Digging Ontology Correspondence Antipatterns

Anselmo Guedes, Fernanda Baião and Kate Revoredo

Department of Applied Informatics. Federal University of the State of Rio de Janeiro – UNIRIO, Rio de Janeiro, Brazil
{anselmo.guedes, fernanda.baiao, katerevoredo}@uniriotec.br

Abstract. A correspondence antipattern is a set of generic correspondences between two ontologies that represents an incorrect alignment. It is useful to help identify incorrect correspondences between two ontologies, thus improving the Ontology Matching process. The specification of a correspondence antipattern requires the identification and correct understanding of a relevant alignment problem, and its representation in a proper modeling language. In this work we investigate the last three editions of OAEI challenge datasets so as to identify correspondence antipatterns from frequent and recurring errors; some of the the resulting antipatterns are presented and discussed.

Keywords: ontology matching, correspondence antipatterns, inconsistent alignment.

1 Introduction

As the research and practice on Ontology become more popular and evolve, several ontology artifacts arise for the same universe of discourse. However, they differ among each other in several perspectives, such as distinct representation languages (syntactic heterogeneity), variations in names referring to the same entity (terminological heterogeneity), different conceptualizations for the same domain (conceptual heterogeneity) and entities being perceived differently (semiotic heterogeneity) [7]. The Ontology Matching area [7][8] deals with all these problems, being considered by many authors the key element for heterogeneity reduction between ontologies.

The Ontology Matching task consists in identifying the correct correspondences among entities of multiple ontologies, which it is a necessary condition for establishing the interoperability among them [8]. A number of techniques can be used to identify correspondences between the entities of two ontologies, including the analysis of subsumption between classes and the similarity between the entity names. However, current results of state-of-the-art techniques are neither complete nor precise, i.e., they are not able to identify all existing correspondences between two ontologies and sometimes suggest correspondences that do not exist [9]. With regard to precision errors, suggesting a correspondence that does not exist may lead to either logical or ontological incompatibilities.

On the other hand, in the context of software development, *antipatterns* are considered a valuable tool for the identification of bad or incorrect practices in the software

development process. Antipatterns prevent or hamper a good execution of the software development or maintenance process. In the context of ontology matching, bad solutions consist of incorrect (including missing) or problematic correspondences. A correspondence antipattern is a matching model for identifying problematic correspondences that may occur repeatedly in ontology matching processes. A correspondence antipattern may be useful in several scenarios in which Ontology Matching is applied (such as in ontology merging, ontology comparison, query translation), since it helps refining an alignment produced by an ontology matching tool.

Looking for correspondence antipatterns, we "dig" the alignments available by OAEI and apply a methodology previously proposed in [11] for building correspondence antipatterns.

This work is divided as follows: Section 2 shows an overview about ontology correspondence antipatterns, Section 3 presents how we "dig" some correspondence antipatterns from the data published by OAEI, Section 4 presents related works and, finally, Section 5 points final considerations of this work.

2 Correspondence Antipatterns

Ontology matching identifies correspondences between the entities of multiple ontologies, and it is a necessary condition to establish interoperability between them [8]. According to Euzenat [7], technically the ontology matching process occurs by taking two ontologies *O* and *O'* as input, optionally considering a set of resources *r*, a set of parameters *p* and an initial alignment *A*. The result of this process is an alignment *A'* between the ontologies *O* and *O'*, and may be represented as $A' = f(O, O', A, p, r)$. Basically, ontology matching is a process in which semantic links between entities of ontologies are established. This process results in a set of semantic links, where each semantic link is called a correspondence. The set of correspondences is called an alignment. Correspondences may stand for several relations, such as equivalence or subsumption [7]. In this work, we consider only equivalence correspondences.

Due to possible precision errors that every ontology alignment tool is subject to, it may be the case that a correspondence included in an ontology alignment is not correct. Take, for example, a real problem illustrated in Figure 1, showing an alignment problem that occurs in the last three OAEI[1] editions, between *ConfOf* and *Edas* ontologies. The Ontology Alignment Evaluation Initiative (OAEI) is a coordinated international initiative whose goal is to evaluate the strengths and weaknesses of the ontology alignment tools. OAEI organizes annual campaigns addressing several domains, and publishes the results of the evaluated tools. The correspondence between the *ConfOf.Conference* and *Edas.Conference* classes is a problematic one. Let's analyze this case: suppose that *x* is an instance of *Edas.Conference*. Since an equivalent relationship between the entities *Edas.Conference* and *ConfOf.Conference* has been established, we may deduce that there is a possible world *w* in which *x* is an instance of *ConfOf.Conference* as well. Since *ConfOf.Conference* is a specialization of *Con-*

[1] http://oaei.ontologymatching.org/

fOf.Event, *x* is necessarily an instance of *ConfOf.Event* in *w*. We also notice that there is an equivalence correspondence established between *ConfOf.Event* and *Edas.Conferece_Event*. Thus, *x* is also an instance of *Edas.Conference_Event* in *w*. However, considering that *Edas.Conference_Event* and *Edas.Conference* are disjoint classes, there should be no possible world in which *x* instantiates both *Edas.Conference* and *Edas.Conference_Event* simultaneously, which leads to a contradiction, thus evidencing an alignment problem.

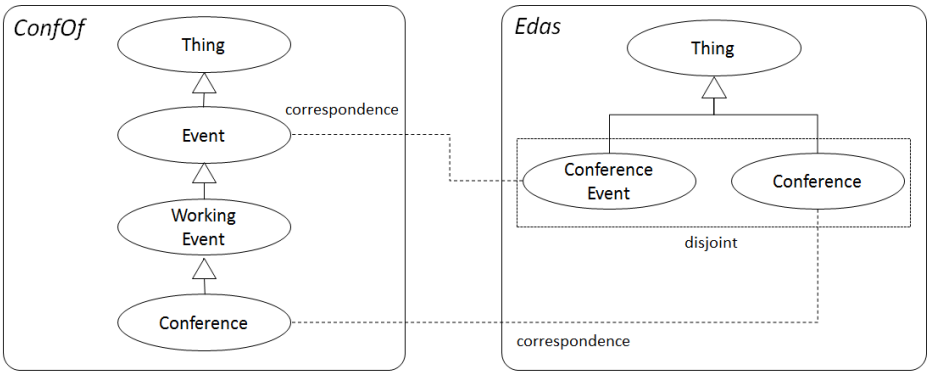

Fig. 1. Fragment of two ontologies and an alignment problem.

Patterns assist in building a collective experience based on the skills of domain specialists. On the other hand, an antipattern is a description of a given solution to a common problem that generates, definitely, negative consequences.

Given two ontologies *O* and *O'* to be aligned, a correspondence antipattern is a set of generic, domain-independent correspondences and/or non-correspondences between the entities of *O* and *O´* that lead to a contradiction. The purpose of a correspondence antipattern is, then, to help domain specialists in identifying a mismatch (a wrong correspondence) within an alignment.

We may generalize the example scenario illustrated in Figure 1 as follows: Consider a class e1 in an ontology o1 that is a subclass of a class e2, which in turn is subclass of a class e3 in o1. If class e3 in the ontology o1 is equivalently correspondent to class e2 in ontology o2, and classes e1 (from ontology o2) and e2 (from ontology o2) are disjoint, then class e1 from ontology o1 cannot equivalently match class e1 from ontology o2. As shown in [28], this correspondence antipattern can be represented as follows:

$$\{(?o1{:}?e1 \equiv ?o2{:}?e1) \sqcap (?o1{:}?e1 \sqsubseteq ?o1{:}?e2) \sqcap (?o1{:}?e2 \sqsubseteq ?o1{:}?e3) \sqcap (?o1{:}?e3 \equiv ?o2{:}e2) \sqcap (?o2{:}?e1 \sqcap ?o2{:}?e2 \sqsubseteq \bot)\} \quad (1)$$

3 Digging Correspondence Antipatterns

As shown in [11], for the development of correspondence antipatterns, the first step is to have the correct understanding of the problem being treated. When properly understood, the identified problem can result in correspondence antipatterns templates. Figure 2 presents the methodology proposed in [11], which can assist in the construction of a correspondence antipattern. This methodology focuses on responding to key issues which are essential for an antipattern identification.

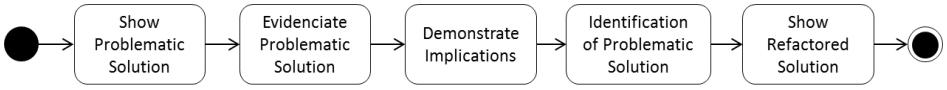

Fig. 2. Methodology to build a correspondence antipattern.

The methodology was applied on the results provided by the OAEI in the last three editions (2011.5, 2012 and 2013). The identification of correspondence antipatterns considered recurring incorrect correspondences generated by the evaluated tools. We identified incorrect correspondences by comparing tool results with the reference alignment published by OAEI. Each step of this process will now be briefly explained and illustrated in the OAEI scenario.

First step: *Show problematic solution*. The first step towards the construction of correspondence antipatterns is the correct understanding of the problem being treated. To start the search for correspondence antipatterns, the first step was the identification of incorrect correspondences, or false positives, in the set of selected alignments. False positives are the correspondences found by the evaluated tools that are not in the reference alignments. Within the universe of identified incorrect correspondences, we selected those that most frequently occurred (i.e., that were identified by many of the evaluated tools). We selected 40 incorrect correspondences, which were the ones that occurred over 50% of the analyzed alignments, as shown in Table 1. The columns *Ontology 1* and *Ontology 2* denotes the ontologies being aligned and the columns *Entity 1* and *Entity 2* denotes the entities involved in the incorrect correspondences found. The *Total Problems* column shows the quantity of alignments analyzed in which the incorrect correspondence was found. The *Total Alignments* column shows the quantity of alignments analyzed. *Percent* is calculated as *Total Problems* / *Total Alignment*.

Table 1. Inconsistent correspondences found in the set of alignments.

Error Nº	Ontology 1	Ontology 2	Entity 1	Entity 2	Total Problems	Total Alignments	Percent
1	Conference	Ekaw	Invited talk	Invited Talk	53	56	95%
2	Cmt	Iasted	Document	Document	53	57	93%
3	Edas	Ekaw	Presenter	Presenter	53	57	93%
4	Iasted	Sigkdd	Document	Document	53	57	93%

5	Conference	Ekaw	Conference partic-ipant	Conference Participant	52	56	93%
6	Edas	Iasted	Person	Person	52	57	91%
7	Conference	Iasted	Presentation	Presentation	52	56	93%
8	Conference	ConfOf	Conference	Conference	52	56	93%
9	Edas	Ekaw	Conference	Conference	52	57	91%
10	Cmt	Conference	Reviewer	Reviewer	51	56	91%
11	Conference	Edas	Conference	Conference	51	56	91%
12	ConfOf	Edas	Conference	Conference	50	57	88%
13	Conference	Ekaw	Conference	Conference	49	56	88%
14	Edas	Ekaw	ConferenceSession	Conference Session	48	57	84%
15	Cmt	ConfOf	Paper	Paper	47	57	82%
16	Conference	Ekaw	Paper	Paper	47	56	84%
17	Conference	Sigkdd	Conference	Conference	47	56	84%
18	Cmt	Conference	Paper	Paper	47	56	84%
19	ConfOf	Edas	hasEmail	hasEmail	46	57	81%
20	ConfOf	Ekaw	Paper	Paper	46	57	81%
21	Iasted	Sigkdd	pay	pay	44	57	77%
22	ConfOf	Edas	hasPhone	hasPhone	43	57	75%
23	Cmt	Sigkdd	name	Name	43	57	75%
24	Iasted	Sigkdd	obtain	obtain	42	57	74%
25	Cmt	ConfOf	writtenBy	writtenBy	41	57	72%
26	ConfOf	Edas	hasPostalCode	hasPostalCode	41	57	72%
27	ConfOf	Edas	hasStreet	hasStreet	40	57	70%
28	Cmt	Sigkdd	date	Date	40	57	70%
29	ConfOf	Edas	hasTopic	hasTopic	39	57	68%
30	mouse	human	MA 0000065	NCI C12685	39	45	87%
31	ConfOf	Edas	hasCountry	hasCountry	39	57	68%
31	mouse	human	MA 0000323	NCI C12378	39	45	87%
33	Cmt	Ekaw	writtenBy	writtenBy	38	57	67%
34	ConfOf	Ekaw	writtenBy	writtenBy	38	57	67%
35	mouse	human	UNDEFINED part of	UNDEFINED part of	37	45	82%
36	Conference	Iasted	is given by	is given by	37	56	66%
37	mouse	human	MA 0000003	NCI C12919	36	45	80%
38	Cmt	Edas	email	hasEmail	31	57	54%

39	Conference	Edas	Call for paper	CallForPapers	29	56	52%
40	Conference	Edas	has an email	hasEmail	27	56	48%

Second Step: *Evidentiate problematic solution.* For a solution to be considered problematic, this should in fact occur [11]. Table 1 confirms that these errors are recurrent. The *Total Problems* column of Table 1 shows the total occurrences of the correspondence in the last three editions of the OAEI.

Third Step: *Demonstrate Implications.* For each incorrect correspondence, the error and its implications are analyzed according to the classification of types of inferences examined in [10]. Some of the errors found and their implications are presented as follows.

o

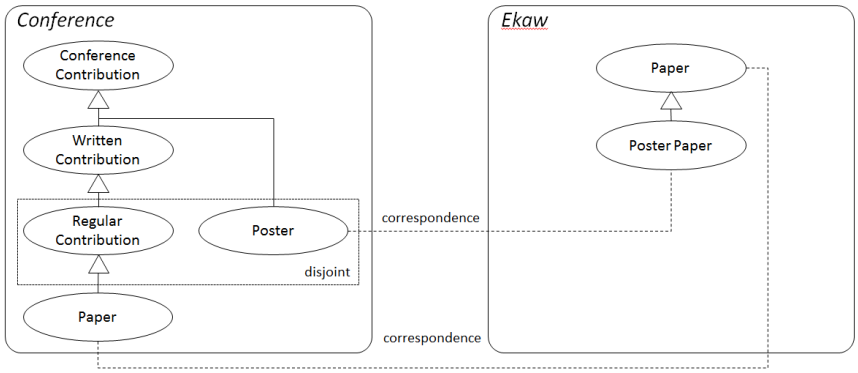

Fig. 3. Alignment problem between Conference and Ekaw ontologies.

Error Number 16: In the set of alignments analyzed, the correspondence ⟨*conference.paper, ekaw.paper,* ≡, _⟩ occurs 47 times. By analyzing the correspondence together with the aligned ontologies we identified the following problem: let *e1* be a class in an ontology *o1* which is subclass of a class *e2*, which in turn is a disjoint class of a class *e3*, also in ontology *o1*. If class *e1* in ontology *o1* equivalently corresponds to class *e1*' in ontology *o2*, class *e2* in ontology *o1* corresponds to class *e2* in ontology *o1* and class *e2'* in *o2* is a subclass of *e1* in ontology *o1*, then there is a contradiction (more specifically, a disjointness-subsumption contradiction alignment problem [10]). Figure 3 shows the case identified on the correspondence number 16, where the above problem occurs.

Error Number 20: In the set of alignment analyzed, the correspondence ⟨*confof.paper, ekaw.paper,* ≡, _⟩ occurs 46 times. By analyzing the correspondence together with the aligned ontologies we established the follow problem: let *e1* be a class in ontology *o1* that is disjoint with class *e2* in the same ontology *o1*, and a class *e1'* in ontology *o2* that specializes class *e2*' in the same ontology *o2*. If class *e1* in *o1* equivalently corresponds to class *e1*' in *o2* and class *e2* in *o1* equivalently corresponds to class *e2*' in *o2*, then there is a contradiction (a disjointness-subsumption contradiction

alignment problem [10]). Figure 4 shows the case identified on the correspondence number 20, where the above problem occurs.

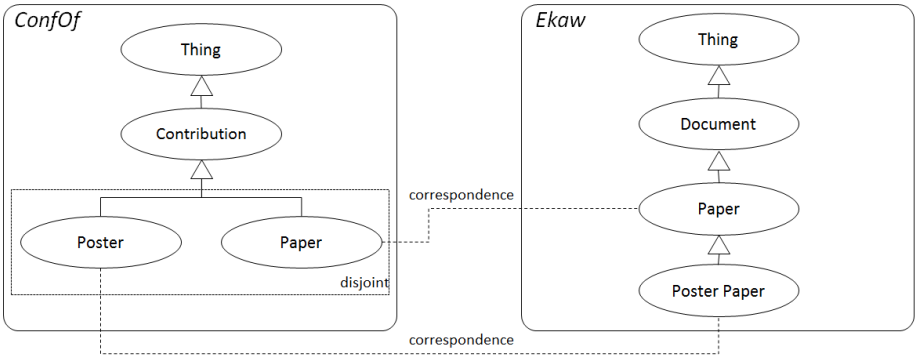

Fig. 4. Alignment problem between ConfOf and Ekaw ontologies.

Error Number 25: In the set of alignment analyzed, the correspondence ⟨*cmt.writtenBy, confof.writtenBy,* ≡*,* _⟩ occurs 41 times. By analyzing the correspondence together with the aligned ontologies we established the following problem: let *p1* be a property in ontology *o1* that has class *e1* as its domain and class *e2* as its range, both in ontology *o1*, and a property *p1*' in an ontology *o2* that has class *e1*' as its domain class *e2*' as its range, both in ontology *o2*. If *p1* in *o1* equally corresponds to the property *p1'* in *o2*, but class *e1* in *o1* does not correspond to class *e1'* in *o2* or class *e2* in *o1* does not correspond to class *e2'* in *o2*, then there is a domain and range incompleteness alignment problem. Figure 5 shows the case identified on the correspondence number 25, where the above problem occurs.

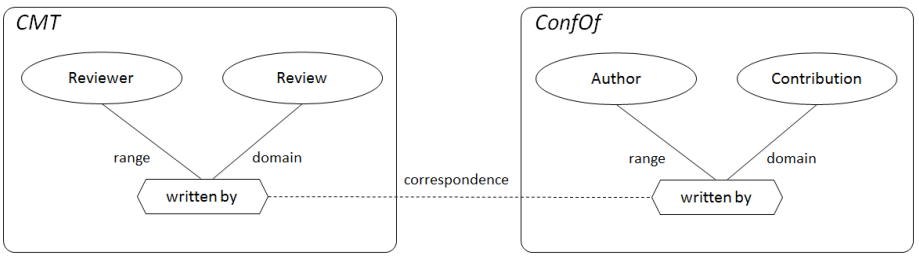

Fig. 5. Alignment problem between CMT and ConfOf ontologies.

Error Number 27: In the set of alignment analyzed, the correspondence ⟨*confof.hasStreet, edas.hasStreet,* ≡*,* _⟩ occurs 40 times. By analyzing the correspondence together with the aligned ontologies we established the following problem: let *p1* be a property in an ontology *o1* that has classes *e1* and *e2* as its domain, both in ontology *o1*, and a property *p1*' in an ontology *o2* that has as its domain a class *e1*' in ontology *o2*. If *p1* in *o1* equally corresponds to the property *p1'* in *o2* and class *e1'* in *o2* does not correspond to any domain class of *p1* in *o1*, then there is a domain and range in-

completeness alignment problem. Figure 6 shows the case identified on the correspondence number 27, where the above problem occurs.

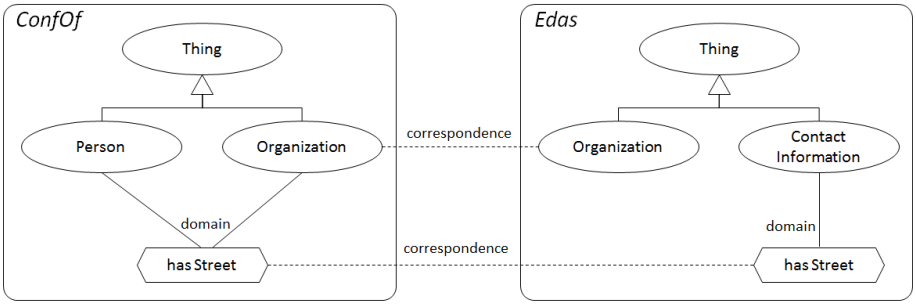

Fig. 6. Alignment problem between ConfOf and Edas ontologies.

Fourth Step: *Identification of the Problematic Solution.* The formal representation of how to identify an alignment problem is what gives life to correspondence antipattern. For each problem analyzed was created one correspondence antipattern, as summarized in Table 2.

Table 2. Antipatterns builded from alignment problems.

Antipattern Item	Short Description
Name	OCA02 - Disjointness-subsumption contradiction with disjoint classes with subclasses.
Antipattern general form	(o1:e1 ≡ o2:e1') ⊓ (o2:e2' ⊑ o2:e1') ⊓ (o1:e1 ⊓ o1:e3' ⊆ ⊥) ⊓ (o1:e2 ≡ o2:e2') ⊓ (o1:e2 ⊑ o1:e3)
Name	OCA03 - Disjointness-subsumption contradiction with disjoint classes without subclasses.
Antipattern general form	(o1:e1 ≡ o2:e1') ⊓ (o2:e2' ⊑ o2:e1') ⊓ (o1:e1 ⊓ o1:e ⊆ ⊥) ⊓ (o1:e2 ≡ o2:e2')
Name	OCA04 - Domain and range incompleteness with no correspondence in domains or ranges
Antipattern general form	(o1:p1≡o2:p1') ⊓ ((o1:e1 ∈ domain(o1:p1) ⊓ o2:e1 ∈ domain(o2:p1') ⊓ ∄(o1:e1≡o2:e1')) ⊔ (o1:e2 ∈ range(o1:p1) ⊓ o2:e2' ∈ range(o2:p1) ⊓ ∄(o1:e2≡o2:e2')))
Name	OCA05 - Domain and range incompleteness with no correspondence in domains
Antipattern general form	(o1:p1≡o2:p1') ⊓ (o1:e1 ∈ domain(o1:p1) ⊓ o2:e1' ∈ domain(o2:p1') ⊓ ∄(o1:e1≡o2:e1'))

For the construction and computational representation of a correspondence antipattern, we adopt EDOAL (Expressive Declarative Ontology Alignment Language), an open and agnostic language [2] [11]. A fragment of the *OCA02 - Disjointness-*

subsumption contradiction with disjoint classes with subclasses correspondence anti-pattern EDOAL representation is illustrated as follows:

```
<map>
  <cell>
    <entity1><Class rdf:about="?o1:?e1"/></entity1>
    <entity2><Class rdf:about="?o2:?e1"/></entity2>
    <relation rdf:resource="equivalence"/>
  </cell>
  <cell>
    <entity1><Class rdf:about="?o2:?e2" /></entity1>
    <entity2><Class rdf:about="?o2:?e1" /></entity2>
    <relation rdf:resource="subsumedBy"/>
  </cell>
  <cell>
    <entity1><Class rdf:about="?o1:?e1" /></entity1>
    <entity2><Class rdf:about="?o1:?e3" /></entity2>
    <relation rdf:resource="disjoint"/>
  </cell>
  <cell>
    <entity1><Class rdf:about="?o1:?e2" /></entity1>
    <entity2><Class rdf:about="?o2:?e2" /></entity2>
    <relation rdf:resource="equivalence"/>
  </cell>
  <cell>
    <entity1><Class rdf:about="?o1:?e2" /></entity1>
    <entity2><Class rdf:about="?o1:?e3" /></entity2>
    <relation rdf:resource="subsumedBy"/>
  </cell>
</map>
```

Fifth Step: *Refactored Solution*. Refactoring in this case means repairing the alignment to eliminate logical inconsistencies. This is not a trivial activity, since there may exist many solutions for a specific scenario. Morevover, the best solution may also depend on the task, or even point some problem in the semantics of the correspondence. Therefore, this task is currently carried out by the specialist, with no automatic support. Further evolution of this approach will investigate automatic approaches for alignment refactoring.

4 Related Work

In ontology research, Ontology Design Patterns (ODPs) are an emerging approach that favors the reuse of encoded experiences and good practices. ODPs are modeling solutions to solve recurrent ontology development problems [1]. Compared with Software Engineering, where patterns have been used for a long period, patterns in Ontology Engineering are still in infancy [2]. The earliest works addressing the issue of patterns in Ontology Engineering are from the beginning of the 2000s. Sales and colleagues present semantic antipatterns for ontology engineering [3]. These antipatterns capture error-prone modeling decisions, which can result in the creation of models that allow for unintended model instances (representing undesired state of affairs). The antipatterns presented by [3] have been empirically elicited through an approach

of ontology conceptual models validation via visual simulation. In [12], the authors collect a list of common antipatterns that can be found in ontologies and that cause a large percentage of inconsistency problems Besides, their list some antipatterns that do not have an impact on the logical consequences of the ontology being developed, but are important to reduce the number of errors in the intended meaning of ontologies or to improve their understandability.

Correspondence patterns, proposed by [2], are essentially correspondences and sets of correspondences with generic entities. They act as role models to help find correspondences more precise than simply relate one entity to another one. Each correspondence pattern is a generic solution to a problem of alignment. Author of [2] proposed a library of correspondence patterns for design that represent solutions to different recurrent mismatches which are quite hard for matchers using usual matching techniques. Padilha [4] proposes design patterns and antipatterns for ontology alignment using high-level ontologies. The proposed design patterns were built based on the OntoUML [5], ontology modeling language which considers the ontological distinctions and axiomatic theories proposed in Foundational Ontology Unified (UFO). The patterns described are design patterns modeling, and there is no any kind of implementation thereof.

5 Final Considerations

Ontology matching is a very active research field in the scientific community, where various techniques and approaches have been proposed. However, existing tools are still likely to identify incorrect correspondences between the entities of the ontologies that are being aligned. The identification of recurrent errors may serve as input for the construction of correspondence antipatterns. A correspondence antipattern is a set of generic correspondences between two ontologies that represents an incorrect alignment. They assist in identifying incorrect correspondences in a given alignment, and should be computationally representated in an open and agnostic language.

OAEI is an important initiative that provides the community with the results os evaluations of several ontology matching techniques and tools. This published data constitutes a rich environment for analyzing recurrent errors in practical alignments.

In this work, the results provided by OAEI in three evaluation editions (2011.5, 2012 and 2013) were analyzed. The identified recurring alignment problems were considered and some correspondence antipatterns were specified and codified and EDOAL, following the methodology proposed in [11].

Future works include the exhaustive analysis and identification of correspondence antipatterns from other OAEI datasets, and the construction of a framework to make use of these antipatterns in refining ontology alignments.

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