

Approaching Regular Polysemy in WordNet

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Abstract— WordNet has been used widely in natural language processing and semantic applications. Despite the reputation of WordNet, the polysemy problem that leads to insufficient quality of applications results is still unsolved. Many approaches have been suggested. However, none of them give a comprehensive solution to the problem. In this paper, we introduce a pattern based approach that solves the polysemy problem in the case of nouns. To achieve this result we introduce a set of novel relations that represent polysemy types and a set of new operations that allow us to organize the specialization polysemy cases.

Keywords— *Lexical databases; WordNet; Homonymy; Polysemy; regular Polysemy; Polysemy Reduction; Lexical semantics; Semantic Search; Knowledge Engineering*

I. INTRODUCTION

Polysemy in WordNet [1][9] is considered to be the main reason that makes it hard to use for natural language processing (NLP) and semantic applications [12][17]. Differentiating between the types of polysemy should be possible through explicit semantic relations between the senses of polysemous terms. Unfortunately, relations between polysemous terms are not provided in WordNet [2]. For instance, WordNet does not provide the distinction between homographs, and complementary terms [6].

In the last, decades many approaches have been introduced to solve the polysemy problem through merging the similar meanings of polysemous terms [4]. These approaches are sometimes helpful in cases, where terms have meanings that are similar enough to be merged. However, polysemous terms with similar meanings are a sub-case of the solution of specialization polysemy [14]. They represent only a small portion of the polysemy problem. In fact, a significant portion of the polysemous senses should not be merged, as they are just similar in meaning [5] and not redundant. In another approach, CORELEX [6] has been introduced as an ontology of systematic polysemous nouns extracted from WordNet. However, CORELEX deals only with the upper level ontology of WordNet that corresponds mainly to the metonymy cases and does not provide a solution for other polysemy types [16].

In this paper, we introduce a pattern based approach that combines several ideas to solve the polysemy problem. Our

approach follows the idea that the polysemy problem is a problem of semantic organization [3]. Thus, the goal of our approach is to reorganize the semantic structure of the polysemous terms in wordNet, where we transform the implicit relations between the polysemous terms at lexical level to explicit relations at the semantic level. This includes extending WordNet by adding new hierarchical and associative relations between the synsets to explicitly denote the polysemy type occurring between the meanings of each polysemous term, as suggested in [2]. To achieve this goal, our approach deals with all polysemy types at all ontological levels of WordNet. It deals with the lower level ontology of WordNet and it extends the merge operation suggested by the polysemy reduction approaches [4][15] by providing new operations that organize the relations between the meanings of polysemous terms. Our approach also deals with polysemy in the middle level, as it is the case in regular polysemy approaches [14] and also in the upper level ontology as in systematic polysemy approaches [6].

This paper is organized as follows: In Section II, we describe the polysemy problem in WordNet. In Section III, we describe the current approaches for solving the polysemy problem in WordNet. In Section IV, we present the semantic relations that denote polysemy types and the operations that reorganize the structure of polysemous terms in WordNet. In Section V, we introduce a pattern based approach for solving the polysemy problem in the case of polysemous nouns. In Section VI, we discuss the results and evaluation of our approach. In Section VII, we conclude the paper and describe our future research work.

II. POLYSEMY IN WORDNET

WordNet is a lexical database that organizes synonyms of English words into sets called synsets, where each synset is described through a gloss. For example, the words *happiness* and *felicity* are considered to be synonyms and grouped into one synset $\{happiness, felicity\}$ that is described through the gloss: *state of well-being characterized by emotions ranging from contentment to intense joy*.

WordNet organizes the relations between synsets through semantic relations, where each word category has a number of relations that are used to organize the relations between the synsets of that grammatical category. For example, the hyponymy relation (X is a type of Y) is used to

organize the ontological structure of nouns. WordNet 2.1 contains 147,257 words, 117,597 synsets and 207,019 word-sense pairs. Among these words there are 27,006 polysemous words, where 15776 of them are nouns.

From linguistics, a term is polysemous if it has more than one meaning [17]. Linguists differentiate between contrastive polysemy, i.e. terms with completely different and unrelated meanings - also called homonyms or homographs; and complementary polysemy, i.e. terms with different but related meanings. Complementary polysemy is classified in three sub types: Metonymy, specialization polysemy and metaphors. Following the above, we can classify the various forms of polysemy as follows:

- 1) Complementary polysemy: terms that have the same spelling and related meanings. Complementary polysemy can be:
 - a. Metonymy: substituting the name of an attribute or feature for the name of the thing itself, such as in the following example:
Peter caught a *chicken* in his garden.
Peter prepared *chicken* for the dinner.
 - b. Specialization polysemy: a term is used to refer to a more general meaning and another more specific meaning, such as in the following example the term *methodology*:
 1. **methodology**, methodological analysis: the branch of philosophy.
 2. **methodology**: the system of methods followed in a particular discipline.
 - c. Metaphors: terms that have the same spelling and have literal and figurative meanings. Consider, for instance, the term *parasite*:
 1. **parasite**: an animal or plant that lives in or on a host (another animal or plant).
 2. leech, **parasite**, sponge, sponger: a follower who hangs around a host (without benefit to the host) in hope of gain or advantage.
- 2) Homographs: terms that have the same spelling and different unrelated meanings, such as the term *bank*:
Peter sat on the *bank* of the river.
Peter deposited money in the *bank*.

In WordNet, the number of senses a polysemous term may range from 2 senses to more than 30 senses. In some rare cases may more; for instance, the noun *head* has 33 senses.

Nevertheless, 90% of the polysemous nouns have less than 5 senses. Table I shows the distribution of these polysemous nouns according to the number of senses they have. Notice that, in this paper, we are concerned with polysemous nouns only and not the verbs, adverbs and adjectives.

The fact that a term has more than two senses implies that the meanings of the term belong to more than one type of polysemy. For example, the term *food* has 3 senses as mentioned below, where the polysemy type between the

first and the second meanings is specialization polysemy, while the third meaning is metaphoric.

TABLE I. POLYSEMUS NOUNS IN WORDNET

# of synsets	# of nouns (in percentage)
2	10186 ($\approx 64\%$)
3	2968 ($\approx 19\%$)
4	1186 ($\approx 7\%$)

1. **food**, nutrient: any substance that can be metabolized by an organism to give energy and build tissue.
2. **food**, solid food: any solid substance that is used as a source of nourishment.
3. **food**, food for thought: anything that provides mental stimulus for thinking.

III. APPROACHES FOR SOLVING POLYSEMY IN WORDNET

The approaches of polysemy can be classified in two main approaches. The first is polysemy reduction, where the focus is on complementary polysemy to produce more coarse-grained lexical resources of existing fine-grained ones such as WordNet. The second type of polysemy approaches focuses on classifying polysemy into systematic or regular polysemy and homographs. Based on this classification, CORELEX was introduced as ontology of systematic polysemous nouns extracted from WordNet. Other approaches, such as in [13][14], were introduced to extract semantic relations between regular polysemous terms in WordNet.

In the following, we summarize Polysemy reduction approaches and CORELEX, the most famous systematic polysemy approaches. Notice that neither polysemy reduction approaches nor CORELEX could solve the polysemy problem in WordNet. In general, Polysemy reduction approaches could not solve the problem of the upper level ontology where CORELEX did not provide a solution for polysemy in the middle and lower level ontology of WordNet.

A. Polysemy Reduction Approaches

In polysemy reduction, the senses are clustered such that each group contains related polysemous words [18][15]. These groups are called homograph clusters. Once the clusters have been identified, the senses in each cluster are merged. To achieve this task, several strategies have been introduced. These strategies can be mainly categorized in semantic-based and statistics-based strategies [17]. Some approaches combine both strategies [15]. Although results of applications of these approaches are reported, these results are taken usually from applying them on sample data sets and there is no way to verify these results independently. Polysemy reduction approaches typically rely on the application of some detection rules such as: *If SI*

and S_2 are two synsets containing at least two words, and if S_1 and S_2 contain the same words, then S_1 and S_2 can be collapsed together into one single synset [10]. However, applying this rule may wrongly result in merging two different senses as in the following example:

1. **smoke, smoking**: a hot vapor containing fine particles of carbon being produced by combustion.
2. **smoke, smoking**: the act of smoking tobacco or other substances.

In general, polysemy reduction can neither predict the polysemy type occurring between the senses of polysemous words nor can deal with metonymy or metaphors. Polysemy reduction does not solve the polysemy problem in linguistic resource. Nevertheless, it can be potentially used to solve part of the problem, namely the identification and merging of genuine redundant synsets.

B. Regular Polysemy Approaches

J. Апресян defined regular polysemy as follows: “A polysemous Term T is considered to be regular if there exists at least another polysemous T' that is semantically distinguished in the same way as T ” [8]. Systematic polysemy approaches rely on this definition. CORELEX, the first systematic polysemy lexical database, follows the generative lexicon theory [3] that distinguishes between systematic (also known as regular or logic) polysemy and homographs. Systematic polysemous words are systematic and predictable while homonyms are not regular and not predictable. The type of polysemy of the word *fish* for example is systematic since the meaning *food* can be predicted from the *animal* meaning and so the word *fish* belongs to the systematic class *animal food*. The two meanings of fish describe two related aspects of *fish*: fish is an animal and fish is a food. That a word is systematic polysemous means that the meanings of this word are not homonyms and they describe different aspects of the same term. Following this distinction, CORELEX organizes the polysemous nouns of WordNet 1.5 into 126 systematic polysemy classes. The systematic polysemy classes in CORELEX have been determined in a top down fashion considering the patterns in the upper level ontology of wordNet only. It does not consider the metaphoric cases. Also, there is no cleaning process carried out on WordNet by CORELEX construction. Another important point is related to the fine grained nature of WordNet where the meanings of some CORELEX classes are very difficult to disambiguate and indistinguishable even for humans [11].

IV. DENOTING POLYSEMY TYPES AND ORGANIZING POLYSEMY IN WORDNET

Making WordNet a more coarse grained lexical resource does not solve the polysemy problem, although there are some fine grained polysemous cases in WordNet. We believe that the polysemy problem in WordNet is primarily a problem of organizing the senses of polysemous terms. In the cases of homographs, metonymy, and metaphors, we

need semantic relations that denote the polysemy type of corresponding cases. The cases of specialization polysemy on the other hand require reorganizing the semantic structure to reflect the (implicit) hierarchical relation between such senses. In the following, we introduce the relations to denote homographs, metonymy, and metaphors and then we present the operations for solving specialization polysemy cases.

A. Polysemy Type Relations

In the following, we explain the suggested relations to denote the polysemy types:

Homographs: There is no relation between the senses of a homograph term. Nevertheless, differentiating homographs from other polysemy types is very important improvement in wordNet. We use the relation *is_homograph* to denote that two synsets of a polysemous term are homographs. For example, this relation holds between the synsets *{saki as alcoholic drink}* and *{saki as a monkey}*.

Metonymy: In metonymy cases, there is always a *base meaning* of the term and other *derived meanings* that express different aspects of the base meaning [19]. For example, the term *chicken* has the base meaning *{a domestic fowl bred for flesh or eggs}* and a derived meaning *{the flesh of a chicken used for food}*. To denote the relation between the senses of a metonymy term, we use the relation *has_aspect*, where this relation holds between the base meaning of a term and the derived meanings of that term. To set up the relation we need to determine the base meaning and then relate the other derived meanings to it.

Metaphors: In metaphoric cases, we use the relation *Is_metaphor* to denote the metaphoric relation between the metaphoric meaning and literal meaning of a metaphoric term. For example this relation is used to denote that *{cool as great coolness and composure under strain}* is metaphoric meaning of the literal meaning *{cool as the quality of being at a refreshingly low temperature}*. In the cases, where this relation is applicable, we need to specify the literal meaning and the metaphoric meaning.

B. Operations for Specialization polysemy

Analysis of specialization polysemy cases shows that such cases can be classified based on the synset synonyms into the following three groups. To explain our idea, we have chosen cases, where the synsets of each term share the same common parent.

Let T be a polysemous term that occurs in two synsets S_1 and S_2 . We consider T in the following three cases:

Case 1: T has synonyms in S_1 and has synonyms in S_2 as in the case of *kestrel*:

1. *kestrel*, *falco sparverius*: small American falcon.
2. *kestrel*, *Falco tinnunculus*: small Old World falcon.

Case 2: T has synonyms in S_1 or in S_2 but not in both as in the case of *dorsum*:

1. *back*, *dorsum*: the posterior part of a human (or animal) body from the neck to the end of the spine.

2. *dorsum*: the back of the body of a vertebrate or any analogous surface.

Case 3: T has no synonyms in S1 or S2 as the in the case of *compatible software*:

1. *compatible software*: application software programs that share common conventions.
2. *compatible software*: software that can run on different computers without modification.

In case 1, T has synonyms in S1 which means that T is exchangeable with the other synonyms of S1 and at the same time is also exchangeable with the synonyms of S2. Let T1, T2 be non polysemous synonyms of T in S1 and S2 respectively. T1 is synonymous with T but not with T2. Otherwise T1 and T2 should appear in the same synset. The fact that T1 and T2 appear in two different sibling synsets indicates that they are not the same. We think that the semantic relatedness between S1 and S2 is encoded at lexical level rather than semantic level. We have the same observation in case 2. The fact that one synset contains T only and the other synset contains additional terms indicates that the synset that contains T only is a more general meaning of the synset that have additional terms. We consider the terms in case 3 as candidates to be merged. Accordingly, we suggest the following operations to organize the relations between the senses in specialization polysemy cases:

Solution for Case 1: We add a new (missing) parent in cases, where the polysemous meanings of a term T can be seen more specific meanings of an absent more general meaning. In such cases, we create the new missing more general meaning and connect the more specific meanings to the new created new parent. This operation is schematized in the figure 1.

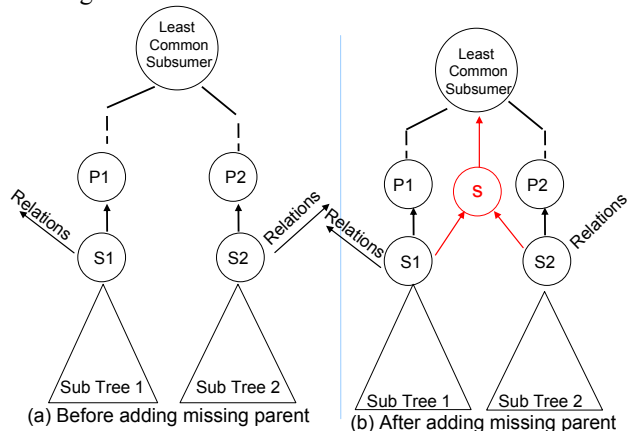


Figure 1. Adding missing parent

Solution for Case 2: In such cases, we establish a new (missing) *is_a* relation to denote that a sense of a polysemous term T is more specific than another more general meaning of T. We schematize this operation as illustrated in figure 2.

Solution for case 3: In such cases, we merge the meanings. The merge operation is schematized as in figure 3.

At the term level, we disambiguate the polysemous terms as follows: in case (1) We remove the polysemous terms from both child synsets and keep the polysemous words in the new added parent synset only. In case (2) We remove the polysemous term from the synset with the more specific

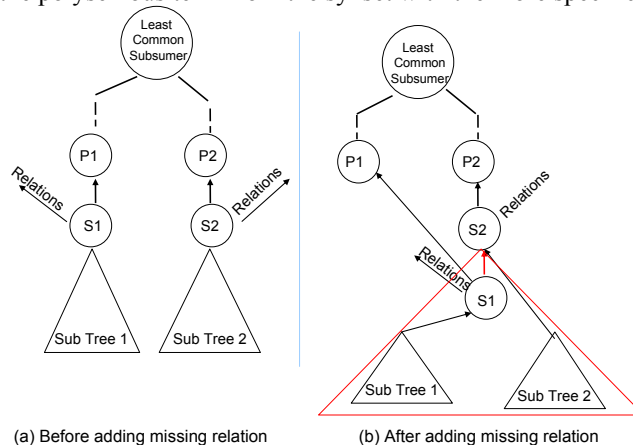


Figure 2. Adding missing relation

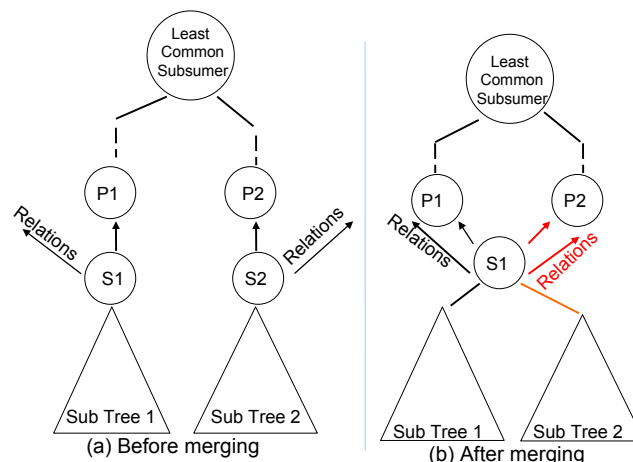


Figure 3. Merge operation

meaning and keep it in the synset with the more generic meaning. The Merge operation in case 3 unifies the terms of both synsets in one synset. Thus, applying the three operations results in reducing the number of polysemous words in WordNet.

V. PATTERN BASED APPROACH FOR SOLVING POLYSEMY

In this section, we describe our approach for solving polysemy in WordNet. The approach has the following four phases. The first and the third phases are automatic, while the second and fourth are manual:

- A. Patterns Identification
- B. Patterns Classification
- C. Polysemy type Assignment
- D. Validation

A. Patterns Identification

We apply a pattern extraction algorithm that computes the regular patterns for the polysemous terms. The algorithm returns the following lists:

1. a list of regular patterns: contains the regular patterns, where at least two terms belong to each pattern.
2. a list of sub patterns: contains the sub patterns of the patterns identified in the regular patterns list.
3. a list of common parent terms: contains the terms, where the synsets or part of the synsets of these terms share the same hypernym.
4. a list of singleton patterns: This list contains the patterns that have less than two terms and are not sub patterns of any regular pattern.

Notice that it is possible for terms that have more than 2 senses to have more than one pattern. In the following, we illustrate the definitions, we used in our algorithm.

Definition 1: Regular Structural Pattern Let T be a polysemous term that has n meanings, $n > 1$. Let S be the set of the synsets of T . Let R be a subset of S . Let Q an ordered sequence of R , where $|R| = m, 2 \leq m \leq n$, and

$Q = \langle s_1, \dots, s_m \rangle, s_i \in R, s_i \neq s_j, \text{ for } i \neq j$. A pattern $ptrn$ of T is defined as $p\#\langle p_1, \dots, p_m \rangle$, such that each p_i is a direct hyponym of p and subsumes $s_i, 1 \leq i \leq m$. A pattern is regular if there are at least two terms that belong to it. For example, the pattern $passerine\#\langle oscine, tyrannid \rangle$ is regular since there are 3 terms that belong to it.

Definition 2: Sub pattern For a regular pattern $ptrn = p\#\langle p_1, \dots, p_m \rangle$. A pattern $ptrn'$ is a sub pattern of $ptrn$ if $ptrn' = p\#\langle p'_1, \dots, p'_k \rangle$ and $\exists p_i, p'_j (p_i = p'_j)$.

Sub patterns are important, since it is possible that the elements of a pattern and its sub patterns have the same polysemy type. For example, the pattern $passerine\#\langle oscine, tyrannid \rangle$ and its sub pattern $passerine\#\langle oscine, wren \rangle$ belong both to the specialization polysemy patterns.

Definition 3: Common parent class A term belongs to the common parent class if it has at least two synsets that share the same hypernym. For example, the synsets of the term *kestrel* in the previous section share the same hypernym. In polysemy reduction approaches, senses that have the common parent property are candidates to be merged. In our approach, such terms are candidates for specialization polysemy. Note that there are many terms that have this property, but they are not considered to be regular according to definition 1 since they have different hierarchical structures.

B. Patterns Classification

In this phase, we manually classify the patterns gained in the previous phase, where we assign each pattern the polysemy type, the terms of the pattern belong to. We classify the patterns into the following groups:

1. Specialization polysemy patterns

2. Metaphoric patterns
3. Metonymy patterns
4. Homonymy patterns
5. Singleton and mixed patterns

The singleton and mixed patterns group contains the singleton patterns and the patterns that contain patterns whose terms may belong to more than one polysemy type. For example, there are terms under the pattern $attribute\#\langle quality, trait \rangle$ that belong metaphoric polysemy and others that belong to specialization polysemy. In the following, we describe our analysis in this phase according to the pattern position in the ontology of WordNet:

Top level patterns: the patterns at the top level ontology correspond to metonymy and metaphoric terms. It is unlikely to find specialization polysemy terms at the top level patterns. Although homonyms is not regular and, it is also possible to determine some homonymy patterns at the top level ontology. For example, the pattern $organism\#\langle animal, plant \rangle$ is considered as homograph pattern, since we exclude the possibility of specialization polysemy, metonymy and metaphoric in the terms that belong to that pattern.

Middle level patterns: the patterns here correspond mainly to specialization polysemy and metaphoric cases. It is possible also to find homograph patterns at this level. To differentiate between specialization polysemy and other polysemy types, we use the following criteria:

- **Specialization polysemy/ metaphors:**

specialization polysemy patterns indicate consistency between the pattern parts, while metaphoric patterns indicate meaning transfer from their literal meaning to a (metaphoric) meaning. For example, *oscine* and *tyrannid* are consistent since they belong to the type *passerine* in the pattern $passerine\#\langle oscine, tyrannid \rangle$, while we find meaning transfer from property $\{a \text{ basic or essential attribute shared by all members of a class}\}$ to trait $\{a \text{ distinguishing feature of your personal nature}\}$ in the pattern $attribute\#\langle property, trait \rangle$.

- **Specialization polysemy/ homographs:**

In contrary to specialization polysemy, homograph patterns indicate inconsistency. For example, *person* is inconsistent with *plant* and the metaphoric link is excluded in the pattern $organism\#\langle person, plant \rangle$.

Lower level patterns: the patterns at the lower level ontology are those patterns that belong to common parent class and they correspond mainly to specialization polysemy. It is possible to find metaphors and/or homographs at the lower level ontology. Such cases are determined and excluded in the validation phase.

C. Polysemy type Assignment

In this phase, the terms are assigned to the polysemy type of the pattern they belong to. The terms that belong singleton and mixed patterns are not assigned and they are subject to manual treatment in the validation phase.

D. Validation

In this phase, we manually validate the assigned polysemy type. This phase includes three tasks:

1. **Validation of the assigned polysemy types:** we check whether each of the nouns belong to its assigned polysemy type.
2. **Assigning the polysemy type:** for the terms that belong to the singleton and mixed patterns.
3. **Excluding of false positives:** we exclude the false positives from the terms of the automatic assigned groups. Our judgments during the validation are based on knowledge organization. Word etymology and linguistic relatedness have secondary role.

In table II, we show the results of our validation for sample patterns. An Example for false positives that we found in the common parent group: the meanings of term *apprehender* are homographs:

knower, apprehender: a person who knows or apprehends.
apprehender: a person who seizes or arrests.

TABLE II. SAMPLE PATTERNS VALIDATION

# of instances	Pattern	Assigned polysemy Type	# of False positives
1002	Common Parent	Spec. polysemy	93
75	attribute#property,quality	Metaphoric	7
52	attribute#quality,trait	Metaphoric	22
30	vascular plant#herb,woody plant	Spec. polysemy	1
29	*abstraction#communication,group	Metonymy	11
28	*abstraction#attribute,measure	Metaphoric	10
21	artifact#commodity,covering	Spec. polysemy	10
19	attribute#property,trait	Metaphoric	0
18	animal#invertebrate,larva	Spec. polysemy	0
16	woody plant#shrub,tree	Spec. polysemy	0

VI. RESULTS AND EVALUATION

In Table III, we present the results of our approach after the manual validation.

TABLE III. VALIDATED RESULTS OF THE ALGORITHM

Polysemy type	# of words	# of words in percentage (%)
Metaphor	559	13.6
Homograph	1011	24.8
Spec. Polysemy	2139	52.5
Systematic and Others	361	7.9

The cases in the column systematic and others are the cases that we think that they should be processed in a

subsequent phase of our approach in the framework of approaching CORELEX systematic polysemy or cases, were the presence of the polysemous term in one of the synsets is inappropriate and should be removed from one of the synsets. An example for such cases is the term *senate* that appears in the synset and its direct hypernym:

United States Senate, U.S. Senate, US Senate, Senate: the upper house of the United States Congress.
 => *senate: assembly possessing high legislative powers*

In Table IV, we present the classification of specialization polysemy. The total number of reduced polysemous words is 2139 words. The total number of merged synsets represents about 10% of the total processed cases. At the same time we have added 1045 new synsets and 2775 new *is a* relations, while have deleted 409 synsets and 409 *is a* relations. This means that in our approach we have increased knowledge rather than decreasing knowledge to solve the polysemy problem.

TABLE IV. SPECIALIZATION POLYSEMY RESULTS

	# of words	# of words in percentage (%)
Missing parent	1045	49
Missing relation	685	32
Merge	409	19.1

To evaluate our approach, 1020 cases have been evaluated by two evaluators. In the following Table V, we report the statistics of the evaluation, where the column polysemy type refers to homonymy, metaphoric, metonymy, or specialization polysemy and polysemy operation refers to creating missing parent, adding missing relation, or merging operation. Note that, polysemy operation is applicable in case of specialization polysemy. The table presents the agreement between the evaluators and our approach. The third row represents the number of cases, where at least one evaluator agrees with our approach.

TABLE V. EVALUATION RESULTS

	Polysemy type agreement	Polysemy operation agreement
Evaluator 1	979 ≈ 96%	924 ≈ 90.5%
Evaluator 2	945 ≈ 92.5%	855 ≈ 84%
Partial agreement	1006 ≈ 98.5%	978 ≈ 96%

As we can see from the results above, although the agreement with the approach is high, in many cases, the evaluators agree on the specialization polysemy type but disagree on the operation type. The explanation for this is that the operation is decided according to the nature of lemmas in both synsets as explained in section IV.

VII. CONCLUSION AND FUTURE WORK

In the present paper, we introduced a pattern based approach for solving the polysemy problem in WordNet. Our approach deals and covers all polysemy cases at all ontological levels of wordNet. Furthermore, it improves the ontological structure of WordNet by transforming the

implicit relations between the polysemous senses at lexical level into explicit semantic relations. The manual treatment in two phases of the approach guarantees the quality of the approach result. We have tested our approach on polysemous nouns that have two senses and the results were promising.

Our next step is to apply the approach on all polysemous nouns in WordNet. In a subsequent phase, we are going to extend our algorithm to handle verbs, adjectives and adverbs.

The main contributions of this work are at two levels:

At the conceptual level, we are providing a new foundation towards the problem of polysemy. At the implementation level, we aim to improve the quality of NLP and knowledge-based applications, especially in the field of the semantic search.

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