracted.

3.5 Multiple Ontologies Functions

Some functions should be provided by the multiple ontologies to satisfy the requirements of applications. Firstly, all semantic bridges in the bridge ontology could provide simple and complex ontology mapping and alignment. Secondly, we could merge many ontologies as a integrated one through the semantic bridges. Third, for the bridge ontology generates the relations across ontologies, we can realize the knowledge inference across multiple ontologies. And the fourth function is that we can query across multiple ontologies because the bridge ontology provide the transform and rewrite of querying expressions. Finally, through the interaction with users' requirement, we can extract sub-ontology with complete semantic and independent function from the multiple ontologies environment (Kang, 2004).

3.6 Expected Applications

Managing multiple ontologies should server for many practical applications. The semantic annotation base on multiple ontologies is a typical application. We use multiple ontologies to provide more detailed semantic data, and can avoid the problems of finding fit ontology or building new ontologies. The information query based multiple ontologies is also a promising application. Many semantic search and query involve multiple ontologies, where the management of multiple ontologies can provide the precise or approximate querying transform. Extracting sub-ontology corresponding to the requirements also is a useful application.

4 RELATED WORK

Some frameworks of managing multiple ontologies are proposed (Noy, Musen, et al., 2004, Cui, 2000, Maedche, 2003, Maedche, 2002). Some research also put forward some challenges of the ontology management (Noy, Musen, et al., 2004, Ding, 2001, Wendt, 2002). Some people deal with the management of single ontology. (Noy, 2004) use ontology tool Prompt Pplugin to manage ontology. (Stojanovic, 2003) discussed the ontology manage through the modification of an ontology with respect to user' needs. These previous work give some foundations for the management of multiple ontologies. Different people have different perspective for the ontology management. (Das, 2001) focus on the ontology management in e-commerce. But we believe that it is a narrow multiple ontologies management. Some work of discuss the ontology management focused on the multiple ontologies evolutions or versioning problems. They all ignore the most important goal of managing multiple ontologies that is using multiple ontologies to realize the more powerful functions which the single ontology can not provide for. Therefore, we propose our function-oriented perspective for managing multiple ontologies. In other way, managing multiple ontologies is a promising way to reuse many existing ontologies.

5 CONCLUSIONS

Managing multiple ontologies is a challenging issue. Most previous work focus on the multiple ontologies maintenance and evolutions, and ignored the developing the functions of multiple ontologies. This paper proposed a new framework for managing multiple ontologies, and its goal is to bring multiple ontologies together to provide more powerful capabilities for the practical applications. The approach is not only feasible, but also robust in the dynamic and distributed Semantic Web environment. Some previous researches provide the foundations for the feasibility of this framework. Building a system to realize all ideas in the framework is the next step work.

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