Interpreting Distributed Ontologies

Yuzhong Qu
Dept. of Computer Science and Engineering
Southeast University, Nanjing 210096, P. R. China
yzqu@seu.edu.cn

Zhiqiang Gao
Dept. of Computer Science and Engineering
Southeast University, Nanjing 210096, P. R. China
zqgao@seu.edu.cn

ABSTRACT
Semantic Web is challenged by the URI meaning issues arising from putting ontologies in open and distributed environments. As a try to clarify some of the meaning issues, this paper proposes a new approach to interpreting distributed ontologies, it's built on the top of local models semantics, and extends it to deal with the URI sharing by harmonizing the local models via agreement on vocabulary provenance. The commitment relationship is presented to allow the URI sharing between ontologies with richer semantics.

Categories and Subject Descriptors
I.2.4 [**Knowledge Representation Formalisms and Methods**]: *Representation languages*.

General Terms
Languages, Standardization, Theory.

Keywords
OWL, Distributed Description Logic, Vocabulary Provenance, Commitment Relationship.

1. INTRODUCTION
To make the Semantic Web vision become reality, we are challenged by the URI meaning issues arising from putting OWL in open and distributed environments. Recently, there are some impetuous debates on the meaning of URI identifier used by OWL within Semantic Web research community. For example (See http://lists.w3.org/Archives/Public/public-sw-meaning/), should the meaning of URI be global or local? Does the use of a URI as a name constitute some kind of a commitment or consent, either to meaning expressed on the web, or intended by a Name-Authority?

As we know, OWL has a mechanism to import an OWL ontology into another OWL ontology. The owl:imports relationship is transitive, and if ontology O_1 imports O_2 and O_2 imports O_1, then they are considered to be equivalent. The owl:imports construct provides just one mechanism for specifying a special kind of semantic relationship between distributed OWL ontologies.

Recently, Paolo Bouquet et al. [1] give an extension to OWL with context, called C-OWL, which is based on local models semantics [2] and distributed description logics [3]. C-OWL allows us to contextualize ontologies. It's definitely a good start towards formal semantics for distributed ontologies. However, the vocabularies of local ontologies are supposed to be pair-wise disjointed, and the globalization can only be obtained by using explicit mappings. It doesn't fit very well in with one of the basic architectural principles of the Web, which allows anyone be able to freely add information about an existing resource using any vocabulary they please.

WWW 2004, May 17–22, 2004, New York, New York, USA.
ACM 1-58113-912-8/04/0005.

Our position to the meaning issues is as follows: A name is meaningless for machine without context, and the distributed ontologies should be the key component of the context. We should find a way to make it clear what "a distributed ontology" should have in addition to a set of local ontologies, and how to interpret "a distributed ontology".

2. DISTRIBUTED ONTOLOGIES
To simplify the presentation of our formalism, the distributed ontologies are assumed to be OWL DL ontologies. Some terminologies are as follows: A name is a URI (literal is not discussed for simplicity). The vocabulary of an ontology is the set of names that occur in the ontology as individuals, classes and properties, except for built-ins. We use Σ to denote a set of ontologies $\{O_i \mid i \in I\}$, here I be a set of indexes. $V(O_i)$ denotes the vocabulary of O_i, while $V_I(O_i)$, $V_C(O_i)$ and $V_P(O_i)$ denote the individual, class, and property vocabulary of O_i, respectively. The vocabulary of Σ, denoted by $V(\Sigma)$, is the union of the vocabularies of ontologies within Σ, more formally, $V(\Sigma)=\{\nu \mid \nu \in V(O_i), O_i \in \Sigma\}$. And $V_I(\Sigma)$, $V_C(\Sigma)$ and $V_P(\Sigma)$ denote the individual, class, and property vocabulary of Σ, respectively. We assume that $V_I(\Sigma)$, $V_C(\Sigma)$ and $V_P(\Sigma)$ are pair-wise disjointed.

Example 1. (***Motivation example***) Consider $\Sigma=\{O_1, O_2\}$:

O_1: SubClassOf(A B); SubClassOf(B C)

O_2: SubClassOf(C D); SubClassOf(D A)

How to interpret the integration of the above two ontologies (with some names shared)? The available approaches couldn't give a satisfied answer to this question.

Basically, our approach is based on the principle of local models semantics [2], i.e. local ontology has its own interpretation universe, and these universes are related with each other by relations. In addition, the URI should and could be shared with different ontologies under some restriction. Such sharing is realizable under agreement on vocabulary provenance, and can be enriched by commitment relationship within distributed ontologies.

Definition 1. (Agreement on vocabulary provenance) Let Σ be a set of ontologies $\{O_i \mid i \in I\}$, an agreement on vocabulary provenance within Σ is a function from $V(\Sigma)$ to I, denoted by $\rho: V(\Sigma) \rightarrow I$, such that $\nu \in V(O_{\rho(\nu)})$ for each $\nu \in V(\Sigma)$, i.e. for each $\nu \in V(\Sigma)$, $\rho(\nu) \in \{ i \in I \mid \nu \in V(O_i), O_i \in \Sigma \}$. We call $\rho(\nu)$ the provenance of the name ν within Σ.

From now on, we use the term “a distributed ontology” to mean a set of ontologies plus an agreement on vocabulary provenance. Usually, we use (Σ, ρ) to denote a distributed ontology.

We interpret distributed ontologies on the notion of local models [2, 3], and evolve it with the presence of agreement on vocabulary provenance.

Definition 2. (Interpretations for distributed ontologies) Let $\Sigma = \{O_i \mid i \in I\}$ be a set of ontologies with ρ as an agreement on vocabulary provenance. An interpretation of (Σ, ρ), denoted by ι, is composed of a pair $<\{\iota_i\}_{i\in I}, \{r_{ij}\}_{i,j\in I}>$ such that

1. ι_i is an OWL DL interpretation of O_i (satisfying all of the axioms within O_i) with local domain of $\Delta^{\iota i}$.
2. r_{ij} is the domain relation from i to j, i.e. a subset of $\Delta^{\iota i} \times \Delta^{\iota j}$. (each r_{ii} is always assumed to be the identity relation on $\Delta^{\iota i}$)
3. The harmonization constraint (HC) is satisfied:

$$\text{If } \nu \in V(O_j) \text{ and } \rho(\nu) = i, \text{ then } \nu^{\iota j} = r_{ij}(\nu^{\iota i}) \qquad \textbf{(HC)}$$

In this paper, we use $r_{ij}(S)$ (for S being a subset of $\Delta^{\iota i}$) to denote the image of S via the domain relation r_{ij}, more formally,

$$r_{ij}(S) = \{y \in \Delta^{\iota j} \mid \exists x \in S \text{ such that } <x, y> \in r_{ij}\}.$$

Notice that an element can be seen as a singleton set. We use $r_{ij}(R)$ (for R being a binary relation on $\Delta^{\iota i}$) to denote the image of R via r_{ij}, more formally, $r_{ij}(R) = r_{ij} \circ R \circ r_{ij}^{-1}$, i.e. $r_{ij}(R) = \{<y_1, y_2> \in \Delta^{\iota j} \times \Delta^{\iota j} \mid \exists x_1, x_2 \in \Delta^{\iota i} \text{ such that } <x_1, y_1> \in r_{ij}, <x_1, x_2> \in R, \text{ and } <x_2, y_2> \in r_{ij}\}$.

Hence, the harmonization constraint can be refined as follows:

$$\text{If } \nu \in V_I(O_j) \text{ and } \rho(\nu)=i, \text{ then } \{\nu^{\iota j}\} = r_{ij}(\{\nu^{\iota i}\}) \qquad \textbf{(HCI)}$$

$$\text{If } \nu \in V_C(O_j) \text{ and } \rho(\nu)=i, \text{ then } \nu^{\iota j} = r_{ij}(\nu^{\iota i}) \qquad \textbf{(HCC)}$$

$$\text{If } \nu \in V_P(O_j) \text{ and } \rho(\nu)=i, \text{ then } \nu^{\iota j} = r_{ij} \circ \nu^{\iota i} \circ r_{ij}^{-1} \qquad \textbf{(HCP)}$$

Example 2*. *(Revisit example 1) Suppose there is an agreement on vocabulary provenance within $\Sigma=\{O_1, O_2\}$ such that:

$$\rho(A)=1, \rho(B)=1, \rho(C)=2, \rho(D)=2$$

Let $<\{\iota_1, \iota_2\}, \{r_{12}, r_{21}\}>$ be an interpretation of (Σ, ρ). We have

$$A^{\iota 1} \subseteq B^{\iota 1} \subseteq r_{21}(C^{\iota 2}) \text{ (i.e. } C^{\iota 1}) \qquad \text{(E21)}$$

$$C^{\iota 2} \subseteq D^{\iota 2} \subseteq r_{12}(A^{\iota 1}) \text{ (i.e. } A^{\iota 2}) \qquad \text{(E22)}$$

We can not obtain that EquivalentClasses(A C) in O_1 or O_2 in general because there is no constraint on the domain relations r_{12} and r_{21}, e.g. $r_{12}(r_{21}(C^{\iota 2}))=C^{\iota 2}$. That’s fine because it reflects the case where there are two different viewpoints co-existed. We will revisit this example after the introduction of commitment relationship.

Definition 3. (Commitment relationship) Let (Σ, ρ) be a distributed ontology, a commitment relation on Σ, denote by Θ, is a binary relation on Σ. We say O_j commits to O_i when $<O_i, O_j> \in \Theta$. A complete commitment relation on Σ, denote by Ξ, is a sub-relation of commitment relation on Σ and required to be transitive.

Definition 4. (Satisfying of commitment). Let Ω = (Σ, ρ, Θ, Ξ) be a distributed ontology with commitment relations. An interpretation of (Σ, ρ), $<\{\iota_i\}_{i\in I}, \{r_{ij}\}_{i,j\in I}>$, satisfies Θ and Ξ, iff

1. The commutability constraint (CC) is satisfied:

   If $<O_i, O_j> \in \Theta$, $\nu \in V(O_i)$ and $k = \rho(\nu)$

   Then $r_{kj}(\nu^{\iota k}) = r_{ij}(r_{ki}(\nu^{\iota k}))$ **(CC)**
2. If $<O_i, O_j> \in \Xi$, then r_{ij} is an embedded identity relation.

When an interpretation of (Σ, ρ) satisfies Θ and Ξ, we call it an interpretation of (Σ, ρ, Θ, Ξ). The complete commitment relationship is introduced to formalize the owl:imports mechanism.

Example 3. (Revisit example 2) Furthermore, suppose O_2 commits to O_1. We will derive that A is equivalent to C in O_2.

Due to the commitment of O_2 to O_1, ρ(C)=2, by (CC), we have $r_{22}(C^{\iota 2}) = r_{12}(r_{21}(C^{\iota 2}))$, so we have

$$C^{\iota 2} = r_{12}(r_{21}(C^{\iota 2})) \qquad \text{(E31)}$$

Together with (E21) and (E22), we have

$$C^{\iota 2} \subseteq r_{12}(A^{\iota 1}) \subseteq r_{12}(r_{21}(C^{\iota 2})) = C^{\iota 2}$$

So we have $C^{\iota 2} = r_{12}(A^{\iota 1})$ (i.e. $A^{\iota 2}$), then it is concluded that EquivalentClasses(A C) in O_2. But we still can’t obtain that EquivalentClasses(A C) in O_1 unless O_1 commits to O_2. That’s the intended effect of the commitment.

3. DISCUSSION

As a try to clarify some of the URI meaning issues, this paper proposes the notion of agreement on vocabulary provenance and the notion of commitment between ontologies, and presents a new approach to interpreting distributed ontologies, which is based on local models semantics approach, and extends it to cope with the URI sharing by harmonizing the local models via provenance agreement and possible commitment relationships.

As compared to C-OWL [1], our approach has more flexibility, and fits in with the principle of Web architecture. In addition, our approach defines the complete commitment relationship as a special sub-relation of commitment relationship to formalize the owl:import mechanism, in other words, our approach extends it to cope with more general distributed ontologies. However, more research work should be taken to deal with the reasoning issue within our semantic framework. Another work is to extend the OWL DL with some constructs representing the vocabulary provenance as well as the commitment relationship.

4. ACKNOWLEDGMENTS

This paper is jointly supported by NSFC with project no. 60173036 and JSNSF with project no. BK2003001.

5. REFERENCES

[1] Paolo Bouquet, et al. C-OWL: Contextualizing Ontologies, ISWC'2003, LNCS 2870, Sept. 2003, pp164-179

[2] C. Ghidini, F. Giunchiglia. Local Models Semantics, or Contextual Reasoning = Locality + Compatibility. Artificial Intelligence, 127(2):221–259, 2001.

[3] A. Borgida and L. Serafini. Distributed description logics: Directed domain correspondences in federated information sources. LNCS 2519, 2002, pp36－53.