Towards Cross-checking WordNet and SUMO Using Meronymy

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Abstract

We describe the practical application of a black-box testing methodology for the validation of the knowledge encoded in WordNet, SUMO and their mapping by using automated theorem provers. In this paper, we concentrate on the part-whole information provided by WordNet and create a large set of tests on the basis of few question patterns. From our preliminary evaluation results, we report on some of the detected inconsistencies.

1 Introduction

Despite being created manually, knowledge resources such as WordNet (Fellbaum, 1998) and SUMO (Niles and Pease, 2003) are not free of errors and inconsistencies. Unfortunatelly, improving, revising, and correcting such large knowledge bases is a never ending task that have been mainly carried out also manually. A few automatic approaches have been also applied focusing on checking certain structural properties on WordNet (e.g. (Daudé et al., 2003), (Richens, 2008)) or using automated theorem provers on SUMO (e.g. (Horrocks and Voronkov, 2006), (Álvez et al., 2012)). Just a few more have studied automatic ways to validate the knowledge content encoded in these resources by cross-checking them. For instance, Álvez et al. (2008) exploit the EuroWordNet Top Ontology (Rodríguez et al., 1998) and its mapping to WordNet for detecting many ontological conflicts and inconsistencies in the WordNet nominal hierarchy.

In Álvez et al. (2017), we propose a method for the automatic creation of *competency questions* (CQs) (Grüninger and Fox, 1995), which enable to evaluate the competency of SUMO-based ontologies. Our proposal is based on several predefined question patterns (QPs) that are instantiated using information from WordNet (Fellbaum, 1998) and its mapping into SUMO (Niles and Pease, 2003). In addition, we also describe an application of automated theorem provers (ATPs) for the automatic evaluation of the proposed CQs.

The main contribution of this paper is to demonstrate the practical capabilities of the method introduced in Álvez et al. (2017) for the detection of semantic agreements and inconsistencies between WordNet and SUMO thanks to their mapping. For this purpose, we propose a new set of CQs that is obtained on the basis of the part-whole data of WordNet. In our ongoing experimentations using the ATPs Vampire (Kovács and Voronkov, 2013) and E (Schulz, 2002), we have automatically detected some knowledge discrepancies and disagreements that were hidden in both WordNet, SUMO and their mapping.

Outline of the paper. In the following three sections, we introduce WordNet, SUMO, and their mapping. Then, we describe our formal interpretation of the mapping information in Section 5 and the proposed question patterns for the creation of competency questions in Section 6. Next, we discuss our preliminary evaluation results in Section 7. Finally, we report on the ongoing work in Section 8 and provide some conclusions in Section 9.

2 Meronymy Relations in WordNet

In WordNet, meronymy —the part-whole relation— holds between synsets like $backrest^1_n$ and $seat^1_n$ (i.e. parts) and $chair^1_n$ (i.e. whole). Parts are inherited from their superordinates: if a chair has a seat, then an armchair has a seat as well. But parts are not inherited "upward" as they may be characteristic only of specific kinds of things rather than the class as a whole: chairs and kinds of chairs have a seat, but not all kinds of furnitures have a seat.

There exist 3 main meronymy relations in WordNet v3.0 that relate noun synsets: *part*, the general meronymy relation; *member*, which relates particulars and groups; *substance*, which relates physical matters and things. In total, there are 22,187 (ordered) synset pairs: 9,097 pairs using *part*, 12,293 pairs using *member* and 797 pairs using *substance*. For example, the synsets $committee^1_n$ and $committee\_member^1_n$ are related by *member*, while $grape^1_n$ and $wine^1_n$ are related by *substance*.

3 SUMO and Adimen-SUMO

SUMO[1] (Niles and Pease, 2001) has its origins in the nineties, when a group of engineers from the IEEE Standard Upper Ontology Working Group pushed for a formal ontology standard. Their goal was to develop a standard upper ontology to promote data interoperability, information search and retrieval, automated inference and natural language processing.

Currently, SUMO consists of about 20,000 terms and about 70,000 axioms organized in several levels. In the the upper two levels —*Top* and *Middle* levels— one can find the concepts, relations and axioms that are meta, generic or abstract. From now on, we refer to the upper two levels of SUMO as its *core*. On the basis of these two levels, concepts that are specific to particular domains are in the so-called *domain* ontologies. Adimen-SUMO (Álvez et al., 2012) is obtained by means of a suitable transformation of the knowledge in the core of SUMO into FOL, which enables its use by FOL ATPs such as Vampire (Kovács and Voronkov, 2013) and E (Schulz, 2002). Adimen-SUMO inherits all the axioms in the core of SUMO that can be expressed in FOL (around an 88% of the axioms).

The knowledge in SUMO is organized around the notions of *individuals* and *classes* —the main SUMO concepts. These concepts are respectively defined in Adimen-SUMO by means of the *meta*-predicates *$instance* and *$subclass*. SUMO individuals and classes are not disjoint, since every SUMO class is defined to be instance of *Class* and, thus, every SUMO class is also a SUMO individual. Additionally, SUMO also differentiates *relations* and *attributes*. In particular, SUMO distinguishes between *individual* relation and attributes —that is, instances of the SUMO classes *Relation* and *Attribute* respectively— and *classes* of relations and attributes —that is, subclasses of the SUMO classes *Relation* and *Attribute* respectively.

SUMO provides specific predicates for dealing with relations and attributes. Among others, we currently use the next ones in Adimen-SUMO:

- *subrelation*, which relates two individual SUMO relations (that is, two instances of the SUMO class *Relation*).
- *subAttribute*, which relates two individual SUMO attributes (that is, two instances of the SUMO class *Attribute*).
- $holds^k$, which relates an individual SUMO relation (that is, an instance of the SUMO class *Relation*) with a k-tuple of SUMO concepts, where k ranges from 2 to 5.
- *attribute*, which relates a SUMO individual[2] with an individual SUMO attribute (that is, an instance of the SUMO class *Attribute*).

For simplicity, from now on we denote the nature of SUMO concepts by adding as subscript the symbols o (SUMO individuals that are neither classes nor relations nor attributes), c (SUMO classes that are neither classes of relations nor classes of attributes), r (individual SUMO relations), a (individual SUMO attributes), R (classes of SUMO relations) and A (classes of SUMO attributes). For example: $Cell_c$, $member_r$ and $Larval_a$.

4 The Mapping Between WordNet and SUMO

WordNet is linked with SUMO by means of the mapping described in Niles and Pease (2003). This mapping connects synsets of WordNet to terms of SUMO using three relations: *equivalence*, *subsumption* and *instance*.[3] *equivalence* denotes that the related WordNet synset and SUMO concept are equivalent in meaning, whereas *subsumption* and *instance* indicate that the WordNet synset is subsumed by the SUMO concept or is an instance of the SUMO concept respectively. Additionally, the mapping also uses the complementaries of *equivalence* and *instance*. We de-

[1] `http://www.ontologyportal.org`

[2] The individual in the first argument of *attribute* is restricted to be instance of *Object* by the *domain* axioms provided by SUMO.

[3] Note that *instance* denotes the relation that is used in the mapping between WordNet and SUMO (for example, in *Integer*@), while *$instance* denotes the meta-predicate that is used in the axiomatization of SUMO.

SUMO Concept Type	Mapping Relation				
	=	+	@	$\widehat{}$	**Total**
Individuals	132 (0)	171 (0)	15 (0)	0 (0)	**318 (0)**
Classes	1,564 (0)	57,018 (546)	8,991 (337)	30 (0)	**67,520 (883)**
Relations	77 (0)	538 (0)	0 (0)	0 (0)	**615 (0)**
Attributes	340 (0)	12,762 (250)	570 (0)	0 (0)	**13,662 (250)**

Table 1: The mapping between WordNet and the core of SUMO

note mapping relations by concatenating the symbols '$=$' (*equivalence*), '$+$' (*subsumption*), '@' (*instance*), '$\widehat{=}$' (complementary of *equivalence*) and '$\widehat{+}$' (complementary of *subsumption*) to the corresponding SUMO concept. For example, the synsets horse^1_n and $\mathit{education}^4_n$ are connected to $\mathit{Horse}_c{=}$ and $\mathit{EducationalProcess}_c{+}$ respectively.

From the 82,115 noun synsets defined in WordNet v3.0, 73,472 noun synsets are directly connected to concepts that are defined in the core of SUMO —and, thus, in Adimen-SUMO—, while only 7,578 synsets are linked to SUMO concepts defined in domain ontologies. As described in Álvez et al. (2017), those synsets linked to concepts defined in domain ontologies are connected to concepts from the core of SUMO by means of the SUMO structural relations *\$subclass*, $\mathit{subrelation}_r$ and $\mathit{subAttribute}_r$. For example, the synset frying^1_n is connected to $\mathit{Frying}_c{=}$, which does not belong in the core of SUMO: Frying_c is defined in the domain ontology *Food* to be subclass of the SUMO core concept $\mathit{Cooking}_c$. Thus, by means of *\$subclass*, we can connect frying^1_n to $\mathit{Cooking}_c{+}$ in order to obtain a whole mapping between WordNet and the core of SUMO.

It is worth to remark that some noun synsets are connected to several SUMO concepts. Concretely, 1,043 synsets.

In Table 1, we provide some figures about the mapping between WordNet and the core of SUMO. More specifically, we provide the amount of noun synsets that are respectively connected to SUMO individuals, classes, relations and attributes by mapping relation. In addition, we also provide the number of multiple connections —or *multiple mappings*— between brackets. It is easy that there is no multiple mapping involving individuals and relations. Furthermore, most of the synsets are connected to SUMO classes and attributes (in total, 81,182 synsets), while only 933 synsets are connected to SUMO individuals and relations.

5 Formal Interpretations of the Mapping Between WordNet and SUMO

The automatic validation of WordNet and SUMO on the basis of CQs and ATPs requires to translate all the information into a formal language. By means of Adimen-SUMO (Álvez et al., 2012), the core information of SUMO is already written in FOL. However, WordNet and its mapping to SUMO are not formally characterized. Therefore, we next describe and compare two possible formal interpretations of the mapping between WordNet and SUMO.

The first possible interpretation is just to literally follow the definition of the mapping relations provided in Niles and Pease (2003). That is:

- *equivalence* is synonymy.
- *subsumption* indicates that the SUMO concept is a hypernym of the associated synset.
- *instance* designates the synset as an individual of the connected SUMO concept.

However, the above literal interpretation of the mapping suffers from several problems. On one hand, *subsumption* and *instance* lack an obvious interpretation when referred to SUMO individuals:[4] it is non-sense to assert that an individual has hyponyms or individuals and, in addition, there is only one SUMO predicate for dealing with relations (i.e. $\mathit{subrelation}_r$) and attributes ($\mathit{subAttribute}_r$) respectively. On the other hand, the literal interpretation of the mapping may yield to inconsistent statements when applied to synsets that are connected to several SUMO concepts. For example, $\mathit{male\_horse}^1_n$ is connected to both $\mathit{Male}_a{+}$ and $\mathit{Horse}_c{+}$. Thus, $\mathit{male\_horse}^1_n$ would be interpreted of hyponym of both Male_a and Horse_c. For this purpose, we would use the

[4]Note that most of the SUMO relations and attributes are individuals.

SUMO predicates *subAttribute*$_r$ and *\$subclass* respectively. However, these two predicates are defined to relate incompatible SUMO concepts: *Attribute*$_c$ and *Class*$_c$ are disjoint classes.[5]

The second possibility is to interpret all the mapping relations exclusively in terms of SUMO individuals. Under this interpretation, we consider synsets to be related to sets of SUMO individuals that are characterized by a) the particular SUMO concept to which the synset is connected and b) the mapping relation that is used in the linking. The set of SUMO individuals that are potentially related to a given synset can be represented using SUMO statements. For the construction of those statements, we associate a different variable to each synset and choose the most suitable SUMO predicate depending of the nature of the SUMO concept to which the synset is connected: *equal* for SUMO individuals, *\$instance* for SUMO classes and *attribute*$_r$ for SUMO individual attributes.[6] The interested reader is referred to Álvez et al. (2017) for further details. For example, the synsets *malacosoma_americana*^1_n and *genus_malacosoma*^1_n are connected to *Insect*$_c$+ and *Larval*$_a$+ respectively. By associating the variables *?X* and *?Y* to each synset, we generate the following Adimen-SUMO statements:

```
($instance ?X Insect)      (1)
(attribute ?Y Larval)      (2)
```

On the basis of the above Adimen-SUMO statements that restrict the set of potential SUMO individuals related to a synset, the second interpretation of the mapping information is completed according to the mapping relation that links the synset and the SUMO concept:

- If the synset is connected using *equivalence* (resp. the negation of *equivalence*), then we can assume that the synset is related to all (resp. is not related to any of) the potential SUMO individuals that satisfy the Adimen-SUMO statement proposed above. For this purpose, the variable associated to the given synset is considered to be universally quantified.
- Otherwise —the synset is connected using *subsumption* (resp. the negation of *subsumption*) or *instance*—, we can only assume that the synset is related to (resp. is not related to) some of the potential SUMO individuals the Adimen-SUMO statement proposed above. This means that the variable associated to the given synset is considered to be existentially quantified.

This second interpretation of the mapping information takes advantage from the fact that most of the SUMO knowledge is based on the notion of *individuals* and that only a few of SUMO predicates provide information at the level of *classes*. From this point of view, this interpretation enables a more precise use of the knowledge of SUMO. In addition, the problem with synsets connected to several SUMO concepts is overcome. Going back to the example about *male_horse*^1_n, its mapping to *Male*$_a$+ and *Horse*$_c$+ can be translated as

```
(and                        (3)
  (attribute ?S Male)
  ($instance ?S Horse))
```

where its associated variable *?S* stands for all the SUMO individuals that are related to *male_horse*^1_n.

6 Competency Questions Based on Meronymy

In this section, we describe the set of CQs that is created on the basis of the part-whole data provided by WordNet.

For this purpose, we consider the second interpretation of the mapping information introduced in Section 5. Since that interpretation does not distinguish between *subsumption* and *instance*, we only consider two linking options for WordNet synsets: synsets connected by *equivalence* (or its negation) and synsets connected by (the negation of) *subsumption* or *instance*. Therefore, there are just 4 possible combinations of mapping relations in the 12,293 ordered synset pairs provided by WordNet and we propose a different question pattern for each of them.

Given an ordered synset pair, the corresponding question pattern is instantiated according to a) the WordNet meronymy relation and b) the SUMO concepts to which synsets are connected.

With respect to WordNet meronymy relations, we have inspected SUMO in order to find the relations that are synonym or semantically similar to

[5] It is worth to recall that *subAttribute*$_r$ relates SUMO individual attributes, which are instance of *Attribute*$_c$, while *\$subclass* relates SUMO classes, which are instance of *Class*$_c$.

[6] The linkings to SUMO relations are discarded.

```
(exists (?X, ?Y)
  (and
    < s_part, ?X >
    < s_whole, ?Y >
    (< SUMO predicate > ?X ?Y)))
```

Figure 1: First question pattern for $\langle s\_part, s\_whole \rangle$ meronymy pairs

them. In SUMO, the main meronymy relation is *part*$_r$ and we can find 30 different subrelations of *part*$_r$ in its core. Among them, we have selected the SUMO predicates *part*$_r$, *member*$_r$ *piece*$_r$ as counterpart of the WordNet relations *part*, *member* and *substance* respectively. As for every SUMO relation, SUMO provides *domain* axioms that restrict the set of SUMO individuals that can be related by the above predicates as follows:

- *part*$_r$ relates pairs of *Object*$_c$ individuals.
- *member*$_r$ relates *SelfConnectedObject*$_c$ individuals (first argument) to *Collection*$_c$ individuals (second argument).
- *piece*$_r$ relates pairs of *Substance*$_c$ individuals.

Additionally, SUMO also defines several incompatibilities between SUMO individuals. Among others, individuals of *CorpuscularObject*$_c$ are not compatible with neither *Collection*$_c$ nor *Substance*$_c$ because *CorpuscularObject*$_c$ and *Collection*$_c$ (also *Substance*$_c$) are defined as disjoint classes.

On the basis of individual SUMO incompatibilities, we can already detect some errors. For example, the synsets *grape*^1_n and *wine*^1_n are related by *substance* (as introduced in Section 2) and respectively connected *FruitOrVegetable*$_c$+ and *Wine*$_c$=. In SUMO, *FruitOrVegetable*$_c$ is defined to be subclass of *CorpuscularObject*$_c$. Consequently, *FruitOrVegetable*$_c$ is incompatible with *Substance*$_c$, which prevents the use of *piece*$_r$ for relating synsets pairs with individuals of *FruitOrVegetable*$_c$ in the first place. The source of this error is discussed in Section 7.

After choosing the most suitable SUMO predicate for a given synset pair, the instantiation of the corresponding question pattern is finished according to the SUMO concepts to which synsets are connected. More specifically, we apply the second interpretation of the mapping information in order to obtain a Adimen-SUMO statement for each synset. The resulting Adimen-SUMO statements are directly used for the instantiation of question patterns.

```
(forall (?X)
  (=>
    < s_part, ?X >
    (exists (?Y)
      (and
        < s_whole, ?Y >)
        (< SUMO predicate > ?X ?Y))))
```

Figure 2: Second question pattern for $\langle s\_part, s\_whole \rangle$ meronymy pairs

In the next subsections, we describe the proposed question patterns.

6.1 First Question Pattern

The first question pattern is designed for its application to meronymy pairs where both synsets are connected using (the negation of) *subsumption* or *instance*.

In Figure 1, we describe the combination of the selected SUMO predicate and the statements that are obtained by following the second interpretation of the mapping information introduced in Section 5. In that combination, the variables associated to both synsets are considered to be existentially quantified.

$$\begin{tikzcd}
{[\langle \textit{genus_malacosoma}^1_n \rangle]} : & {[\mathrm{Larval}_a+]} \\
{[\langle \textit{malacosoma_americana}^1_n \rangle]} : \arrow[u, "\langle member \rangle"] & {[\mathrm{Insect}_c+]} \arrow[u, dotted, "?\ {[member_r]}"]
\end{tikzcd}$$

Figure 3: *malacosoma_americana*^1_n and *genus_malacosoma*^1_n.

Next, we illustrate the instantiation of the resulting question pattern by considering again the synsets *malacosoma_americana*^1_n and *genus_malacosoma*^1_n, which are related by *member* and connected to *Insect*$_c$+ and *Larval*$_a$+ respectively as described in Figure 3. The combination of the SUMO statements (1,2) that result from their mapping information with the SUMO predicate *member*$_r$ yields the following CQ:

```
(exists (?X, ?Y)                                    (4)
   (and
      ($instance ?X Insect)
      (attribute ?Y Larval)
      (member ?X ?Y)))
```

6.2 Second Question Pattern

The second question pattern is designed for meronymy synset pairs $\langle s\_part, s\_whole\rangle$ where s_part is connected by (the negation of) *equivalence* and s_whole is connected by (the negation of) *subsumption* or *instance*.

In this case, the variable associated to s_whole is considered to be universally quantified, while the variable associated to s_part is considered to be existentially quantified. The resulting question pattern is described in Figure 2.

$$\begin{tikzcd}
{[\langle \mathit{calcium_oxide}^{1}_{n}\rangle :} & {[\mathrm{CompoundSubstance_c}+]} \\
{[\langle \mathit{calcium}^{1}_{n}\rangle :} \arrow[u, "\langle substance\rangle"'] & {[\mathrm{Calcium_c}=]} \arrow[u, dotted, "{?\ [piece_r]}"']
\end{tikzcd}$$

Figure 4: *calcium*^1_n and *calicum_oxide*^1_n.

In order to illustrate the instantion of this second question pattern, we consider the synset pair *substance(calcium*^1_n*,calcium_oxide*^1_n*)*, where the involved synsets are respectively connected to *Calcium*$_c$= and *CompoundSubstance*$_c$+ as described in Figure 4. On the basis of the above mapping information, the selected SUMO predicate is *piece*$_r$ and we obtain the following CQ:

```
(forall (?X)                                        (5)
   (=>
      ($instance ?X Calcium)
      (exists (?Y)
         (and
            ($instance ?Y CompoundSubstance)
            (piece ?X ?Y)))))
```

6.3 Third Question Pattern

The third question pattern is the dual of the second one because it is designed for meronymy synset pairs $\langle s\_part, s\_whole\rangle$ where s_part is connected by (the negation of) *subsumption* or *instance*, and s_whole is connected by (the negation of) *equivalence*.

Consequently, the variables associated to s_whole and s_part are considered to be universally and existentially quantified respectively.

This third question pattern is applied to synset pairs like *member(committee*^1_n*,committee_member*^1_n*)*, where synsets are respectively connected to *Human*$_c$+ and *Commission*$_c$=. By using the SUMO predicate *member*$_r$, the resulting CQ is:

```
(forall (?Y)                                        (6)
   (=>
      ($instance ?Y Commission)
      (exists (?X)
         (and
            ($instance ?X Human)
            (member ?X ?Y)))))
```

6.4 Fourth Question Pattern

The last question pattern is designed for its application to meronymy pairs where both synsets are connected using (the negation of) *equivalence*.

$$\begin{tikzcd}
{[\langle \mathit{cell}^{2}_{n}\rangle :} & {[\mathrm{Cell_c}=]} \\
{[\langle \mathit{cell_nucleus}^{1}_{n}\rangle :} \arrow[u, "\langle part\rangle"'] & {[\mathrm{CellNucleus_c}=]} \arrow[u, dotted, "{?\ [part_r]}"']
\end{tikzcd}$$

Figure 5: *cell*^2_n and *cell_nucleus*^1_n.

In this case, the question pattern is obtained by the conjunction of the second and the third question patterns. In order to illustrate its application, we consider the synset pair *part(cell*^2_n*,cell_nucleus*^1_n*)*, where synsets are respectively connected to *Cell*$_c$= and *CellNucleus*$_c$= as described in Figure 5. The resulting CQ is:

```
(and                                                (7)
   (forall (?X)
      (=>
         ($instance ?X CellNucleus)
         (exists (?Y)
            (and
               ($instance ?Y Cell)
               (part ?X ?Y)))))
   (forall (?Y)
      (=>
         ($instance ?Y Cell)
         (exists (?X)
            (and
               ($instance ?X CellNucleus)
               (part ?X ?Y))))))
```

7 Discussion

In this section, we discuss the results obtained from our ongoing validation of WordNet and SUMO by applying the evaluation framework proposed in Álvez et al. (2017).

In Table 2, we report on some figures about the instantiation of the 4 question patterns introduced in the above section using the 22,187 meronymy pairs provided by WordNet. The information is organized in 11 columns as follows: according to the different WordNet meronymy relations (first column), we first provide the total amount of synset pairs (second column) and the number of synset-pairs which do not satisfy SUMO domain restrictions (third columnn); in the remaining 8 columns, we respectively provide the amount of synset pairs (Pairs columns) that have been applied to each question pattern and the number of resulting competency questions (CQs columns). To sum up, we have obtained 2,137 different CQs —$1,418 + 447 + 197 + 75$ CQs— from 7,674 synset pairs, while 14,513 pairs have not been used due to SUMO incompatibilities. Most of those synset pairs (11,920) are related by *member*, which relates $SelfConnectedObject_c$ individuals (first argument) to $Collection_c$ individuals (second argument).[7] By a manual inspection, we discover that the source of the problem in more than 8,000 pairs is the same: pairs where both synsets are connected to the same concept although the first synset denotes an individual organism and the second one the species, genus or family to which the organism belongs. For example, $bear^1_n$ and $Ursidae^1_n$ are both connected to $Mammal_c+$, which is subclass of $SelfConnectedObject_c$. In those cases, we decide that the mapping is not consistent because it does not correctly characterize the knowledge of WordNet in terms of SUMO: $Ursidae^1_n$ does not refer to any particular mammal, but to a group of mammals.

Another divergence between the knowledge of WordNet and SUMO that can be detected by means of SUMO incompatibilities is given by the pair *substance*($grape^1_n$,$wine^1_n$), as described in Section 6. In this case, the WordNet pair is not complete, since $grape\_juice^1_n$ is neither related to $grape^1_n$ nor $wine^1_n$.

Regarding our preliminary experimental results using ATPs, we have already checked that the proposed CQs enable to validate some pieces of the information of WordNet, SUMO and their mapping, and also to detect some conflicts. For example, the following CQ

```
(forall (?Y)                                        (8)
   (=>
      (attribute ?Y PoliceOfficer)
      (exists (?X)
         (and
            ($instance ?X PoliceOrganization)
            (member ?X ?Y)))))
```

is obtained from the synset pair *member*($police\_officer^1_n$,$police\_force^1_n$) by applying the third question pattern, since $police\_officer^1_n$ is connected to $PoliceOfficer_a=$ and $police\_force^1_n$ is connected to $PoliceOrganization_c+$. ATPs are able to prove conjecture (8), consequently both the WordNet meronymy pair, the mapping of the related synsets and the involved SUMO information are validated. On the contrary, ATPs do not find any proof for conjecture (6) or its negation. This fact leads us to discover that SUMO lacks from information conveniently relating the concepts of $Human_c$ and $Commission_c$ by $member_r$.

In the rest of this section, we proceed to illustrate three different kinds of discrepancies or disagreements that can be detected by the application of ATPs to the proposed CQs as described in Álvez et al. (2017).

In the first place, the use of ATPs enables to detect additional inconsistencies in the mapping between WordNet and SUMO. For example, ATPs are able to prove the negation of conjecture (4), which reveals the existence of a problem with the synsets $malacosoma\_americana^1_n$ and $genus\_malacosoma^1_n$. More specifically, the mapping of $genus\_malacosoma^1_n$ to $Larval_a+$ is not suitable.

Secondly, our proposal enables to detect conflicts which are due to the knowledge represented in SUMO. For example, the negation of conjecture (5) is proven by ATPs. By inspecting the proof, we discover that the problem is related to the following SUMO axiom (described in Adimen-SUMO syntax):

```
(=>                                                 (9)
   (piece ?SUBSTANCE1 ?SUBSTANCE2)
   (forall (?CLASS)
      (=>
         ($instance ?SUBSTANCE1 ?CLASS)
         ($instance ?SUBSTANCE2 ?CLASS))))
```

[7] It is worth to recall that $SelfConnectedObject_c$ and $Collection_c$ are disjoint classes.

Meronymy relations	Pairs Total	Pairs Error	1st QP Pairs	1st QP CQs	2nd QP Pairs	2nd QP CQs	3rd QP Pairs	3rd QP CQs	4th QP Pairs	4th QP CQs
part	9,097	2,221	5,974	1,252	725	430	116	104	61	59
member	12,293	11,920	348	78	14	14	10	7	1	1
substance	797	372	248	83	152	89	10	10	15	15
Total	**22,187**	**14,513**	**6,570**	**1,418**	**745**	**447**	**282**	**197**	**77**	**75**

Table 2: Instantiation of question patterns

In particular, $Calcium_c$ is subclass of $ElementalSubstance_c$, which is disjoint with $CompoundSubstance_c$. Therefore, no individual of $CompoundSubstance_c$ can inherit the property of being instance of $Calcium_c$.

Finally, we can also detect inconsistencies which are related to WordNet meronymy pairs. For example, ATPs are able to prove the negation of conjecture (7), thus revealing a problem related to the pair *part*($cell^2_n$,$cell\_nucleus^1_n$). More specifically, that pair is incompatible with the fact that some cells lack a nucleus, as stated by the following SUMO axiom (described in Adimen-SUMO syntax):

```
(=>                                                (10)
    ($instance ?C RedBloodCell)
    (not
        (exists (?N)
            (and
                ($instance ?N CellNucleus)
                (part ?N ?C)))))
```

Consequently, the synset pair *part*($cell^2_n$,$cell\_nucleus^1_n$) is not consistent.

8 Ongoing Work

Currently, we are finishing our experimental evaluation of WordNet, SUMO and their mapping by applying the methodology proposed in Álvez et al. (2017). For this purpose, we are using the ATPs Vampire (Kovács and Voronkov, 2013) and E (Schulz, 2002) for checking whether the conjectures resulting from the set of CQs proposed in this paper are entailed or not by Adimen-SUMO. All the resources —the ontology, the set of CQs and conjectures, and the resulting execution reports— will be available at `http://adimen.si.ehu.es/web/AdimenSUMO`.

By analysing our preliminary experimentation results, we can conclude that our proposal enables a sophisticated cross-checking of the information in WordNet, SUMO and their mapping. In particular, by means of practical examples, we have illustrated that the proposed system enables (a) the validation of some pieces of information and (b) the detection of missing information and inconsistencies. Further, our preliminary experimental results also demonstrate the suitability of the involved resources for its application to practical tasks related to natural language processing.

9 Concluding Remarks

In this work, we enlarge the set of CQs proposed in Álvez et al. (2017) by means of part-whole data of WordNet, which illustrates the fact that our proposal can be generally applied to any data extracted from WordNet. Nowadays, our complete set of CQs includes around 3,000 CQs obtained from antonymy and around 2,000 CQs obtained from *Morphosemantic Links* database of WordNet. In the last case, we exclusively concentrate on the relations *event*, *agent*, *instrument* and *result*. In the next future, we plan to extend our benchmark by considering additional WordNet relations.

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