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# Algorithms for the Reconciliation of Ontologies in Open Environments

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**Abstract.** The dynamic changing feature of Semantic Web determines that the ontology which is a part of Semantic Web needs constantly to be modified in order to adapt outer environment. In this paper we make a careful analysis of the ontology changes' complexity under open environment. The main contents discussed are as follow. At first we point out all possible relation types between any two ontology change sequences including directly conflict relation, indirectly conflict relation, dependent relation and compatible relation according to ontology change's definition. And then we propose a new algorithm named Algorithm of Searching Maximum and Sequential Ontology Change Sequence Set(ASMSOCSS) to find all maximum and sequential ontology change sequence subset in the prime ontology change sequence set and prove the independence of the result which may be got after running ASMSOCSS. At last we put forward the algorithm by using these maximum and sequential ontology change sequence sets to create new ontology versions according to the dependence relation between ontology change sequences.

**Keywords:** Ontology Changes Sequence, Maximum and Sequential Ontology Changes Sequence, Ontology Change.

## 1 Introduction

Ontology Evolution is the timely adaptation of an ontology to the arisen changes and the consistent propagation of these changes to dependent artifacts. Ontology change disposal, as a part of ontology evolution, focuses on exploring some ontology evolution's methods and technologies to modify ontology on the assumption with not breaking ontology consistency. By far, a lot of research work has been done on ontology change disposal and they may be classified into some based on logical reasoning<sup>[6]</sup> and others based on belief revision<sup>[8]</sup>. But all of them mainly focus on ontology change disposal under centralized environment. The research on ontology change disposal under open environment is infrequent. [1] discussed ontology change disposal under open environment for the first time. Its main contribution is to define

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the mapping relation between any two ontology versions by analyzing these logs of editing ontology. But [1] is not all-inclusive because it can't provide some guide for ontology evolution's trend in semantic level.

Multiple ontology versions will be achieved under open environment. But these ontology versions are not all worthy. Moreover, too many ontology versions will make it more difficult to manage the base of ontology versions. Unfortunately, how to get worthy ontology versions under open environment is seldom concerned. In addition, the problem on ontology change of analysis and disposal is independent of the problem on merging multiple ontology versions. And it is well known that the work of merging ontology versions is very heavy. If the work of merging ontology versions can be integrated into the course of analysis and disposal of ontology changes it will greatly save the work of ontology evolution. In this paper, we propose a new method which may not only create a worthy ontology version but also avoid the work of merging ontologies through analyzing and disposing ontology change sequences.

This paper is organized as follow. The whole scheme of ontology change disposal under open environment is given in section 2. And then we make certain all possible relation types between ontology change sequences in section 3. We propose Algorithm of Searching Maximum and Sequential Ontology Change Sequence Set in section 4 and put forward the algorithm used to create new ontology versions in section 5. Related works are mentioned in section 6 and conclusion and the next work are arranged in the last section.

## 2 Description of the Approach

Our approach on ontology change in an open environment is composed of four steps as illustrated in Figure 1.

**Step 1:** Having accesses to a version  $O_i$  of an ontology, several users have separate copies  $O_i$  of this ontology in their working spaces.

**Step 2:** Each user makes changes  $chs_j$  to his/her copy respectively.

**Step 3:** Given sequences of users' ontology changes, we algorithmically analyze the relevance between ontology change operations and search for the maximal consistent subset of the whole ontology change operations, which is called the maximal ontology changes set. We put such subsets together and denote them as a collection of ontology change sequences, i.e.,  $\{CHS_1, CHS_2, \dots, CHS_k\}$ , where each  $CHS_i$  ( $1 \leq i \leq k$ ) represents a maximum sequential ontology changes.

**Step 4:** Several versions of ontologies may be derived from the original  $O_i$  by applying one of maximal ontology changes. Obviously,  $\{CHS_1, CHS_2, \dots, CHS_k\}$  will produce  $k$  distinguished ontologies.

The above-mentioned step 3 and step 4 are the crucial parts of our approach, next we will give their details in the remainder of this paper.

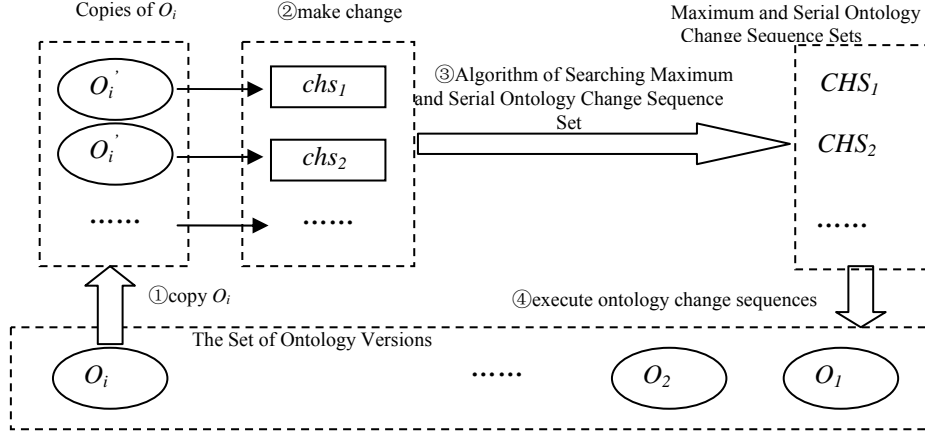


Fig. 1. Description of our approach

### 3 Formal Description of Ontology Change

Definition 1: an **ontology**  $O$  is defined as a 5-tuple:

$$O = \{C, R, H^c, Rel, A^o\}. \quad (1)$$

where:

- $C$  is the set of ontology concepts.
- $H^c \subseteq C \times C$  is a set of taxonomic relationships between concepts.
- $R$  is the set of non-taxonomic relationships. The function  $Rel: R \rightarrow C \times C$  maps the relation identifiers to the actual relationships.
- $A^o$  is a set of axioms, usually formalized into some logic language.

For brevity,  $O$  is short for ontology throughout this paper. Its instances are denoted by  $O.I$ , concept set by  $O.C$ , non-taxonomic relationships by  $O.R$ . We think of an ontology as a knowledge base, which contains not only the elements of an ontology, but also instances of the concepts  $C$  and relationships  $R$ .

Stojanovic categorizes all ontology changes into “Add” ontology changes and “Remove” ontology changes respectively. To highlight what type of changes is made to what object, we redefine ontology change as follows:

Definition 2: an **ontology change**  $ch$  is defined as:

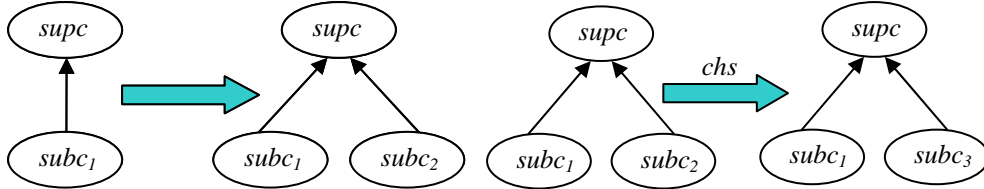
$$ch = \{name, type, object, args\}. \quad (3)$$

where:

- $name$  is the identifier of this change  $ch$ .
- $type \in \{“Add”, “Remove”\}$ , is type of  $ch$ .
- $object \subset O.I \cup O.C \cup O.R$ , are the elements which  $ch$  act on.  $O$  is an ontology.  $O.C$  is the set of concepts of  $O$  and  $O.R$  is the set of non-taxonomic relationships of  $O$ .

- $args \subset O.I \cup O.C \cup O.R$ , is a list of one or more change arguments. There are changes with one, two or three arguments.

For example,  $ch = \{\text{"AddSubConcept"}, \text{"Add"}, \{subc_2\}, \{supc\}\}$  denotes an ontology change that a concept  $subc_2$  is added to an ontology as subconcept of  $supc$ . This can be pictured as Figure 2.



**Fig.2.** An illustration of an ontology change.

**Fig.3.** An illustration of an ontology change sequence.

Definition 3: an **ontology change sequence**  $chs$  is defined as

$$chs = \langle ch_1 ch_2 \dots ch_n \rangle, ch_i (1 \leq i \leq n) \text{ is an ontology change} \quad (4)$$

if and only if  $n=1$  or  $\forall 1 \leq i \leq n-1, ch_i$  always is executed ahead of  $ch_{i+1}$ .

### 3.1 Argument Pool and Remove Pool of an Ontology Change Sequence

For an ontology change sequence  $chs = \langle ch_1 ch_2 \dots ch_n \rangle$ , the **argument pool** of  $chs$  is used to enumerate all  $ch_i.args$  when  $ch_i.type$  is "Add" and the **remove pool** of  $chs$  is used to enumerate all  $ch_j.object$  when  $ch_j.type$  is "Remove". Further, the argument pool  $chs.APool$  and the remove pool  $chs.RPool$  of an ontology change sequence  $chs = \langle ch_1 ch_2 \dots ch_n \rangle$  can be obtained when we apply the ACAPRP algorithm to  $chs$ .

Given a simple example illustrated in Fig.3, we suppose:

- $chs = \langle ch_1 ch_2 \rangle$
- $ch_1 = \{\text{"RemoveConcept"}, \text{"Remove"}, \{subc_2\}, \{\}\}$
- $ch_2 = \{\text{"AddSubConcept"}, \text{"Add"}, \{subc_3\}, \{supc\}\}$

When ACAPRP algorithm is applied to  $chs$  the output is  $chs.RPool = \{subc_2\}$  and  $chs.APool = \{supc\}$ .

### 3.2 Relation Types between two Ontology Change Sequences

Definition 4: An ontology change sequence  $chs_1$  **depends on** another ontology change sequence  $chs_2$  if and only if  $chs_1.RPool \cap chs_2.APool \neq \emptyset \wedge chs_2.RPool \cap chs_1.APool = \emptyset$ .  $dependence(chs_1, chs_2)$  means that  $chs_1$  depends on  $chs_2$  and  $\neg dependence(chs_1, chs_2)$  means that  $chs_1$  doesn't depend on  $chs_2$ .

Definition 5: An ontology change sequence  $chs_1$  **directly conflicts** with another ontology change sequence  $chs_2$  if and only if  $chs_1.RPool \cap chs_2.APool \neq \emptyset \wedge chs_2.RPool \cap chs_1.APool \neq \emptyset$ .  $directlyConflict(chs_1, chs_2)$  means that  $chs_1$  and  $chs_2$  directly conflict with each other and  $\neg directlyConflict(chs_1, chs_2)$  means that  $chs_1$  and  $chs_2$  don't directly conflict with each other.

Algorithm 1: ACAPRP( $chs$ )  
Input: an ontology change sequence  $\langle ch_1 ch_2 \dots ch_n \rangle$   
Output:  $chs.RPool, chs.APool$

1.  $chs.RPool \leftarrow \emptyset; chs.APool \leftarrow \emptyset; i \leftarrow 1;$
2. WHILE( $i \leq n$ )
3.      $chs.APool \leftarrow chs.APool \cup ch_i.args;$
4.     IF  $ch_i.type = \text{"Remove"}$
5.          $chs.RPool \leftarrow chs.RPool \cup ch_i.object;$
6.     IF  $ch_i.type = \text{"Add"}$  and  $ch_i.object \subseteq chs.RPool$
7.          $chs.RPool \leftarrow chs.RPool \cup ch_i.object$
8.      $i++;$
9. Return  $chs.RPool$  and  $chs.APool$

Definition 6: For a few of ontology change sequences  $chs_1, chs_2, \dots, chs_n$ ,  $chs_1$  **indirectly conflicts** with  $chs_n$  iff  $dependence(chs_1, chs_2), dependence(chs_2, chs_3), \dots, dependence(chs_n, chs_1)$  all are true, where  $indirectlyConflict(chs_1, chs_n)$  means that  $chs_1$  and  $chs_n$  indirectly conflict with each other and  $\neg indirectlyConflict(chs_1, chs_n)$  means that  $chs_1$  and  $chs_n$  don't indirectly conflict with each other.

Definition 7: An ontology change sequence  $chs_1$  is **compatible** with another ontology change sequence  $chs_2$  iff  $chs_1.RPool \cap chs_2.APool = \emptyset \wedge chs_2.RPool \cap chs_1.APool = \emptyset$ , where  $compatible(chs_1, chs_2)$  means that  $chs_1$  and  $chs_2$  are compatible each other.

#### 4 Algorithm of Searching Maximal Ontology Changes Set

According to the relation type between two ontology change sequences, four lemmas may be deduced.

Lemma 1: If an ontology change sequence  $chs_1$  directly conflicts with another ontology change sequence  $chs_2$ , not all of  $chs_1$  and  $chs_2$  are executed no matter what the execution order may be.

Lemma 2: If an ontology change sequence  $chs_1$  depends on another ontology change sequence  $chs_2$ ,  $chs_1$  and  $chs_2$  can be all executed if and only if  $chs_2$  is executed ahead of  $chs_1$ .

Lemma 3: If an ontology change sequence  $chs_1$  indirectly conflicts with another ontology change sequence  $chs_n$ , not all of  $chs_1$  and  $chs_n$  are executed no matter what the execution order may be.

Lemma 4: If an ontology change sequence  $chs_1$  is compatible with another ontology change sequence  $chs_2$ ,  $chs_1$  and  $chs_2$  may always be executed no matter what the execution order may be.

According lemma 1,2,3 and 4, if any two of a group of ontology change sequences are not *directlyConflict* or *indirectlyConflict* all these ontology change sequences may be executed. In order to find all maximum subset of all ontology change sequences

that may be executed from a given group of ontology change sequences, we propose the Algorithm of Searching Conflict Set(ASCS) to be used to find all ontology change sequence pairs which indirectly conflict or directly conflict with each other and the Algorithm of Searching Maximum and Sequential Ontology Change Sequence Set (ASMSOCSS).

Definition 8: Given a group of ontology change sequences  $CHS=\{chs_1, chs_2, \dots, chs_n\}$ ,  $MSOCSS_{CHS}$  is defined as **Maximum and Sequential Ontology Change Sequence Set** if and only if  $\neg \exists T \subseteq CHS$  makes all  $T \supset MSOCSSM_{CHS}$  and  $\forall t_1, t_2 \in T$ ,  $\neg directlyConflict(t_1, t_2) \wedge \neg indirectlyConflict(t_1, t_2)$  to be true.

In ASMSOCSS, step 2 means to traverse all elements of  $CONF$  in unknown order. It is puzzling whether the order of traversing elements can change the final  $MSOCSSSet$  or not. The problem can be explained by lemma 5.

Lemma 5: The final  $MSOCSSSet$  is identical no matter what the order of traversing elements may be.

**Proof**

$\forall (e1, e2), (e3, e4) \in CONF, e1 \in CHS \wedge e2 \in CHS \wedge e3 \in CHS \wedge e4 \in CHS$  is given.

Suppose that  $e1 \neq e3 \wedge e1 \neq e4 \wedge e2 \neq e3 \wedge e2 \neq e4 \wedge e1 \neq e2 \wedge e3 \neq e4$  is true.

If  $(e1, e2)$  is traversed ahead of  $(e3, e4)$ ,  $MSOCSSSet_0 = \{CHS/\{e1\}, CHS/\{e2\}\}$  is got. After  $(e3, e4)$  is traversed,  $MSOCSSSet_1 = \{CHS/\{e1, e3\}, CHS/\{e1, e4\}, CHS/\{e2, e3\}, CHS/\{e2, e4\}\}$  is got. In turn, if  $(e3, e4)$  is traversed ahead of  $(e1, e2)$ ,  $MSOCSSSet_0 = \{CHS/\{e3\}, CHS/\{e4\}\}$  is got. After  $(e1, e2)$  is traversed,  $MSOCSSSet_2 = \{CHS/\{e3, e1\}, CHS/\{e3, e2\}, CHS/\{e4, e1\}, CHS/\{e4, e2\}\}$  is got. Obviously  $MSOCSSSet_1 = MSOCSSSet_2$ .  $MSOCSSSet_1 = MSOCSSSet_2$  is easy proved when  $e1 = e3 \wedge e1 \neq e4 \wedge e2 \neq e3 \wedge e2 \neq e4 \wedge e1 \neq e2 \wedge e3 \neq e4$  is true.

$\forall (e1, e2), (e3, e4) \in CONF$ , the same conclusion may be drew easily whichever of  $e1 \notin CHS \wedge e2 \in CHS \wedge e3 \in CHS \wedge e4 \in CHS$  or  $e1 \notin CHS \wedge e2 \notin CHS \wedge e3 \in CHS \wedge e4 \in CHS$  or  $e1 \notin CHS \wedge e2 \in CHS \wedge e3 \notin CHS \wedge e4 \in CHS$  or  $e1 \notin CHS \wedge e2 \notin CHS \wedge e3 \notin CHS \wedge e4 \notin CHS$  is given.

So we may know that the order of traversing any two elements of  $CONF$  is exchangeable. Further, Lemma 5 may be deduced easily according to related mathematical characteristics.

□

## 5 Algorithm of Generating New Ontology Versions

According to ASMSOCSS,  $\forall E \in MSOCSSSet, \forall (e1, e2) \in E, e1$  must not directly conflict or indirectly conflict with  $e2$ . So  $\forall E \in MSOCSSSet$ , all elements in  $E$  are executed once. When a  $MSOCSS_{CHS}$  is applied to an ontology  $O$ , a new ontology version can be got. The algorithm of generating a new ontology version is AGNOV.

Algorithm 2: ASCS(*CHS*)

Input: a group of ontology change sequences  $\{chs_1, chs_2, \dots, chs_n\}$

Output: a conflict set *CONF*

1.  $CONF \leftarrow \emptyset$ ;  $i1 \leftarrow 1$ ;  $i2 \leftarrow 1$ ;
2. WHILE( $i1 \leq n$ )
3.     WHILE( $i2 \geq i1$  and  $i2 \leq n$ )
4.         IF( $directConflict(chs_{i1}, chs_{i2})$  or  $indirectConflict(chs_{i1}, chs_{i2})$ ) and  $i1 \neq i2$
5.              $CONF \leftarrow CONF \cup \{chs_{i1}, chs_{i2}\}$ ;
6.              $i2++$ ;
7.          $i1++$ ;  $i2 \leftarrow i1$ ;
8. RETURN *CONF*

Algorithm 3: ASMSOCSS(*CHS*, *CONF*)

Input: a group of ontology change sequences  $\{chs_1, chs_2, \dots, chs_n\}$  and ASCS( $\{chs_1, chs_2, \dots, chs_n\}$ )

Output: the set of all possible maximum and serial ontology change sequence set *MSOCSSSet*

1.  $MSOCSSSet \leftarrow \{CHS\}$ ;  $i1 \leftarrow 1$ ;  $i2 \leftarrow 1$ ;
2. FOR EACH  $(chs_1, chs_2) \in CONF$
3.     FOR EACH  $e \in MSOCSSSet$
4.         IF  $chs_1 \in e$  and  $chs_2 \in e$
5.              $MSOCSSSet \leftarrow MSOCSSSet - \{e\}$ ;
6.              $e_1 \leftarrow e - \{chs_1\}$ ;  $e_2 \leftarrow e - \{chs_2\}$ ;
7.             IF  $\neg \exists e' \in CAND, e_1 \subset e'$
8.                  $MSOCSSSet \leftarrow CAND \cup \{e_1\}$ ;
9.             IF  $\neg \exists e' \in CAND, e_2 \subset e'$
10.                  $MSOCSSSet \leftarrow CAND \cup \{e_2\}$ ;
11. RETURN *MSOCSSSet*

Algorithm 4: AGNOV(*O*)

Input: an ontology *O*

Output: the set of all new ontology version *OVs*

1.  $OVs \leftarrow \emptyset$ ;
2. FOR EACH  $E \in MSOCSSSet$
3.      $O' \leftarrow O$ ;
4.     WHILE( $E \neq \emptyset$ )
5.         IF  $\exists chs_i \in E, \forall chs_j \in E - \{chs_i\}, \neg dependence(chs_i, chs_j)$
6.              $O' \leftarrow chs_i(O)$ ;  $E \leftarrow E - \{chs_i\}$ ;
7.      $OVs \leftarrow OVs \cup \{O'\}$ ;
8. RETURN *OVs*



## 6 Related Work

Ontology versioning<sup>[5]</sup> typically involves the storage of several ontology versions and identification issues, the relationship between different versions as well as compatibility information.[9] uses the term versioning to describe their approach of ontology change. They define ontology versioning as the ability to manage ontology changes and their effects by creating and maintaining different variants of the ontology. Adequate methods and tools must be used to distinguish and identify the versions. [4] presents a new ontology evolution approach. The approach keeps track of the different virtual versions of ontology concepts throughout their lifetime by combining the manual request for changes by the ontology engineer with an automatic change detection mechanism. [7] proposes a logic framework used to reason with multiversion ontologies. In the framework such problems can be solved as querying log of semantic change, selecting a appropriate ontology version, etc.

## 7 Conclusion and Future Work

We propose a formal method used to analyze and dispose a group of ontology change sequences under open environment. But our discussion is specific to the same ontology subject to a group of ontology change sequences. In future, we will use graph theory to rephrase such a problem.

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