Abstract

Synonymy and translational equivalence are the relations of sameness of meaning within and across languages. As the principal relations in wordnets and multi-wordnets, they are vital to computational lexical semantics, yet the field suffers from the absence of a common formal framework to define their properties and mutual relationship. This paper proposes a unifying treatment of these two relations, which is validated by experiments on existing resources. The theory establishes a solid foundation for critically re-evaluating prior work in cross-lingual semantics, and facilitating the creation, verification, and amelioration of lexical resources.

1 Introduction

Wordnets, such as the original Princeton WordNet (Fellbaum, 1998), as well as their multilingual generalizations (multi-wordnets), such as BabelNet (Navigli and Ponzetto, 2012), depend on synonymy and translation to define the basic units of their ontologies, synsets. As sources of lexical knowledge, they are extensively used in many state-of-the-art NLP systems. In particular, they serve as the standard English sense inventory for semantic tasks such as word sense disambiguation (WSD).

The principal problem that our work aims to address is the lack of understanding of the relationship between senses, synonymy, and translation in wordnets and multi-wordnets. In much of the prior work, theoretical assumptions and terminology are either unclear or simply incorrect. Despite their importance, there is no commonly accepted set of best practices for creating lexical resources, leaving several open questions. Which of the competing expand and merge paradigms should be applied for multi-wordnet construction? Can fine-grained senses be clustered while preserving fundamental properties of synsets? How can synonymy be maintained when extending synsets in multilingual settings? Since lexical resources for NLP research are increasingly constructed semi-automatically, can effective error detection techniques be derived from sound theoretical foundations?

Our main contribution is a clear and consistent theoretical framework for reasoning about senses, concepts, and translations. Building on a set of unambiguous axioms, we formulate and prove several theorems that characterize the relationship between synonymy and translational equivalence at the level of both words and senses. These results allow us to reassess previous methods, and explore their consequences and implications, which lead towards resolving open issues. While some of these propositions may reflect unstated intuitions discernible in prior work, their explicit statement and derivation from first principles constitutes a novel contribution.

Our work offers practical benefits to the research community. We provide experimental evidence for the validity of our theory. Analysis of the apparent exceptions to our theorems shows that most of them are due to errors in existing lexical resources. This leads us to propose a direct practical application of our theoretical results: an algorithm that can not only flag such errors but also correct them.

Finally, we show that our theory implies important consequences for lexical semantics. Since word senses are determined by word synonymy, sense granularity cannot be substantially reduced without violating the fundamental properties of wordnets. The expand model of multi-wordnet construction has the potential of preserving those properties, but at the cost of increased sense granularity. The most surprising finding is that the existence of an exact matching between synsets...
across wordnets implies the universality of lexicalized concepts in natural languages.

This paper has the following structure: In Section 2, we provide precise definitions of the basic terms and assumptions. In Section 3, we formulate and prove several theorems and corollaries. In Section 4, we describe our validation experiments and propose an error correction algorithm. In Section 5, we discuss the implications of our theory for multilingual semantics.

2 Semantic Equivalence

In this section, we define the theoretical properties of wordnets and multi-wordnets, and propose a unified treatment of synonymy and translational equivalence. The properties, which follow from the basic definitions and assumptions in the original WordNet, are often implicitly assumed in prior work, but have never been precisely formulated. We view existing lexical resources as imperfect approximations of the theoretical models.

2.1 Synonymy

Synonymy, the relation of sameness of meaning, can be established by a substitution test; two expressions are considered synonymous if and only if they can be substituted for one another in a sentence without changing its meaning (Murphy and Koskela, 2010). Absolute synonyms can be substituted for one another in any context, whereas near-synonyms are interchangeable in some but not all contexts (Edmonds and Hirst, 2002). Considered as relations, both absolute synonymy and near-synonymy are reflexive and symmetric, but only the former is transitive. As a consequence, absolute synonymy is an equivalence relation, which partitions expressions into semantic equivalence classes. In this paper, the term synonymy by itself refers to absolute synonymy.

2.2 Word Senses

Although synonymy can be defined on various types of linguistic units, including sentences and phrases (paraphrases), our main focus is on words and their senses. We assume that every content word token has a particular meaning, and define a word sense (or simply sense) as a partition of these meanings (Kilgarriff, 1997). It follows that every content word token is used in exactly one sense, and that every content word type has at least one sense. Words are either monosemous or polysemous depending on whether they have only one or multiple senses.

2.3 Synsets

A wordnet is a lexical ontology in which words (including non-compositional expressions, such as ‘single out’) are organized into synsets. A synset is a set of words that are interchangeable in some context (Fellbaum, 1998). Therefore, words which share a synset must be either absolute or near-synonyms. Each word in a synset can be used to express a common lexicalized concept (Miller, 1995).

Synsets provide another way of defining a word sense, namely as a (concept, word) tuple. In Table 1, columns correspond to words, rows correspond to concepts (or synsets), and each non-empty cell is a word sense. Each concept is lexicalized by at least one word, and each word lexicalizes at least one concept. The number of its senses of each content word is equal to the number of concepts that it lexicalizes. Thus, synsets can be equivalently defined as either sets of words or sets of unique word senses.

Consider the relation between two senses that holds if and only if the senses share a synset. The reflexivity, symmetry, and transitivity of the relation follow directly from the definition of a synset, which is based on the substitution test defined in Section 2.1. Since the senses represent the same lexicalized concept, this equivalence relation represents absolute synonymy of senses. Therefore, synsets can be viewed as the equivalence classes of the relation of absolute synonymy of senses. This novel proposition, which we refer to as the wordnet assumption, is one of the foundations of our theory.

We define five synset properties which follow from the preceding definitions and assumptions, and which must be maintained in wordnets:

1. A word is monosemous if it is in a single synset. A word is polysemous if it is in multiple synsets.
2. Words are near-synonyms iff they share at least one synset. Words are absolute synonyms iff they share all their synsets.

3. Word senses are synonymous iff they are in the same synset.

4. Every word sense belongs to exactly one synset.

5. Every sense of a polyseous word belongs to a different synset.

2.4 Translational Equivalence

Having defined synonymy, wordnets, and synsets in the monolingual setting, we are now in a position to extend these notions to the multilingual setting. The cross-lingual analogue of synonymy is translational equivalence, which is the relation of sameness of meaning between expressions in distinct languages. Translational equivalence can be established by a translation test: two expressions in distinct languages are (absolute) translational equivalents if and only if each can be translated into the other in any context.

We postulate that the relations of synonymy and translational equivalence can be combined via a simple union operation to produce a single relation of semantic equivalence, which is applicable to any pair of expressions in the same or different natural languages.

2.5 Multi-Synsets

The notion of trans-lingual semantic equivalence is fundamental to multilingual semantic networks, or multi-wordnets, such as BabelNet (Navigli and Ponzetto, 2012). Just as wordnets are comprised of inter-connected synsets, the basic units of multi-wordnets are multilingual synsets, which we refer to as multi-synsets. Multi-wordnets and multi-synsets are extensions of the corresponding monolingual notions to the multilingual setting. In particular, multi-synsets contain words in one or more languages that express the same concept (Camacho-Collados et al., 2015). For example, BabelNet multi-synsets are populated by translations of word senses that represent a given concept (Navigli and Ponzetto, 2010).

Lexical gaps occur when a concept is lexicalized in some but not all natural languages. A compositional phrase or a hypernym can be employed to translate such a concept (Rudnicka et al., 2012). In multi-wordnets, lexical gaps can be represented by special tokens within multi-synsets (Bentivogli and Pianta, 2003).

There are two principal approaches to the construction of multilingual wordnets (Vossen, 1996). The expand model uses a monolingual “pivot” wordnet (typically the Princeton WordNet) to establish a base set of concepts and relations, to which words or synsets in other languages are then linked. The merge model attempts to link the synsets of independently constructed monolingual wordnets using a pre-defined set of inter-lingual relations.

We posit that multi-synsets should maintain the properties of monolingual synsets. If this postulate is satisfied, monolingual synsets can be obtained from multi-synsets by simply restricting them to a given individual language. Furthermore, we posit that words from distinct languages share a multi-synset if and only if they are mutual translations in some context. Since the senses that share multi-synsets represent the same lexicalized concept, they are absolute translational equivalents. Therefore, multi-synsets can be viewed as the equivalence classes of the relation of semantic equivalence between senses within and across languages. This novel proposition, which we refer to as the multi-wordnet assumption, is the second pillar of our theory.

3 Theorems

Having established our terminology and assumptions, we now proceed to present our theoretical results. Each of the following four subsections presents a novel theorem in lexical semantics.

3.1 Synonymy and Translation of Senses

We first present our principal theorem and two corollaries which establish the relationship between synonymy and translational equivalence at the level of senses. Our notation follows the example in Table 1. We use different base letters for distinct languages: $s$ vs. $t$ for senses, $e$ vs. $f$ for words, and $E$ vs. $F$ for languages. Subscripts distinguish between senses and words within the same language. The predicates $\text{syn} (\cdot,\cdot)$ and $\text{tr} (\cdot,\cdot)$ express the propositions that two expressions (senses or words) are absolute synonyms or translational equivalents, respectively.

**Theorem 1.** Given two pairs of word senses $(s_x, t_x)$ and $(s_y, t_y)$ that are translational equiv-

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$^1$As postulated by Kwong (2018).
alents: $s_x$ and $s_y$ are synonymous if and only if $t_u$ and $t_v$ are synonymous.

Proof. By synset property #4, every sense belongs to exactly one multi-synset. By synset property #3, if two word senses are synonymous, they must be in the same multi-synset. By the multi-wordnet assumption, $s_x$ must share a multi-synset with $t_u$, and $s_y$ must share a multi-synset with $t_v$. Therefore, if either $s_x$ and $s_y$ or $t_u$ and $t_v$ are synonymous, all four senses must belong to the same multi-synset, which implies that they are semantically equivalent.

Both of the following corollaries differ from Theorem 1 in that they involve triples of senses, rather than quadruples. The first corollary, which can be viewed as a special case of Theorem 1, states that senses that translate into the same foreign sense must be synonymous. This observation could lead to an algorithmic method for constructing or augmenting synsets using sense-annotated bitexts.

**Corollary 1. Translational Equivalence of Senses Implies Synonymy:** $\forall s_x, s_y \in E : \forall t_z \in F : tr(s_x, t_z) \land tr(s_y, t_z) \Rightarrow syn(s_x, s_y)$.

The second corollary establishes the reverse implication — all senses that are synonymous must translate into the same sense, provided that a single-word translation exists in the other language.

**Corollary 2. Synonymy of Senses Implies Translational Equivalence:** $\forall s_x \in E, s_y \in E, t_z \in F : syn(s_x, s_y) \land tr(s_y, t_z) \Rightarrow tr(s_x, t_z)$.

Both corollaries, as well as Theorem 1 itself, follow from the transitivity of the relation of semantic equivalence.

### 3.2 Synonymy and Translation of Words

Yao et al. (2012) observe that prior work, such as Gale et al. (1992) and Diab and Resnik (2002), had been based on one of the two “alternate” assumptions, which have the same antecedent but different consequents:

- **Antecedent:** Two different words $e_x$ and $e_y$ in language $E$ are aligned to the same word $f_z$ in language $F$.
- **Consequently:**
  1. $f_z$ is polysemous ("polysemy assumption")
  2. $e_x$ and $e_y$ are synonymous ("synonymy assumption")

Yao et al. (2012) perform experiments on two bilingual corpora, using a lexical sample of 50 words from OntoNotes (Hovy et al., 2006), and conclude that neither assumption holds significantly more often than the other. However, they stop short of proposing a principled solution to the problem.

According to our theory, neither of the two assumptions need hold universally. For example, although both time and weather are translations of the Italian word tempo, it would be wrong to conclude that the two English words are near-synonyms. This is because, unlike absolute synonymy of senses, near-synonymy of words is not transitive in either monolingual or multilingual setting. On the other hand, although both bundle and package are translations of the Italian involto, this does not imply that the Italian word is polysemous; indeed, both English words translate a single sense of involto.

We postulate that the polysemy and synonymy assumptions can be integrated into a single theorem. In fact, the two consequents are not exclusive; for example, test and trial, which are synonymous, are both translations of Italian prova, which is polysemous. Thus, the theorem entails a non-exclusive union of the two consequents:

**Theorem 2.** Given two words $e_x$ and $e_y$ in language $E$ and a word $f_z$ in language $F$: if $e_x$ and $e_y$ are both translations of $f_z$ then $e_x$ and $e_y$ are near-synonymous or $f_z$ is polysemous.

Proof. If $f_z$ is polysemous, the implication holds trivially. Otherwise, $f_z$ must be monosemous, so by synset property #1, there exists only one multi-synset that contains $f_z$. By the multi-synset property, both $e_x$ and $e_y$ must share a multi-synset with $f_z$. Therefore, by synset property #2, since $e_x$ and $e_y$ share a synset, $e_x$ and $e_y$ are near-synonyms.

In conclusion, our theory demonstrates that systems which are based exclusively on one of the two assumptions, such as Bannard and Callison-Burch (2005) and Lefever et al. (2011), fail to consider a substantial number of relevant instances. Theorem 2 provides a more reliable foundation, which we validate empirically in Section 4.4.

### 3.3 Absolute Synonymy of Words

Yao et al. (2012) use the term synonymy to mean
near-synonymy. What does our theory predict if synonymy of words is taken to mean absolute synonymy instead? It turns out that exactly one of the two assumptions, the synonymy assumption, holds universally.

In Section 3.1, we formulated Theorem 1 and its two corollaries to characterize the relation between absolute synonymy and translation of senses. We can formulate analogous results to characterize the relation between absolute synonymy and translation of words.

**Theorem 3.** Given two pairs of words \((e_x, f_u)\) and \((e_y, f_v)\) that are absolute translational equivalents: \(e_x\) and \(e_y\) are absolute synonyms if and only if \(f_u\) and \(f_v\) are absolute synonyms.

**Proof.** By synset property #5, every sense of a given word belongs to a different synset. By synset property #2, absolute synonyms share all their synsets. By the multi-wordnet assumption, \(e_x\) must share all its multi-synsets with \(f_u\), and \(e_y\) must share all its multi-synsets with \(f_v\). Therefore, if either \(e_x\) and \(e_y\) or \(f_u\) and \(f_v\) are absolute synonyms, all four words must share all their multi-synsets, which implies that they are semantically equivalent.

Just like Theorem 1, Theorem 3 implies two corollaries. First, if two different words can always be translated by the same foreign word (and vice-versa), then the two words are absolute synonyms. Second, the sets of translations of absolute synonyms must be identical. We omit the formal statements of the two corollaries, as they are almost identical to Corollaries 1 and 2 in Section 3.1.

### 3.4 Translations of Near-Synonyms

Our final theorem can be viewed as the converse of the synonymy assumption from Section 3.2. Theorem 4 states that near-synonymy implies the existence of a shared translation. Since the theorem needs to account for lexical gaps, we use a general term “expression” which encompasses both words and compositional phrases.

**Theorem 4.** Given two words \(e_x\) and \(e_y\) in language \(E\): if \(e_x\) and \(e_y\) are near-synonyms then there exists an expression \(\varphi\) in language \(F\) such that both \(e_x\) and \(e_y\) can be translated by \(\varphi\).

**Proof.** Since \(e_x\) and \(e_y\) are near-synonyms, there exists a multi-synset \(M\) that they share. By the substitution test, there must exist a pair of sentences \(S_1\) and \(S_2\) that have the same meaning, and differ only in containing either \(e_x\) for \(e_y\) at the same position. Since \(S_1\) and \(S_2\) have the same meaning, they can both be translated by the same sentence \(T\) in language \(F\). The sequence of one or more words within \(T\) that translate \(e_x\) and \(e_y\) in \(S_1\) and \(S_2\), respectively, constitutes the expression \(\varphi\).

As a corollary, if the concept that corresponds to the multi-synset \(M\) is lexicalized in language \(F\) (i.e., there is no corresponding lexical gap in \(F\)), then there exists a word \(f_z\) that can translate both \(e_x\) and \(e_y\).

### 4 Experimental Evidence

In this section, we describe experiments that test the predictions of our theory, and demonstrate how our theory can be used to automatically detect and correct errors in semantic resources.

#### 4.1 Methodology

Our methodology is based on cross-checking the evidence for synonymy and translation equivalence between different semantic resources. We empirically validate our theorems on a sense-annotated word-aligned parallel corpus (bitext) coupled with a multi-wordnet that covers the two languages of the bitext. We assume that each sense annotation in the bitext exists in the multi-wordnet. We operationalize the relations of synonymy and translational equivalence on senses as follows: (a) senses are synonymous if they share a synset and (b) senses are translational equivalents if a pair of words annotated with those senses are aligned in the bitext.

Not all predictions of our theory can be tested in this way. An alignment link in a sense-annotated bitext demonstrates that two words or senses can be translated into each other. However, since no bitext, regardless of its size, can be guaranteed to contain all possible translations, it cannot furnish conclusive proof that two words are absolute translational equivalents, or that they both can be translated into the same foreign word. Similarly, no bilingual dictionaries or thesauri include exhaustive lists of all translations and synonyms. However, all of our theorems and corollaries are proven using the same theory of sense, synonymy, and translation. Therefore, the empirical results that we present for Theorems 1 and 2 and Corollary 1
provide indirect support for Theorems 3 and 4 and Corollary 2.

4.2 Resources

The multi-wordnet we use in our experiments is MultiWordNet\(^2\) (MWN) version 1.5.0 (Pianta et al., 2002), a lexical resource created by applying the expand model of multi-wordnet construction to the Princeton WordNet. It consists of WordNet 1.6 synsets which have been expanded into multi-synsets containing English and/or Italian words. The synsets in MWN are compliant with the synset properties listed in Section 2.3. We map the WordNet 1.6 synsets to WordNet 3.0 using a publicly available mapping.\(^3\)

As our word-aligned sense-annotated bitext, we use MultiSemCor\(^4\) (MSC) version 1.1 (Bentivogli and Pianta, 2005), a sense-annotated English-Italian bitext crafted by bilingual lexicographers using a professional translation of SemCor (Miller et al., 1993). It contains 11,451 and 11,149 distinct lemmas, annotated with 17,875 and 22,352 distinct senses, on the English and Italian side, respectively. We extracted all 92,992 aligned English-Italian word pairs. As our experiments will demonstrate, the Italian sense annotations are largely independent of the English SemCor annotations.

4.3 Absolute Synonymy and Translation

Absolute word synonymy is considered rare, to the point that its very existence is denied (Jurafsky and Martin, 2009). By synset property #2, words that share all their synsets are absolute synonyms. According to this criterion, 69,775 words in Princeton WordNet have at least one absolute synonym. They include variant spellings, such as liter and litre, variant terminology, such as atmometer and evaporimeter, and abbreviations, such as kg and kilogram.

The multilingual extension of absolute synonymy is believed to be similarly rare (Urešová et al., 2018). Yet, we find that MultiWordNet contains 45,717 English-Italian word pairs which appear in exactly the same synsets, indicating that one can always translate the other. Many of these absolute translational equivalents are cognates, such as globally and globalmente, and borrowings, such as internet.

### Table 2: Results of the four verification experiments on MultiSemCor.

|                  | Corollary 1 | Theorem 1 |
|------------------|-------------|-----------|
| Instances        | 1792        | 10597     | 19080     | 21689     |
| Exceptions       | 194         | 1069      | 1965      | 3298      |
| Conformity       | 89%         | 90%       | 90%       | 85%       |

4.4 Word-Level Verification

We test Theorem 2 on MSC by analyzing all triples that consist of two different English words and an Italian word that they are both aligned to at least once in MSC, e.g., (inverse, opposite, contrario). We find that among 17,272 distinct triples, 17,136 include a polysemous Italian word, 3,343 contain a pair of English near-synonyms, and 3,207 involve both polysemy and synonymy. This shows that in MSC the polysemic assumption holds substantially more often than the synonymy assumption, which differs from the conclusions of Yao et al. (2012) (Section 3.2). We attribute this discrepancy to their use of a coarse-grained OntoNotes sense inventory, as well as testing relatively small lexical samples, rather than entire lexicons. Since no exceptions to Theorem 2 are found, we conclude that the experiment fully confirms its validity.

4.5 Sense-Level Verification

We test Theorem 1 and Corollary 1 in both translation directions. In each of the four sense-level experiments, we identify in the annotated bitext all unique instances that satisfy the premise of the proposition that is being tested. For Corollary 1, the instances are sense triples that consist of pairs of source senses that are aligned with the same target sense. For Theorem 1, the instances are sense quadruples that consist of pairs of source senses that are aligned with two distinct but synonymous target senses. The two source senses must be distinct, but they may belong to the same word. Finally, we verify whether the two source senses are synonymous, as predicted by our theory.

The results of the experiments are summarized in Table 2. The first row shows the number of unique instances found in MSC. The second row shows the number of instances that appear to contradict our theory. The final row shows the fraction of instances that conform to our theory.

We find that the overall level of reliability of Corollary 1 and Theorem 1 in the MSC bitext

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\(^2\)http://multiwordnet.fbk.eu

\(^3\)http://www.talp.upc.edu/page-resources-lists

\(^4\)http://multisemcor.fbk.eu/index.php
is similar to the sense annotation precision estimate of 87.9% reported by Bentivogli and Pianta (2005). We speculate that the greater number of exceptions in the *it*→*en* direction is related to the asymmetric construction of MSC: the Italian side was created by translating the English side. In the following sections, we attempt to estimate what fraction these apparent exceptions represent actual exceptions to our theory.

### 4.6 Exception Analysis

For both Corollary 1 and Theorem 1, we randomly selected 25 of the thousands of apparent exceptions in the *en*→*it* direction. Each of these exceptions consists of two English-Italian sense alignment pairs, which involve Italian senses that are either identical (for Corollary 1) or distinct but synonymous (for Theorem 1). For each of the 50 exceptions, we manually analyze a sample of up to 10 of the corresponding English sentences from the bitext. We consider synset contents, as well as glosses and usage examples.

We find that all 50 apparent exceptions can be dismissed as errors in the resources. The types of detected errors, in order of frequency, are: (1) annotation errors on the English side, (2) incomplete MWN multi-synsets, and (3) annotation errors on the Italian side. We interpret this as very strong support for the soundness of our theory.

### 4.7 Substitution Test Experiment

In order to extend the scope of our error analysis, we performed an annotation experiment based on the substitution test for synonymy (Section 2.1). The rationale of the experiment is that a sense annotation must be incorrect if substituting it with another sense from the same synset either changes the meaning of the sentence or renders it meaningless.

We identified 77 of the 194 exceptions to Corollary 1 such that exactly one of the two English senses shares a synset with a sense of the word of the other English sense. We then created a set of 77 English sentence pairs that differ only in the word in question. The original sentence for each exception is randomly selected from the set of the sentences that correspond to the exception. In the modified sentence, the word annotated with the first sense is replaced with the word of the second sense from the same synset. For example, the sentence *Their world turned black* is modified to *Their world reversed black*.

We asked two native English speakers to decide independently whether the original and modified sentences had the same meaning. Where possible, different sentences and substitutions were used for each annotator. 82% of the responses indicated that the annotators judged that the meaning was not preserved, which indicates a sense annotation error in MSC. Only 8 sentence pairs were considered by both annotators to carry the same meaning after substitution.

We manually analyzed those 8 instances by considering additional information that was unavailable to the annotators, namely the contents, glosses and usage examples of the synsets. We found that six of the eight instances were also sense annotation errors. For the remaining two instances, we were not able to decide between the two possible senses. We conclude that the substitution test experiment yields no clear exceptions to our theory.

### 4.8 Automatic Error Correction

The sense-level verification experiments demonstrate that our theory can be applied to detecting errors in sense-annotated corpora. In this section, we propose an algorithm for correcting such errors, which is also able to amend a corresponding multi-wordnet. The algorithm is based on Theorem 1, which predicts that any two pairs of aligned bitext senses that are related by synonymy in either language must all share the same multi-synset.

The pseudo-code of the error correction algorithm is shown in Figure 1. The algorithm takes as input two sense translation alignment pairs, and outputs a suggested error correction for any exception to Theorem 1. When an exception to Theorem
is detected, the algorithm either corrects the corresponding annotation in the bitext or suggests a new sense to be added to the multi-wordnet. The algorithm can be applied in either translation direction.

When applied to the English part of MSC and MWN, the algorithm suggests 9028 corrections to the sense annotations, and 1166 sense additions to multi-synsets. We verified the suggestions on a sample of 50 manually-analyzed exceptions described in Section 4.6. We find that 34 out of 39 proposed sense corrections and 9 out of 13 proposed sense additions are correct, yielding an overall accuracy of 83%. We conclude that the algorithm could be effective at correcting errors in bitexts and multi-wordnets, especially if those resources were automatically created to begin with.

5 Concept Universality

We have demonstrated that word senses in wordnets are objectively determined by the relation of near-synonymy between words. Synsets are equivalence classes of synonymous senses, which represent lexicalized concepts. These concepts are discrete and disjoint. Although existing wordnets do contain occasional cases of synset gloss pairs that seem to imply non-empty intersection of senses, glosses are subordinate to near-synonymy for the purpose of defining senses (Miller et al., 1990).

Our theory does not contradict the well-known thesis of Kilgarriff (1997) that word senses can only be defined relative to an intended application. His critique, which was formulated before WordNet’s adoption as the standard WSD sense inventory, is aimed at dictionary senses defined by lexicographers independently for each word. In contrast, wordnet senses are grounded in the concept of synonymy, and our theory is driven by multilingual applications, including translation.

Since senses are induced by near-synonymy relations between words, we posit that the number of senses in a wordnet cannot be substantially reduced without violating the synset properties formulated in Section 2.3. In particular, synset property #2 states that near-synonyms share at least one synset, but not all synsets. Therefore, each near-synonym word pair must involve at least three distinct word senses.

The theorem and corollaries in Section 3.1 establish that all senses that are synonymous or translationally equivalent share the same multi-synset. This suggests a one-to-one mapping between synsets across languages, with lexical gaps represented by empty synsets. If we view a pair of wordnets as a bipartite graph in which nodes are non-empty synsets and edges represent the relation of translational equivalence, then every node has a degree of at most one. Since every synset represents a different lexicalized concept, this implies that a concept in one language cannot correspond to more than one concept in another language. We refer to this implication of our theory as the concept universality principle.

In practical terms, the concept universality principle implies that any differences in coverage between concepts across languages must be resolved by increasing the granularity of the corresponding multi-wordnets. For example, if one language makes a lexical distinction between “father’s brother” and “mother’s brother or aunt’s husband” and another language has different words for “parent’s brother” and “aunt’s husband”, then all of these concepts need to be represented by distinct synsets in a multi-wordnet. This concept-splitting approach is necessary to preserve the multi-wordnet assumption, which ensures that multi-synsets encode correct word translation pairs.

The concept universality principle, which we have shown to follow logically from the fundamental assumptions of wordnets, provides theoretical support for constructing multi-wordnets using the expand model, as opposed to the merge model (Section 2.5). At the same time, the principle provides a basis for avoiding bias towards English lexicalization patterns, which has its roots in the practice of founding new multi-wordnets on the synset structure of the original WordNet. We hope that the application of this principle will lead to the incorporation of conceptual distinctions from other languages, thus guiding the evolution of multi-wordnets away from the hegemony of English, and toward greater linguistic diversity.

6 Conclusion

We have proposed a unifying treatment of the notions of sense, synonymy and translational equivalence. The resulting theory formalizes the relationship between words and senses in both monolingual and multilingual settings. In the future, we

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5 A similar argument can be made for color terminology (McCarthy et al., 2019).
plan to investigate how our theory can best facilitate the task of automating the construction of semantic resources. We expect that sound theoretical foundations will also lead to improvements in both word sense disambiguation and machine translation.

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