Towards modelling SUMO attributes through WordNet adjectives: a Case Study on Qualities

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Abstract

Previous studies have shown that the knowledge about attributes and properties in the SUMO ontology and its mapping to WordNet adjectives lacks of an accurate and complete characterization. A proper characterization of this type of knowledge is required to perform formal commonsense reasoning based on the SUMO properties, for instance to distinguish one concept from another based on their properties. In this context, we propose a new semi-automatic approach to model the knowledge about properties and attributes in SUMO by exploiting the information encoded in WordNet adjectives and its mapping to SUMO. To that end, we considered clusters of semantically related groups of WordNet adjectival and nominal synsets. Based on these clusters, we propose a new semi-automatic model for SUMO attributes and their mapping to WordNet, which also includes polarity information. In this paper, as an exploratory approach, we focus on qualities.

Keywords: Adjectives, WordNet, SUMO, Commonsense Reasoning

1. Introduction

Adjectives are words that express qualities and properties and usually modify nouns. They have been usually studied from a syntactic and lexico-semantic point of view. In WordNet (Fellbaum, 1998) adjectives are derived into two classes: descriptive and relational. Descriptive adjectives establish to their related head nouns values of (typically) bipolar attributes and consequently are organized in terms of binary oppositions (antonymy) and similarity of meaning (synonymy). For instance, the synsets hot_a^1 and $cold_a^1$ are related by the semantic relation *antonym* in WordNet[1]. Moreover, each of these adjectives is linked to semantically similar adjectives by similarity. These comparable adjectives are called satellites. In Figure 1, we present the bipolar adjective cluster structure formed by hot_a^1 and $cold_a^1$ and their respective satellites.

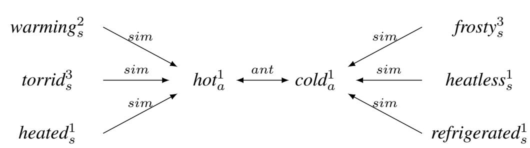

Figure 1: Example of a bipolar adjective cluster

Thus, in a commonsense reasoning scenario, descriptive adjectives need to be represented as attributes of certain nominal and verbal concepts. Therefore, it is necessary to study where this type of adjectives can be used as attributes or properties. Following the example of the pair hot_a^1 and $cold_a^1$, this means that they are possible values of *temperature*. Previous studies have shown that the knowledge about attributes and properties in the SUMO ontology (Niles and Pease, 2001) and its mapping to WordNet adjectives (Niles and Pease, 2003) lacks of an accurate and complete characterization (Álvez et al., 2019a). For instance, many WordNet adjectives have been mapped to SUMO processes instead to SUMO attributes. A proper characterization of this type of knowledge is required to perform formal commonsense reasoning based on the attributes encoded in SUMO, for example, if we want to distinguish one concept from another based on their properties.

In this framework, two main problems arise when reasoning with the SUMO knowledge related to WordNet adjectives and their antonymy relations. The first one is related to the SUMO mapping and the second one is related to an incomplete axiomatization.

Regarding the mapping, antonymous synset pairs such as $certain_a^3$ and $uncertain_a^2$ are mapped to the same SUMO concept, in this case, to the predicate *knows*. As they are under the same SUMO concept and no contrariness is stated, it is not possible to infer the attributes they express are opposite to each other.

Concerning the under-specification, antonym synset pairs such us $beautiful_a^1$ and $ugly_a^1$ are mapped to the SUMO classes of attributes *SubjectiveStrongPositiveAttribute* and *SubjectiveStrongNegativeAttribute* respectively. Looking at the name of the labels, it seems that the contrariness is expressed, but the only information relating these classes in the ontology is that they are subclasses of *SubjectiveAssessmentAttribute*. Therefore, the ontology is under axiomatized regarding the contrary attribute information.

In this work, we present a case study on qualities and their related adjectives with the aim of improving SUMO and their mapping to WordNet. To that end, we construct adjectival-nominal clusters from WordNet and based on these clusters we create new semantic relations in the Multilingual Central Repository (MCR) (Gonzalez-Agirre et al., 2012) and classes in the Adimen-SUMO ontology (Álvez et al., 2012).

The contributions of this exploratory paper are: a) a de-

[1] In this paper, we will refer to the synsets using the format $word_p^s$, where s is the sense number and p is the part-of-speech: n for nouns and a for adjectives.

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tailed analysis of adjectival clusters of qualities b) new etymology and morphology based relations for wordnets with the aim of making explicit to which concept attributes should be applied, c) an axiomatization model for qualities and d) a mapping proposal that includes polarity information.

This paper is structured as follows: in Section 2, we present the works related to adjectives in wordnets and in ontologies; in Section 3 we present our knowledge framework; in Section 4 we introduce the improvements proposed for the knowledge about adjectives; in Section 5 we validate our new proposal and, finally, in Section 6 we conclude and outline the future work.

2. Related Work

In this section we provide a brief overview of the approaches used in different lexical knowledge bases and ontologies for representing and exploiting adjectives. The adjectives in the English WordNet (Fellbaum, 1998) are divided into descriptive and relational adjectives. The basic relation between descriptive adjectives is antonymy (direct or indirect). Moreover, by similarity they are linked to semantically comparable adjectives, which are called satellites. This way, bipolar cluster are formed as the one presented in Figure 1. Relational adjectives are also related to nouns and color adjectives are regarded as a special case (Fellbaum et al., 1993). Furthermore, in the morphosemantic links (Fellbaum et al., 2007) adjectives are related to their derived/derivative nouns and verbs. In GermaNet (Hamp and Feldweg, 1997; Henrich and Hinrichs, 2010) the cluster-approach is not followed: adjectives are hierarchically structured, as in the case of nouns and verbs, and, thus, the relation of indirect antonyms is eliminated. Moreover, adjectives are categorised into different semantic classes such as perceptional, spatial, or weather-related.[2] Building on GermaNet adjectival classification, Tsvetkov et al. (2014) propose supersense (high-level semantic classes) taxonomy for English adjectives. They distinguish 11 classes such as motion, substance or weather[3].

Regarding the ontologies, the SIMPLE Ontology (Peters and Peters, 2000) distinguishes the adjectives according to their predicative function: intensional adjectives and extensional adjectives. Intensional adjectives have the following subclasses: temporal, modal, emotive, manner, object-related, and emphasizer. The subclasses of the extensional adjectives are: psychological property, social property, physical property, temporal property, intensifying property, and relational property. The DOLCE family of ontologies relates qualities as individuals to regions, that belong to quality spaces (Gangemi et al., 2016) e.g. *hasQuality(AmazonRiver,wide)*. The Suggested Upper Merged Ontology (SUMO) (Niles and Pease, 2001) and, therefore, its First-order logic conversion Adimen-SUMO (Álvez et al., 2012) has a class called *Attribute* that includes all qualities, properties, etc. As SUMO is linked to WordNet (Niles and Pease, 2003), the adjectives in WordNet fall into *Attribute* and its subclasses such as *SubjectiveAssessmentAttribute*, *SubjectiveStrongNegativeAttribute*, *ShapeAttribute*, or *SubjectiveWeakPositiveAttribute*. In the ontology, these classes are poorly axiomatized and, therefore, we can consider them as *underspecified*.

With respect to its exploitation, the knowledge related to adjectives in WordNet and its mapping into SUMO have been used for semi-automatically creating a large commonsense reasoning benchmark for SUMO-based ontologies (Álvez et al., 2019b). For this purpose, the authors base on the relations about adjectives *antonymy* and *similarity*, and also considered other relations such as *hyponymy*, which relates noun synsets. Álvez et al. (2019a) perform a detailed analysis of the experimental results obtained using the proposed benchmark with the objective of shedding light on the commonsense reasoning capabilities of both the benchmark and the involved knowledge resources. One the main reported conclusions is that among the analyzed problems only 35 % of the resolved antonym problems were based on correct mapping information against 76 % of the resolved hyponym problems. Further, among the problems where the expected answer is obtained, only 40 % of antonym problems are based on correct mapping information against 85 % hyponym problems. Therefore, the authors conclude that the information about adjectives in SUMO and its mapping is not suitable for reasoning purposes.

3. Knowledge Framework

For our research purposes, the language resource we use is the Multilingual Central Repository (MCR) (Gonzalez-Agirre et al., 2012), a repository that integrates wordnets from six different languages: English, Spanish, Catalan, Basque, Galician and Portuguese in the same EuroWordNet framework. Additionally, it also integrates other language resources such as Adimen-SUMO (Álvez et al., 2012), the Top Ontology (Rodríguez et al., 1998) and the Basic Level Concepts (BLC) (Izquierdo et al., 2007). In the MCR adjectives are characterized as in the English WordNet, but they are related to other PoS via the relations *pertainym*, *related*, and *xpos*. For brevity, we will use henceforth *related* to refer to the aforementioned three relations interchangeably.

In this paper, we study a subset of adjective-noun clusters and their corresponding antonyms. As a starting point, we have decided to focus on clusters whose nouns are the hyponyms of the synset $quality_n^1$, which is according to WordNet "an essential and distinguishing attribute of something or someone". $quality_n^1$ is the most frequent hypernym in the adjective-noun clusters and as BLC, it has 1,352 descendants. According to the mapping to WordNet, $quality_n^1$ is subsumed by the SUMO class *Attribute*. To sum up, there are 3,802 pairs of antonym adjectives in WordNet and 204 of those pairs appear in the studied adjective-noun clusters. In addition, the two adjective synsets are connected to the same SUMO concept in 934 antonym pairs of WordNet, from which 55 pairs appear in the studied adjective-noun clusters. Thus, we have considered around a 5 % of the adjectives in SUMO.

[2]The full classification can be found in this link: http://www.sfs.uni-tuebingen.de/GermaNet/adjectives.shtml#Adjective%20Classes.

[3]Data can be found in this link: www.cs.cmu.edu/~ytsvetko/adj-supersenses.gz

3.1. Adjective clusters under Quality

We characterized the *quality* adjective-noun clusters in four different types.

The first type (as in Figure 2) is a four-sided cluster where antonym adjectives are related to antonym nouns, which are hyponyms of *quality*$_n^1$. In this example, the adjective *changeable*$_a^2$ is related to the synset *changeability*$_n^1$ and is antonym of the adjective *unchangeable*$_a^1$. At the same time, *unchangeable*$_a^1$ is related to *unchangeability*$_n^1$, which is antonym of *changeability*$_n^1$. Both nouns have the same hypernym, *quality*$_n^1$. We represent this cluster in Figure 2.

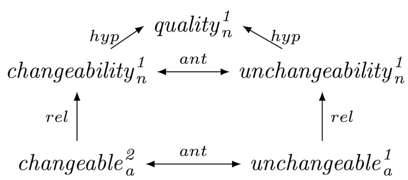

Figure 2: Example of a four-sided cluster

In this case, the three nominal synsets *quality*$_n^1$, *changeability*$_n^1$ and *unchangeability*$_n^1$ are subsumed by the SUMO class *Attribute* while the adjective synsets *changeable*$_a^2$ and *unchangeable*$_a^1$ are subsumed by *capability*$_r$. Obviously, the current knowledge encoded in both WordNet and SUMO do not allow to infer that these qualities (being nouns or adjectives) refer to the capacity or incapacity of things to change. In fact, this cluster should be related somehow to the verbal synset *change*$_v^1$. Additionally, the SUMO concepts associated to the synsets of the cluster also require a more specific characterization and axiomatization to perform a proper inference about this quality.

These clusters, moreover, can have more than one level due to the hyperonymy. In Figure 3, we show a four-sided cluster with two levels of hyperonymy (second type).

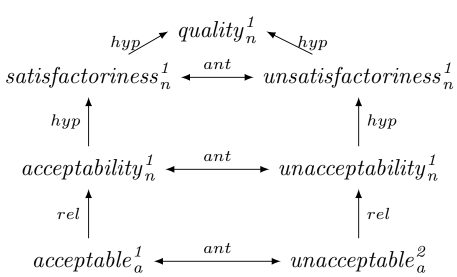

Figure 3: Example of a four-sided cluster with various levels of hyponymy

In this case, the nominal synsets *satisfactoriness*$_n^1$ and *acceptability*$_n^1$ and its antonyms are subsumed by the SUMO class *SubjectiveAssessmentAttribute* while the adjective synsets *acceptable*$_a^1$ is subsumed by the SUMO class *SubjectiveWeakPositiveAttribute* and *unacceptable*$_a^2$ is subsumed by *SubjectiveStrongNegativeAttribute*. Again, the current knowledge encoded in both WordNet and SUMO is not sufficient for a proper reasoning about this quality. Moreover, the SUMO classes *SubjectiveWeakPositiveAttribute* and *SubjectiveStrongNegativeAttribute* are not incompatible in SUMO.

The third example of cluster is illustrated in Figure 4. In this case, both adjectives *able*$_a^1$ and *unable*$_a^1$ are related to the noun *ability*$_n^1$, which is an hyponym of *quality*$_n^1$, forming a three-sided cluster.

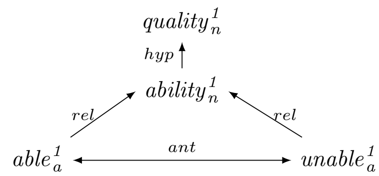

Figure 4: Example of a three-sided cluster

In this case, the nominal synset *ability*$_n^1$ is subsumed by the SUMO class *Attribute* while the adjective synsets *able*$_a^1$ and *unable*$_a^1$ are subsumed by the SUMO relation *capability*$_r$. Again, the current knowledge encoded in both WordNet and SUMO is not sufficient for a proper reasoning about abilities.

And, finally, the fourth case is presented in Figure 5, a three-sided cluster with an hyponymy chain in one side.

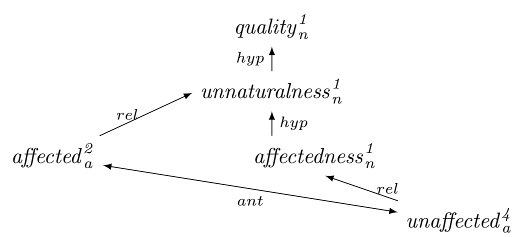

Figure 5: Example of a three-sided cluster with hyponymy

Similarly to previous examples, the nominal synset *unnaturalness*$_n^1$ and *affectedness*$_n^1$ are subsumed by the SUMO class *SubjectiveAssessmentAtribute* while the adjective synsets *affected*$_a^2$ and *unaffected*$_a^1$ are subsumed by the SUMO class *Pretending*$_c$. Again, the current knowledge encoded in both WordNet and SUMO is not sufficient for a proper reasoning about this behaviour.

In Table 1 we present the number of clusters per type presented above. In total there are 263 adjective clusters associated to *quality*$_n^1$ involving 359 adjective synsets and 302 nominal synsets.

Cluster type	**Cluster Number**
Four-sided clusters	51
Four-sided clusters (various levels)	102
Three-sided clusters	98
Three-sided clusters (various levels)	12
Total	263

Table 1: Number of Cluster for Type

We have also detected that some clusters are not fully-formed. That is, some antonym relations between the adjectives or between the nouns are missing. These incomplete clusters will be studied in a near future.

4. Improving the knowledge framework

Being one of our main motivation to reason with SUMO properties, we need to properly augment the ontology with new knowledge related to qualities from WordNet and, on the other hand, we need to correctly map the quality clusters to the ontology.

4.1. Improving WordNet relations for qualities

Inspired by the WordNet morphosemantic links, the idea is to create new semantic relations between synsets in a cluster to the corresponding nouns and verbs they are related, if possible. The morphosemantic links took into account English morphology to create the relation. In this work, on the one hand, we have taken more derivative relations into account, and, on the other hand, we also have considered the morphology of the latinate borrowings. For example, we have linked the adjective *impalpable*$_a^1$ and the noun to which is already related, *impalpability*$_n^1$, to the verb *touch*$_v^2$. This work has been done manually taking into account the following guidelines. For brevity, we only use one member of the cluster in the examples.

- Link the nouns and the adjectives in the cluster to the synset with the most general meaning e.g. *advisable*$_a^1$ “worthy of being recommended or suggested; prudent or wise” to the verb *advise*$_v^1$ “give advice to”.
- In case of the *ambiguous* clusters, link to all the possible synsets. For example, the adjective *comprehensible*$_a^1$ “capable of being comprehended or understood” to the verbs *understand*$_v^1$ “know and comprehend the nature or meaning of” and *comprehend*$_v^1$ “get the meaning of something”.
- In case of clusters with various levels and repeated hypernyms, keep the link to the same synset if possible. For instance, in the clusters with *changeability*$_n^1$ as hypernym that includes in other levels respectively the adjectives *variable*$_a^1$, *mutuable*$_a^1$, *alterable*$_a^1$ among others are linked to the same verb: *alter*$_v^1$ “cause to change; make different; cause a transformation”.
- Do not link if there is no right sense e.g. *auspicious*$_a^1$ cf. Spanish *auspiciar* or Italian *auspicare* evolved from Latin *auspicium* and *auspicare*.

This way, we have created 233 new *quality_of* relations, 139 for events and 94 for nouns. Henceforth, we will denominate *the top synset of the cluster* the synset (the noun or the verb) they are linked to, i.e. the concept/event whose qualities they express.
However, 69 clusters could not be related to any noun or verb and these have been marked as pure. An example of this is the cluster that contains the adjectives *good*$_a^1$ <-> *bad*$_a^1$ and the nouns *goodness*$_n^1$ <-> *badness*$_n^1$.

4.2. Grouping clusters under quality

As a result of the new relations, we organized the synset clusters under *quality*$_n^1$ as follows:

- **Qualities of Events:** These are clusters related to qualities of verbs. For instance, the cluster *changeable*$_a^2$ [*changeability*$_n^1$] <-> *unchangeable*$_a^1$ [*unchangeability*$_n^1$] denotes qualities related to the verb *change*$_v^1$ (see Figure 2). There are 107 clusters related to events.
- **Qualities of Nouns:** These are clusters related to concrete and abstract nouns. For example, the clusters including the hypernyms *faithfulness*$_n^1$ and *humanness*$_n^1$ have been related respectively to *faith*$_n^4$ “loyalty or allegiance to a cause or a person” and *person*$_n^1$ “a human being”. There are 86 clusters related to nouns.
- **Pure Qualities:** In this case, the members of these clusters cannot be linked to verbs or nouns and we have marked them as *pure* e.g. *bad*$_a^1$ and *badness*$_n^1$. There are 70 clusters classified as pure.

These groupings are the basis for the ontologisation model.

4.3. New top ontology for qualities

As we are working with qualities, we select the class of attributes *Attribute*, whose semantics —according to SUMO documentation— is *“Qualities which we cannot or choose not to reify into subclasses of”*, as super-concept of all the new defined concepts. Since the hypernym of all the considered clusters is *quality*$_n^1$, the first new concept we propose in our model is *QualityAttribute*, which is defined as a subclass of the SUMO class *Attribute*. *QualityAttribute* is the top class of the model constructed for the considered clusters.

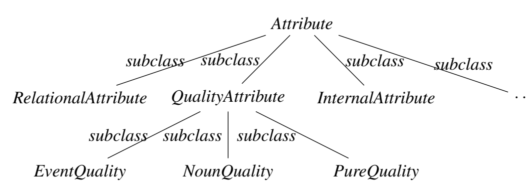

Figure 6: New ontology model for qualities

According to the created subtypes of qualities, we define three new direct subclasses of *QualityAttribute*: *EventQuality*, for qualities of events; *NounQuality*, for qualities of nouns; and *PureQuality*, for pure qualities (see Figure 6).

4.4. Integrating the clusters and the new ontology

Further, we create a new class of attributes for each top synset of the cluster, which is defined as direct subclass of *EventQuality*, *NounQuality* or *PureQuality* according to the subtype of the top synset. Hence, we introduce 61 new subclasses of *EventQuality*, 45 new subclasses of *NounQuality* and 32 new subclasses of *PureQuality*. The labels of these new classes are formed by capitalizing the first letter of the wordform of the top synset of the cluster and appending the string *Quality*. This way, *ChangeQuality* has been created on the basis of the synset *change*$_v^1$ by converting it to *Change* and concatenating *Quality*. From now on, we will refer to the class created for the top synset of a cluster as the *cluster class*.

On the basis of the proposed new ontology of qualities, we obtain a new mapping for the nouns and adjectives in the clusters by using the *equivalence* mapping relation and its complementary. For this purpose, we automatically connect the antonym pairs of noun and adjectives synsets of a given cluster to its cluster class, but with opposite semantics: that is, given a pair of antonym synsets in a cluster where A is the cluster class, one of the antonym synsets is stated to be related with A by *equivalence*, while the other one is stated to be related with A by the complementary of *equivalence*. For simplicity, from now on we say that the polarity of a synset is *positive* if it is related with the corresponding cluster class by *equivalence*, and it is *negative* otherwise (related with the complementary of *equivalence*). When we refer to polarity in this paper we do not take into account the polarity of the concept, but the polarity of the word: if the attribute is present or not. That is, *fear* can be understood as a negative concept, and *fearless* as a positive, but in this paper, *fear* is positive in the sense that the attribute *fear* is present and *fearless* is negative because it implies that there is no *fear*.

In order to automatically decide the polarity of the antonym synsets in a cluster, we analyze the senses of the involved synsets in the following way: given two antonym synsets with senses s_1 and s_2 respectively such that s_2 is substring of s_1,

- If either "*a-*", "*de-*", "*dis-*", "*il-*", "*im-*", "*in-*", "*ir-*", "*mis-*", "*non-*" or "*un-*" is prefix of s_1, then the polarity of s_1 is *negative* and the polarity of s_2 is *positive*.
- Else if "*-less*" is suffix of s_1, then the polarity of s_1 is *negative* and the polarity of s_2 is *positive*.
- Otherwise, the polarity of s_1 and s_2 is unknown.

For example, let us consider the cluster in Figure 2. Since the "*changeable*"/"*changeability*" are substring of "*unchangeable*"/"*unchangeability*", which has "*un-*" as prefix, then the polarity of "*changeable*"/"*changeability*" is *positive* while the polarity of "*unchangeable*"/"*unchangeability*" is *negative*. Consequently, "*changeable*"/"*changeability*" are connected to *ChangeQuality* by *equivalence* while "*unchangeable*"/"*unchangeability*" are connected to *ChangeQuality* by the complementary of *equivalence* in the new proposed mapping.

However, the above mentioned heuristics cannot be applied in some clusters because the polarity of the antonym synsets is unknown. In this case, we create two new classes of attributes, which are defined as contrary each other and subclass of the cluster class. This enables to state that each synset from antonym pairs are related to incompatible classes of attributes and, this way, the process of mapping the antonym nouns and adjectives of the considered clusters is fully automatic. For example, the antonym nouns *difficultness*$_n^1$ and *simpleness*$_n^3$ and antonym adjectives *difficult*$_a^1$ and *easy*$_a^1$ form a four-sided cluster (first type) with *DifficultyQuality* —which is subclass of *NounQuality*— as cluster class, but the polarity of the antonym synsets cannot be automatically decided by our proposed method. To overcome this problem, we create two new contrary classes of attributes, *DifficultnessQuality* and *SimplenessQuality*, which are defined as subclass of *DifficultyQuality*. Thus, in the resulting mapping, *difficultness*$_n^1$ and *difficult*$_a^1$ are related with *DifficultnessQuality* by *equivalence* and *difficultness*$_n^1$ and *easy*$_a^1$ are related with *SimplenessQuality* by also *equivalence*. This way, we create 29 pairs of new contrary classes (that is, 58 new classes) distributed as follows: 8 new subclasses of *EventQuality*, 24 new subclasses of *NounQuality* and 26 new subclasses of *PureQuality*.

5. Validation

In this section, we summarize and validate the result of our proposal for the new ontology for qualities, the new WordNet relations and the new SUMO mapping to WordNet adjectives.

In total, we have augmented SUMO by introducing 200 new classes of attributes, which have been defined as subclass of *Attribute*. For their axiomatization, we have stated that 41 pairs of attribute classes are contrary of each other.

Using the new axiomatization, we have successfully connected 722 synsets: 61 verbs, 302 nouns and 359 adjectives. Further, the mapping of the adjectives can be propagated to another 1,384 satellite adjectives by using the *similarity* relation.

We have also checked the suitability of the resulting mapping. More specifically, we have verified that all the antonym pairs have an incompatible mapping between each other. Consequently, the new proposed ontology and mapping can be applied in commonsense reasoning tasks involving WordNet adjectives.

6. Conclusion and Future Work

In this paper we have presented the first steps towards modeling the attributes expressing qualities in SUMO based on the knowledge encoded in WordNet. To that end, in this experimental sample, we have focused on studied the clusters of adjectives and nouns related to the synset *quality*$_n^1$. When necessary, we have related the clusters to the corresponding nominal and verbal qualities. Based on these relations, we have created new classes in the ontology and we have mapped the synsets to them.

For the future, we plan to explore how to spread this approach as automatically as possible. First we want to study the non fully formed clusters (those that have a missing relations), and other adjective types such as those denoting properties. We also plan to explore other options or resources to associate the polarity to synsets (Agerri and García-Serrano, 2010). Moreover, we foresee to test the model and the added information in a commonsense reasoning system relating properties.

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