Repairing Networks of Ontologies using Weakening and Completing

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Abstract

The quality of ontologies and their alignments is crucial for developing high-quality ontology-based applications. Traditional debugging techniques repair ontology networks by removing unwanted axioms and mappings, but may thereby remove consequences that are correct in the domain of the ontology. In this paper we propose an interactive approach for repairing ontology networks that alleviates the effect of removing unwanted axioms and mappings using weakening and completing.

1. Introduction

As ontologies become more prevalent and are used extensively in many different domains, the quality of ontologies and ontology networks, i.e., a set of ontologies connected through alignments, has become a key factor for supporting semantically-enabled applications. Therefore, ontology networks with defects such as semantic and modeling defects, need to be repaired. However, most current repairing approaches suffer from the following issues. First, they are purely logic-based and therefore may remove correct axioms (e.g., [1]). Therefore, in the formalization of the repairing problem in [2] an oracle (e.g., a domain expert) should be involved in validating logical solutions. Furthermore, removing an axiom or mapping may remove more knowledge than necessary. To alleviate the negative effect of removing too much information, techniques such as weakening (e.g., [3, 4, 5]) or completing (e.g., [6]) may be used.

In [7] we proposed a framework for repairing $\mathcal{EL}$ ontologies, where, given a set of wrong asserted axioms, these axioms are removed but the effects of removing are mitigated by using weakening and completing to add (back) correct knowledge. That work was the first that combines these operations. It was shown that there are different ways to combine these operations and that the choice of combination has an influence on the amount of validation work by a domain expert and the completeness of the final ontology. It was also shown that earlier work on weakening (without completing) only considered one of the possible combinations. Similarly, earlier work on completing (without weakening) also considered only one of the possible combinations.

In this **short** paper we extend the framework in [7] to deal with $\mathcal{EL}$ ontology *networks*.

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2. Preliminaries

2.1. Ontology networks. In this paper we assume that ontologies are represented by description logic TBoxes. Alignments are sets of mappings which are represented using description logic axioms. We assume that the mappings are subsumption mappings, and that equivalence mappings are represented by two subsumption mappings. Although we base our work and examples on [7] where the description logic $\mathcal{EL}$ was used, the discussions hold for ontologies represented by description logics in general. An ontology network is a collection of ontologies together with their alignments and can be represented by a TBox as well (Def. 1).

Definition 1. *Let* $\mathcal{T}_1$, ...,$\mathcal{T}_n$ *be TBoxes representing ontologies* $\mathcal{O}_1$, ..., $\mathcal{O}_n$, *respectively. For* $i, j \in [1..n]$ *with* $i < j$, *let* $\mathcal{A}_{ij}$ *be an alignment between ontology* $\mathcal{O}_i$ *and* $\mathcal{O}_j$. *The network of the ontologies and their alignments is then represented by* $\mathcal{T} = (\bigcup_{i=1..n} \mathcal{T}_i) \cup (\bigcup_{i,j=1..n, i<j} \mathcal{A}_{ij})$.

Our aim is to find repairs that add as much correct knowledge (back) to our ontology network as possible. Therefore, we introduce the preference relation *more complete* between TBoxes (Def. 2) that formalizes this intuition. The TBoxes could represent ontologies or ontology networks.

Definition 2. *(more complete) TBox* $\mathcal{T}_1$ *is* more complete *than TBox* $\mathcal{T}_2$ *(or* $\mathcal{T}_2$ *is* less complete *than* $\mathcal{T}_1$*) according to oracle Or iff* $(\forall \psi : (\mathcal{T}_2 \models \psi \wedge \ Or(\psi) = true) \rightarrow \mathcal{T}_1 \models \psi)) \wedge (\exists \psi : Or(\psi) = true \ \wedge \mathcal{T}_1 \models \psi \wedge \mathcal{T}_2 \not\models \psi)$. *They are* equally complete *iff* $\forall \psi : Or(\psi) = true \rightarrow (\mathcal{T}_1 \models \psi \leftrightarrow \mathcal{T}_2 \models \psi)$

2.2. Removing, weakening and completing.

`Operations.` The framework in [7] defines the basic operations removing, weakening and completing. Although the operations were defined on axioms for single ontologies, we use here variants that deal with axioms in the ontologies as well as mappings. In the remainder we use the term axiom for the axioms in the ontologies and the mappings. When we mean axioms in the ontologies, we will explicitly state this.

Removing deletes all the wrong asserted axioms in a given set W from the ontology network. Given an axiom, *weakening* aims to find other axioms that are weaker than the given axiom, i.e., the given axiom logically implies the other axioms within the network. For the repairing this means that a wrong axiom $\alpha \sqsubseteq \beta$ can be replaced by a correct weaker axiom $sb \sqsubseteq sp$ such that sb is a sub-concept of α and sp is a super-concept of β, thereby mitigating the effect of removing the wrong axiom (Fig. 1). *Completing* aims to find correct axioms that are not derivable from the ontology yet and that would make a given axiom derivable. For a given axiom $\alpha \sqsubseteq \beta$, it finds correct axioms $sp \sqsubseteq sb$ such that sp is a super-concept of α and sb is a sub-concept of β (Fig. 1). This means that if $sp \sqsubseteq sb$ is added to $\mathcal{T}$, then $\alpha \sqsubseteq \beta$ would be derivable. Completing is performed on correct axioms, and in repairing, it is applied to weakened axioms.

Note that weakening and completing are dual operations where the former finds weaker axioms and the latter stronger axioms. Both these operations make an ontology network more or equally complete than it was before the operation.

In [7] we introduced different ways to combine removing, weakening and completing. These different ways take into account the different choices that can be made in terms of, e.g., the order in which the operations are performed, the order in which the axioms are processed, whether one axiom is dealt with at a time or all at once, and when the TBox is updated. The different

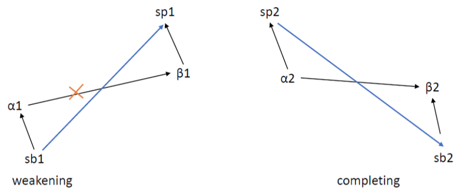

Figure 1: Weakening and Completing

combinations were classified in Hasse diagrams where combinations higher up in the diagrams lead to more validation work for the domain expert, but also more complete ontologies, which is the aim of weakening and completing.

`Algorithms.` There are different ways to weaken and complete axioms. Algorithms for weakening have been provided in e.g., [3, 4, 5, 7], while different completing algorithms are given in e.g., [8, 6, 7]. Further, as discussed above, there are different ways to combine these basic operations. In the examples in this paper we have used one of the algorithms in [7] (Algorithm C8) that combines removing, weakening and completing, which allows us to discuss repairing of ontology networks. Our discussion would still hold if we used other algorithms.

Algorithm C8: Weaken/complete one at a time, add completed axiom sets and remove all wrong axioms at end

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Input: TBox $\mathcal{T}$, Oracle Or, set of unwanted axioms W

Output: A repaired TBox

for each $\alpha \sqsubseteq \beta \in W$ **do**
  $\mathcal{T}_r \leftarrow$ Remove-axioms($\mathcal{T}$, $\{\alpha \sqsubseteq \beta\}$)
  $w_{\alpha\sqsubseteq\beta} \leftarrow$ weakened-axiom-set($\alpha \sqsubseteq \beta, \mathcal{T}_r, Or$)
  $c_{\alpha\sqsubseteq\beta} \leftarrow \emptyset$
  for each $sb \sqsubseteq sp \in w_{\alpha\sqsubseteq\beta}$ **do**
    $c_{sb\sqsubseteq sp} \leftarrow$ completed-axiom-set($sb \sqsubseteq sp, \mathcal{T}, Or$)
    $c_{\alpha\sqsubseteq\beta} \leftarrow c_{\alpha\sqsubseteq\beta} \cup c_{sb\sqsubseteq sp}$
  end for
end for
$\mathcal{T}_r \leftarrow$ Add-axioms($\mathcal{T}$,$\bigcup_{\alpha\sqsubseteq\beta} c_{\alpha\sqsubseteq\beta}$)
return Remove-axioms($\mathcal{T}_r$,W)

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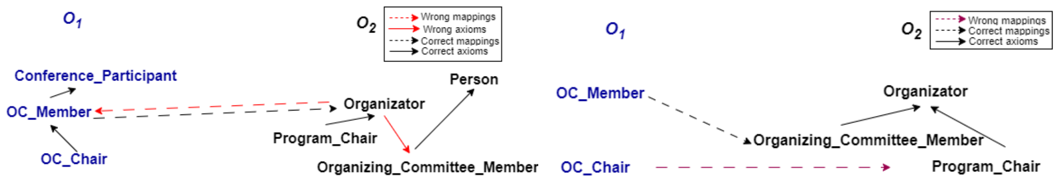
3. Problem definition

In this section we define the repair problem for ontology networks. Def. 3 is an extension of the definition of repair for single ontologies as defined in [7]. We are given a set of wrong asserted axioms W that we want to remove from the ontology network and that when they are removed, they cannot be derived from the TBox representing the ontology network anymore. These axioms in W can be axioms in the ontologies or mappings. Further, to guarantee a high level of quality of the ontology (i.e., so that no correct information is removed or no incorrect information is added), domain expert validation is a necessity (e.g., [1]). Therefore, we assume an oracle (representing a domain expert) that, when given an axiom, can answer whether this axiom is correct or wrong in the domain of interest of the ontology network. A repair for the ontology network given the TBox $\mathcal{T}$, oracle Or, and a set of wrong axioms W, is a set of correct axioms that when added to the TBox where the axioms in W are removed will not allow deriving the axioms in W.

Definition 3. *(Repair) Let $\mathcal{T} = (\bigcup_{i=1..n} \mathcal{T}_i) \cup (\bigcup_{i,j=1..n,i<j} \mathcal{A}_{ij})$ represent a network of ontologies $\mathcal{O}_i$ represented by TBoxes $\mathcal{T}_i$, and their alignments $\mathcal{A}_{ij}$. Let Or be an oracle that given a TBox axiom returns true or false. Let W be a finite set of TBox axioms in $\mathcal{T}$ such that $\forall\ \psi \in W$: $Or(\psi)$ = false. Then, a repair for Debug-Problem DP($\mathcal{T}, Or, W$) is a finite set of TBox axioms A such that (i) $\forall\ \psi \in A$: $Or(\psi)$ = true, and (ii) $\forall\ \psi \in W$: $(\mathcal{T} \cup A) \setminus W \not\models \psi$.*

4. Repairing ontology networks

In this section we discuss repairing ontology networks as well as alignment repair. We use the Ekaw and Sigkdd ontologies from the conference track of the Ontology Alignment Evaluation Initiative (OAEI, http://oaei.ontologymatching.org/) with minor modifications as in Fig. 2 as examples.



(a) General case (b) Alignment repair

Figure 2: Small networks. O_1 is based on Ekaw. O_2 is based on Sigkdd.

4.1 General case. When repairing ontology networks, unwanted axioms (W in Def. 3) can appear in the ontologies as well as in the mappings. Further, the axioms to be added (A) to alleviate the negative influence of removing the axioms in W, can be axioms in the ontologies as well as mappings. In this case we can directly use the techniques described in [7] (including Algorithm C8) to obtain a repair by applying the approaches on the TBox representing the ontology network. We note that, when computing the sub- and super-concepts of α and β during weakening or completing axiom $\alpha \sqsubseteq \beta$, there is a choice to use the whole network or to only use axioms within the respective ontologies. Using the whole network will lead to more validation work, but a potentially more complete ontology network.

As an example, consider the small network in Fig. 2(a) with the wrong mapping Organizator $\sqsubseteq$ OC_Member and the wrong axiom Organizator $\sqsubseteq$ Organizing_Committee_Member in the second ontology. Using only sub- and super-concepts within ontologies, when weakening the wrong axiom Organizator $\sqsubseteq$ Organizing_Committee_Member, there is a weakened correct axiom Organizator $\sqsubseteq$ Person. Similarly, the correct weakened axiom for the wrong mapping Organizator $\sqsubseteq$ OC_Member is Organizator$\sqsubseteq$ Conference_Participant. Then applying completion on the above weakened axioms, two correct completed axioms Organizing_Committee_member $\sqsubseteq$ OC_Member and Organizing_Committee_Member $\sqsubseteq$ Organizator will be added to the ontology.

When using the complete Ekaw and Sigkdd ontologies with their alignments where some part is modified as in Fig. 2(a), we have the following results. For the mapping Organizator $\sqsubseteq$ OC_Member there are 15 candidate weakened axioms (5 sub-concepts of Organizator and 3 super-concepts of OC_Member) which need to be validated of which one correct mapping (Organizator $\sqsubseteq$ Conference_Participant) leads to the most complete network. There are 72 possibilities (6 super-concepts of Organizator and 12 sub-concepts of Conference_Participant) to complete the weakened axiom, which leads to a new mapping Organizing_Committee_Member $\sqsubseteq$ OC_Member. For the wrong axiom in Sigkdd Organizator $\sqsubseteq$ Organizing_Committee_Member there are 25 candidate weakened axioms (5 sub-concepts of Organizator and 5 super-concepts of Organizing_Committee_Member) of which Organizator $\sqsubseteq$ Person is chosen. For completing there are 216 possibilities (6 super-concepts of Organizator and 36 sub-concepts of Person) of which Organizing_Committee_Member $\sqsubseteq$ Organizator is chosen.

4.2. Alignment repair. Alignment repair is a special case of ontology network repair where the given set of unwanted axioms W only contains mappings. Most ontology alignment systems do alignment repair rather than ontology network repair as they assume that the ontologies in the network are correct, while mappings can be removed, e.g., [9, 10, 11, 12, 13, 14].

There are two sub-cases of alignment repair. In **case 1** a repair A can contain axioms in the ontologies and mappings. This is essentially the general ontology network repair where the input W has been restricted to a set of mappings. The techniques from Sect. 4 can be used to compute a repair. In **case 2** a repair A can only contain mappings. This case is based on the intuition that the ontologies should not be changed. For this case the techniques in [7] need to be adapted such that only mappings are returned in the repair. This can be done by adding an extra check requiring that for all elements $P \sqsubseteq Q$ in A, P and Q belong to different ontologies.

Ontology networks repaired using case 1 are more or equally complete than using case 2. By only allowing mappings in the repair in case 2, possible solutions that include new axioms within ontologies are missed. As an example, consider the small network in Fig. 2(b). When weakening the unwanted axiom OC_Chair $\sqsubseteq$ Program_Chair, for both cases, there is one weakened correct axiom which is OC_Chair $\sqsubseteq$ Organizator. Applying completing on this weakened axiom, results in two candidate axioms to add to the ontology network: OC_Chair $\sqsubseteq$ OC_Member and OC_Chair $\sqsubseteq$ Organizing_Committee_Member. Both axioms are correct in the domain. In case 1 we would prefer to add OC_Chair $\sqsubseteq$ OC_Member as it is the strongest, but as this is an axiom within an ontology it is disallowed for case 2. In case 2 we add OC_Chair $\sqsubseteq$ Organizing_Committee_Member. We note that in the ontology network repaired using case 1, both these axioms can be derived, while in case 2 OC_Chair $\sqsubseteq$ OC_Member is not derivable. The repaired ontology network using case 1 is more complete than using case 2.

When using the complete Ekaw and Sigkdd ontologies with their alignments where some part is modified as in Fig. 2(b), we have the following results. In both cases there are 11 candidate weakened axioms (1 sub-concept of OC_Chair and 11 super-concepts of Program_Chair) which need to be validated of which one (OC_Chair $\sqsubseteq$ Organizator) leads to the most complete network. In case 1 there are 108 possibilities (12 super-concepts of OC_Chair and 9 sub-concepts of Organizator) to complete the weakened axiom, while in case 2 there are 54 (6 super-concepts of OC_Chair from Sigkdd and 3 sub-concepts of Organizator from Ekaw plus 6 super-concepts of OC_Chair from Ekaw and 6 sub-concepts of Organizator from Sigkdd). The final axioms to add to the network are as above. As discussed earlier, there is more validation work in case 1 than case 2, but the network is more complete.

5. Conclusion

In this paper we have shown how to alleviate the problem of removing too much information when removing unwanted axioms or mappings from ontology networks using weakening and completing. Alignment repair is treated as a special case of ontology network repair. We have also shown that assuming that ontologies are correct and complete, may lead to missing opportunities to complete ontologies within the networks.

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