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SEMANTICS BASED ON DISTRIBUTED INTERPRETATION FOR ONTOLOGY INTEGRATION

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ABSTRACT

Under the background of information integration, the semantics of ontology integration is still an open issue. In this paper, we propose a revised distributed interpretation which is adapted from distributed description logics. In our proposal, ontology integration is taken as global ontology and local ontologies connected by ontology mapping. They are respectively interpreted with description logic semantics and semantic import semantics. Due to the latter, consistency checking can be focused on global ontology and the mapped relations from local ontologies to global ontology. In this way, our method can facilitate understanding and maintenance of ontology integration.

Keywords: *Ontology Integration, Distributed Interpretation, Description Logic, Ontology mapping*

1. INTRODUCTION

Ontology has played a great role in resolving the heterogeneous of information[1][2][3]. Generally, ontologies are mapped to an upper ontology in order to communication among information sources. These works mainly pay attention to how to find more exactly matched concepts or roles and handle queries on heterogeneous information and seldom discuss its semantics. So how to interpret ontology integration is still an open issue.

Naturally, ontology integration which comprises a set of ontologies is viewed as a whole large one and given a global interpretation. This method makes it easy to reuse classical description logic reasoner to check satisfiability and make further diagnoses[3]. But it will encounter the sufficiency of reasoning existing in large ontology. Fahad[4] talked about semantics of merged ontologies. However, according to [5], there are some differences between ontology merging and ontology integration so that it is not suitable to directly use semantics of ontology merging.

In this paper, we propose a method constructing semantics based on distributed interpretation for ontology integration. We differentiate ontology integration as global ontology and local ontology. A set of interpretations explain semantics of each local ontology and global ontology respectively and use semantic import to interpret mapped relations between them. Our approach makes a distinction between ontologies integrated and mapping relations among them. It can make understanding and maintenance of ontology integration more convenient. Due to semantic import, we can check consistency and satisfiability on global ontology and mapped relations. This decreases the amount and avoids reasoning on large ontology. Our approach can apply to the situation in which each local ontology is only mapped to global ontology and no relations exist between local ontologies. If there is any, our approach is invalid.

The rest of paper is organized as follows: Section 2 explains the motivation of our method. Section 3 talks about some preliminary knowledge of description logics. Section 4 introduces our proposed method. In section 5, we make some discussion with our method. Section 6 introduces some related work. We make conclusions in section 7.

2. MOTIVATION

In [7][8], Borgida and Serafini proposed DDL to describe integration information system(IS). Each IS is described with DL, and then relations between each IS are turned into bridge rules between DL ontologies. Flow of information from one IS to another one can also be described by bridge rules. This situation is applied to information integration. But bridge rules employ correspondence to describe relations of concepts or roles between two DL ontologies. It is not DL tradition which uses subsumption expressions or something else. And more, limited to bridge rules, DDL takes one

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ontology as another one's context, so its reasoning uses context reasoning method[9]. In the case of information integration, query answering is usually handled at global side and queries are translated into ones over local ends. Context reasoning is not well suited to query decomposition.

In fact, global ontology and local ontologies in information integration have relations and should not be separated. This means some concepts or roles have direct relations between global ontology and local ontologies. It is similar with some cases of ontology reuse, but ontologies on each side do not include any syntactic symbols from the other side. This inspires us to introduce semantic import[10] to improve this situation.

3. PRELIMINARIES

In this section, we will introduce some contents about description logics(DL) and its model semantics.

Generally, ontology can be viewed as a set of DL axioms. According to the expressivity, DL is divided into several types, such as ALC, $SHIQ$, $SHOIN(D)$ etc. The difference between them is amount of the constructors each of them adopts.

Basically, ALC provides the minimal set of constructors including C ó D (conjunction), C ò D (disjunction), $\neg C$ (negation), $\forall r.C$ (universal qualification) and $\exists r.C$ (existential qualification).

For ALC, interpretation I is given on a pair ($\varDelta^I$, $\cdot^I$). $\varDelta^I$ is a set which is not empty. $\cdot^I$ is a function which maps each class or role to a subset of as following:

(1) • $^I = C^I$,

(2) $D^I = \varnothing$,

(3) C ô $D = C^I \cap D^I$,

(4) $(C$ ó $D)^I = C^I \cup D^I$,

(5) $(\neg C)^I = \varDelta^I \setminus C^I$,

(6) $(\exists r.C)^I = \{ x \in \varDelta^I \mid (x,y) \in r^I \wedge y \in C^I \}$,

(7) $(\forall r.C)^I = \{ x \in \varDelta^I \mid (x,y) \in r^I \rightarrow y \in C^I \}$.

A DL knowledge base comprises TBox and ABox which include asserted axioms. Here we only talk about TBox. If a given interpretation□ I can satisfy $C^I \subseteq D^I$, then C ô D is satisfied by I, also marked as I ' C ô D. If I can satisfy $C^I = D^I$, then $C \equiv D$ is satisfied. It means I ' $C \equiv D$. If every axiom like C ô D or $C \equiv D$ is satisfied, this DL TBox T is consistent. Sometimes I is called a model of T.

4. OUR PROPOSED APPROACH

4.1 Ontology Mapping And Ontology Integration

In our approach, we adopt hybrid ontologies to describe information integration [1], but we make a little modification. This method uses local ontologies to represent information sources and global ontology to integrate all local ontologies, as showed in figure 1.

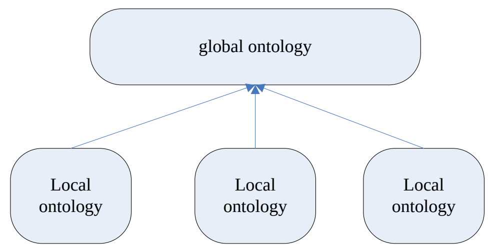

Figure 1: Hybrid Ontologies

There are mappings between global ontology and local ontologies which relate concept or roles. But different from Wache[11], there no relations among local ontologies. Then global ontology can serve as bridges or connections between local ontologies.

Hybrid ontologies can also be denoted by T = $< T_g, \{T_i\}_{i\in I}, \{B_{ig}\}_{i\in I} >$. T_g means global ontology and T_i represents each local ontology. B_{ig} shows that a local ontology T_i has mapping relations with global ontology T_g.

Global ontology and local ontologies have concepts or roles relations. In DDL, their relations are represented by bridge rules. We choose bridge rules to represent mapping relations from local ontologies to global ontology.

From a syntactic point of view, mappings do not appear on global or local side. It lists concepts or roles names and their relation type.

Definition 1(concept mapping): A concept mapping from ontology T_i to T_j is denoted by b_{ij}. It includes three types of relations:

(i) equation: i:C $\xrightarrow{\equiv}$ $j:D$

(ii) into: i:C $\xrightarrow{ô}$ $j:D$

(iii) disjointness: i:C $\xrightarrow{\perp}$ $j:D$

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Similarly, the definition of roles mapping is given in definition 2, but for roles mapping, there is no disjointness relations.

Defintion 2(role mapping): A role mapping from ontology R_i to R_j is denoted by b_{ij} which includes two types of relations:

(i) equation: $i{:}R \xrightarrow{\equiv} j:S$

(ii) into: $i{:}R \xrightarrow{ô} j:S$

The notation $\rightarrow$ is borrowed from DDL. Some ontology matching tools can help to find equation or into relation between concepts.

Example 1: there are two ontologies. One is University and the other is UNIV. They have the following concept and role mappings which are expressed using bridge rule as following.

$b_1 : University : Professor \xrightarrow{ô} UNIV : Professor$

$b_2 : University : Course \xrightarrow{ô} UNIV : Course$

$b_3 : University : teach \xrightarrow{ô} UNIV : teacherOf$

In this example, ontology University is mapped to UNIV. Professor and Course in University has a corresponding concept in UNIV and role teach is mapped into teacherOf in UNIV. Then,

$$\mathsf{T} = \{ T_{UNIV}, \{ T_{University} \}, \{ b_1, b_2, b_3 \} \}.$$

In the situation of information integration, global ontology is the center and its semantics is the most important. All other local ontologies' semantics should conform to it.

For ontology integration, mapping relations point from local ontologies to global ontology. Under this situation, the semantics of global ontology should maintain and its consistency should not violate. Three types of relations can be turned into the following axioms:

(i) $i:C \equiv j:D$ or $i:R \equiv j:D$

(ii) $i:C$ ô $j:D$ or $i:R$ ô $j:D$

We call these expressions cross concepts or roles inclusions. In this situation, concepts or roles from different ontologies can make inclusions directly. For example, $i:C$ is directly used in axioms (i), just like $C \equiv D$ in an ontology, but the prefix i or j should be listed showing which ontology this class or role belongs to.

4.2 Interpretation

Global interpretation is a usual way to expain the semantics of DL ontology. But it is not suitable for ontology integration.

1) All related ontologies will be united as one ontology. If there are many ontologies to be integrated, the efficiency of reasoning will be an issue.

2) Resolving inconsistency among so many ontologies will be another problem.

3) It is not easy to maintain. Under global interpretation, all ontologies should be stored in one file or one physics place, it is difficult to read or maintenance so large ontology.

When ontology T_i is mapped to another ontology T_j, from the point view of ontology T_j, concepts or roles defined in ontology T_i which are mapped to T_j can be seen ontology reuse by T_j. It means that ontology T_j reuse some concepts or roles from ontology T_i. And more, under the background of ontology integration, these reused concepts or roles should change their semantics to conform to ontology T_j.

Concretely, a distributed interpretation which is denoted by I comprises a set of interpretation. I = $<\{\{ I_i \} i \in I, I_g \}>$.

For each T_i, an interpretation I_i should consider two aspects[10]:

(1) if $i:C$ is a class name in T_i, then $(i:C)^{Ij} = (i:C)^{Ii} \cap ⊿^{Ij}$.

This case is showed in figure 2. It means that a class defined in an ontology should conform to the semantics of the ontology which it is mapped to. Thus it may differ from its original semantics.

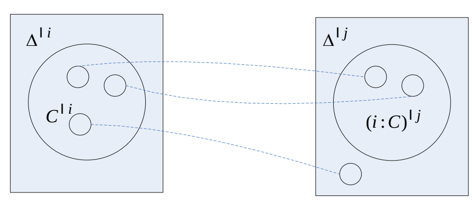

Figure 2: Interpretation For A Mapped Class

(2) if i:R is a role name in T_i, then for all d $\in ⊿^{Ii} \cap ⊿^{Ij}$, for all d' $\in ⊿^{Ij}$, <d, d'> $\in R^{Ij}$, iff <d, d'> $\in (i:R)^{Ii}$.

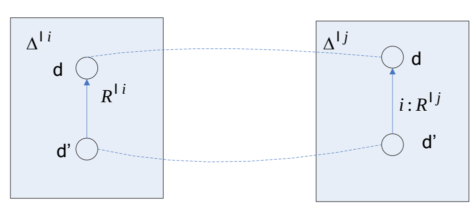

Figure 3: Interpretation For A Mapped Role

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Figure 3 shows how the semantics of a role changes when it is mapped to another one.

4.3 Satisfiability And Consistency

Similar to classical description logics, the definition of satisfiablility is based on interpretation. But for ontology integration, satisfiablity focuses on mapping between global ontology and local ontologies.

Definition 3 (Satisfiability): A distributed interpretation Ι $= <\{\{I_i\}\, i \in I\,,\ I_g\}>$ satisfies Τ , when the following conditions are satisfied:

(1) Ι ‘ $I_g \cup \{$Β$_{ig}\}_{i\in I}$,

if I_g ‘ T_g, and I_g ‘ $\{$Β$_{ig}\}_{i\in I}$;

(2) Ι ‘ T_i, if I_i ‘ T_i ;

(3) for every concept axiom in Β$_{ig}$,

Ι ‘ $i:C \equiv g:D$, if $(i:C)^{I_g} = (g:D)^{I_g}$

Ι ‘ $i:C$ ô $g:D$, if $(i:C)^{I_g} \subseteq (g:D)^{I_g}$;

Ι ‘ $i:C$ ó $g:D$ ô $\perp$,

if $(i:C)^{I_g} \cap (g:D)^{I_g} = \varnothing$

(4) for every role axiom in Β$_{ig}$

Ι ‘ $i:R \equiv g:S$, if $(i:R)^{I_g} = (g:S)^{I_g}$;

Ι ‘ $i:R$ ô $g:S$, if $(i:R)^{I_g} \subseteq (g:S)^{I_g}$

This interpretation is also called a model of Τ .

I_i in this definition is not same as the I_i in Ι . One is that I_i should not only satisfy the corresponding local ontology T_i , but also satisfy the concepts or roles reused from global ontology. I_g , as showed by condition 3.

Based on the definition of satisfiability, consistency is given in definition 4.

Definition 4 (Consistency): for an ontology integration Τ , if a model can be found to satisfied Τ , then Τ is consistent, or else it is inconsistent.

Example 2: In ontology T_1, there are an axiom which states that penguin is a bird. There are another axiom which says fling is disjunction with notFlying in T_2. And there exists two bridge rules from T_1 to T_2 as following.

T_1: *Penguin* ô *Bird*

T_2: *Flying* ô $\neg$*NotFlying*

Β : 1: *Penguin* ô 2: *NotFlying*

1: *Bird* ô 2: *Flying*

If T_1, T_2 and Β are put into one ontology, we can draw an conclusion 1: *Penguin* ô 2: *Flying* which conflicts with 1: *Penguin* ô 2: *NotFlying* . But according to our proposed distributed interpretation, although class Penguin and Bird are mapped into Β and has semantics given by T_2 , the axiom *Penguin* ô *Bird* is not admitted by T_2 and will not affect the semantics of T_2. So it is consistent.

4.4 Consistency Checking Algorithm

Based on the defintion of consistency of ontology intergration, we give the following consistency checking algorithm.

Table 1: Consistency Checking Algorithm

Consistency checking algorithm: Input: an integrated ontology Τ Output: true or false	
01.	Get each ontology including global ontology from Τ and record as O={ T_i }
02.	for each T_i in O
03.	{
04.	Check the consistency of T_i ; if (T_i is not consistent) return false;
05.	}
06.	Get all mappings from all local ontologies to global ontology and record as B={ b_{ig} };
07.	Combine B and global ontology T_g ;
08.	Check the consistency of $T_g \cup$ B; if($T_g \cup$ B is not consistent) return false;
09.	return true;

Firstly, it checks consistency of global ontology and each local ontology separately. We should separate them from Τ (1) and then, it will invoke the classical DL reasoner, such as Pellet, Racer Pro etc to perform this work (2-5).

Secondly, we retrieve mapping relations from global ontology and each local ontology (6). Generally, these relations are translated from the results of ontology matching tools, such as Alignment API etc. Whatever the format of matching result is, they all will be expressed with OWL axioms which is stated aforementioned. Then, these mapping relations can be handled by DL reasoners.

Thirdly, these mapping relations are combined with global ontology (7) and tested whether they are consistent or not (8). This results from the semantics proposed in our approach. According to

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the definition, when a class or role is mapped into another ontology, its meaning is subjected to that ontology. Its original relations with other concepts can not be transferred to that ontology. For example, in example 2, the axiom $Penguin$ ô $Bird$ defined in T_1 is not admitted by T_2. So from the point view of this algorithm, ontology integration is consistent.

5. EXAMPLE AND DISCUSSION

We show ontology integration with an example adapted from [11]. In this example which is showed in figure 4, there are four ontologies. One is UNIV which serves as global ontology and the others are local ontologies which named as University, College and Publication. Some of their concepts or roles are mapped to ontology UNIV. It states that In figure 4, only mapped roles are showed. For example, from University to UNIV, there are some relations like the following:

(1) mapped concepts:

$$University : Person \xrightarrow{ô} UNIV : Person$$
$$University : Professor \xrightarrow{ô} UNIV : Professor$$
$$University : Student \xrightarrow{ô} UNIV : Student$$
$$University : Course \xrightarrow{ô} UNIV : Course$$

(2) mapped roles:

$$University : teach \xrightarrow{ô} UNIV : teacherOf$$
$$University : degreeFrom \xrightarrow{ô} UNIV : degreeFrom$$

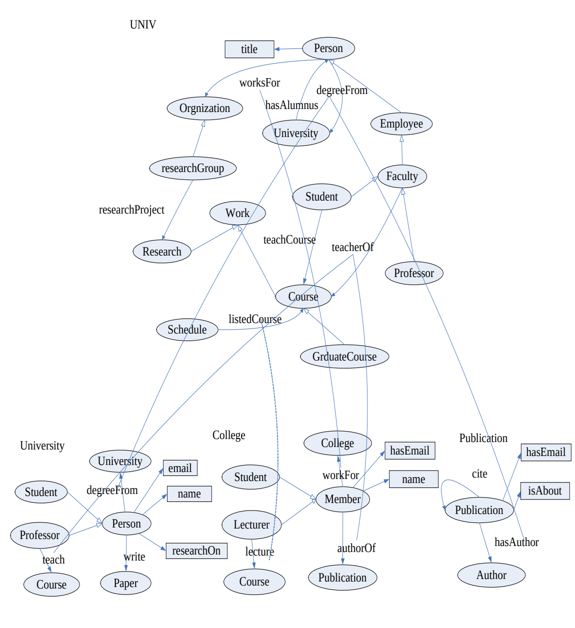

Figure 4: An Example of Ontology Integration

Global interpretation is a nature way to explain ontology integration which means that integrated ontologies are seen as a whole ontology. In this way, many existing methods and tools can be reused. But, if there are so many heterogeneous ontologies and so much dissimilarity, it is hard work to check consistency and repair inconsistency, especially when the amount of ontologies reaches a degree.

Compared to global interpretation, distributed interpretation has some advantages. It conforms to the status of scatterred ontologies. For example, as to the case of ontology integration in figure 4, four ontologies will be checked to test whether they are consistent or not. But depending on distributed interpretation, there is no need to check all these four ontologies at the same time. It first check the consistency of ontology UNIV, University, College and Publication respectively and then check the combination of UNIV and those concepts and roles which are mapped from University, College and Publication to UNIV.

Our method recieve some inspirations from DDL which first propose distributed interpretation, but DDL limits ontology mapping only between two ontologies and cross concept or role inclusions are not allowed, such as $University : Person$ ô $UNIV : Person$. It doesn't consider the need of combination. In our method, ontology mapping connects distributed ontologies and class or roles subsumptions across ontologies are permitted.

DDL explains the semantics of ontology mapping with domain relation, but it is not available for ontology mapping expressed with cross inclusions in our approach. We take cross concepts inclusions as ontology reuse and use semantic import to interpret its semantics which differs from DDL much.

Our method still operates when ontology integration overlaps which means global ontology acts as local ontology in another ontology integration. But DDL can not interpret it.

6. RELATED WORK

Jimenez-Ruiz and Grau[4] base their work on global interpretation . They propose a framework named ContentMap to check and repair consistency which fully makes use of existing ontology debugging technology.

Similar to ontology integration, Fahad[5] talks about semantics of ontology merge and algorithms of check consistency. As Flouris[6] have talked

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about, there are some differences between ontology integration and ontology merge. So ontology integration cannot fully adopt methods proposed in [5].

In [7][8], DDL is discussed. Borgida and Serafini introduce distributed description logics to express ontologies connected with ontology mappings which called bridge rules. They use domain relation to interpret bridge rules. Serafini [9][12] continues to design reasoning algorithms of DDL.

Connected ontology servers as a bridge between local ontology and shard ontology. Grau[13] talks about linking ontologies with ε -connections which uses a set of new OWL constructs.

Bao[14][15] discusses modular ontologies and its semantics. At some extent, we can conceive of ontology integration as some modular ontologies linked together. But some of its features are not suitable for ontology integration.

7. CONCLUSIONS AND FUTURE WORK

In this paper, we talk about the semantics for ontology integration under the background of information integration. Distributed interpretation is used to explain its semantics. In our method, a set of interpretations is used to explain the semantics of global ontology and local ontologies respectively. The mappings between them which are expressed by bridge rules are interpreted with semantic import. Based on distributed interpretation, consistency checking algorithm is given on global ontology and mappped relation. As long as these bridge ruels can be satisfied by distributed interpretation, ontology integration is consistent. We use an example to compare our method with global interpretation and prove that distributed interpration is more suitable for ontology integration. But it is limited when local ontologies have relations each other.

Nowadays, our appraoch mainly focuses on constructing the proper theory of distributed interpretation for ontology integration. In the future, we will make some research on how to link the theory with OWL and put our approach into practice.

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