# Evaluating Bilingual Embeddings in Bilingual Dictionary Alignment

# Çift Dilli Kelime Temsilleri ile Sözlük Eşlenmesi

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# Declaration of Authorship

I, Yiğit Sever, declare that this thesis titled, “Evaluating Bilingual Embeddings in Bilingual Dictionary Alignment” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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# Abstract


Yiğit Sever

*Evaluating Bilingual Embeddings in Bilingual Dictionary Alignment*

Dictionaries catalog and describe the semantic information of a lexicon. WordNet provides an edge by presenting distinct concepts with the hierarchy information among them. Research in computer science has been using this hand crafted tool in natural language applications such as text summarization and machine translation. Original WordNet has been compiled for English yet counterparts for other languages are not as readily available nor as comprehensive. In order for research on languages other than English to benefit from the power of a WordNet, machine assisted creation and evaluation methods are essential.

Word embeddings can provide a mapping between words and points in a real valued vector space. Using these vectors, representing documents as well as forming geometric relationships between them is a well studied area of research. In this thesis we start by hypothesizing that a dictionary definition captures the semantic basis of the described word. We used word embeddings as building blocks to map dictionary definitions into a multidimensional space. These spaces can be aligned to accommodate two languages, allowing the transfer of information from one language to another. We investigate the success of retrieving and matching discrete senses across languages by employing supervised and unsupervised methods. Our experiments show that dictionary alignment can be evaluated successfully by using both unsupervised and supervised methods but corpora sizes should be taken into consideration. We further argue that some methods are not viable considering their poor performance.

# Acknowledgements

The acknowledgments and the people to thank go here, don’t forget to include your project advisor…

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For/Dedicated to/To my…

# Chapter 1

# Introduction

## 1.1 Dictionaries

Dictionaries vary with regard to their use case, target audience, and scope. For instance, bilingual dictionaries present words alongside their translations in the target language. Domain-specific dictionaries list technical terms that target people who are familiar with the terminology. Yet, the term *dictionary* on its own brings forth the monolingual, sometimes known as descriptive dictionary into consideration. This type of dictionary presents words alongside their definitions following an alphabetical order [1]. Their primary intention is to inform the user about the words [2]. Some words are polysemous, sharing the same spelling and having related, often derivative meanings. Multiple definition entries clarify the differences between these related senses. Likewise, homonymous words have distinct meanings while having identical spellings through coincidence. They are often denoted using discrete blocks of descriptions. Another lexical relation we are concerned with is the synonymity. A word is synonymous to another if they share the same meaning but are not spelled alike. Synonymity is seldom shown in dictionaries. The term that precedes the entries is called *headword* or *lemma*. Usually, lemmas are the form of a word without inflections. The sense they convey is as comprehensive as possible, reducing the number of otherwise redundant entries that would have been the derivatives of the unmarked form [3].

Dictionaries take an immense amount of time and expertise to prepare. We can talk about the examples after narrowing our scope down to the dictionaries that are still available to use today. A survey by Uzun [4] notes that the first instalment of the modern Turkish dictionary, led by a team of experts, has taken over 6 years to prepare. Kendall [5] talks about how Noah Webster, the writer of the *An American Dictionary of the English Language* had to mortgage off his home in order to finish his project which took over 26 years.

Early lexicographers had to invest tremendous amounts of time putting together a collection of documents and other written material in order to establish a *corpus* [4]. This endeavour is necessary since a corpus is crucial to create the vocabulary of a language. After processing the corpus, lemmas can be extracted and the resulting wordstock is called the *lexicon* of the language.

The internet radically changed the way researchers aggregate data. The advancements in digital storage technology allowed the data to be persistent. Improvements in networking ensured that people can share the volume of it among themselves. With the popularization of social media, the internet generates everyday conversations at an unprecedented rate that researchers are using for natural language applications. Moreover, efforts on open, collaborative, web based encyclopedias generate structured, multilingual data often used in machine translation and text categorization tasks. Once the cumbersome task of corpus attainment is now akin to web crawling. With the digitized data, it was only natural for dictionaries to go digital as well since it's generally acknowledged that they are no longer viable if they are not electronic [1].

## 1.2 WordNet

George A. Miller started the WordNet project in the mid-1980s. On its early days, project members studied theories that were aimed towards enabling computers to understand natural language as intrinsically as humans do. While working on then popular semantic networks and sense graphs, they have started something that will evolve into an expansive, influential resource [6].

Traditional dictionaries are rigid, constrained by the nature of the printed form. Today, WordNet can be used as a browser much like an online dictionary or thesaurus that informs users about the senses, accessed by queries. Behind the scenes, a sprawling lexical database has relationship information for more than 117000 senses. Figure 1.1 shows a brief result for the query string "run".

WordNet lists terms, much like a traditional dictionary, alongside its synonyms. Additionally, there is a horizontal association; for any sense, the lemmas that share the row with the target term are synonyms. This set of synonyms is aptly named *synsets*. A short description is also provided to clarify the meaning fully.

WordNet also includes other relationships such as *hypernymy* and *hyponymy*, semantic relation of senses being type-of one another [7]. For instance, the term "building" is a hyponym of "restaurant" since it encompasses a more general sense; the restaurant is type of a building. While coffee shop is a hypernym to the restaurant since it is a more specific sense. One other relation is the meronymy, defined as a sense being part of or a member of another [8]. Keeping to our building example, windows are meronym to buildings. Other relationships exist but listing them is outside the scope of this thesis. Bottom line is the effort that has gone through to map $117,000$ senses according to different semantic relationships. According to Sagot & Fišer [9], the semantic relationships betwen senses are not tied to a specific language. The If we assume that terms keep their semantic relationships when translated, we can infer the effort behind the WordNet does not need to be replicated but can be translated to other languages.

**Noun**

S: (n) **run**, tally (a score in baseball made by a runner touching all four bases safely) *"the Yankees scored 3 runs in the bottom of the 9th"; "their first tally came in the 3rd inning"*

*direct hyponym / full hyponym*

- S: (n) earned run (a run that was not scored as the result of an error by the other team)
- S: (n) unearned run (a run that was scored as a result of an error by the other team)
- S: (n) run batted in, rbi (a run that is the result of the batter's performance) *"he had more than 100 rbi last season"*

*direct hypernym / inherited hypernym / sister term*

- S: (n) score (the act of scoring in a game or sport) *"the winning score came with less than a minute left to play"*

***derivationally related form***

- W: (v) run [Related to: run] (make without a miss)
- W: (v) tally [Related to: tally] (keep score, as in games)
- W: (v) tally [Related to: tally] (gain points in a game) *"The home team scored many times"; "He hit a home run"; "He hit .300 in the past season"*

S: (n) test, trial, **run** (the act of testing something) *"in the experimental trials the amount of carbon was measured separately"; "he called each flip of the coin a new trial"*

S: (n) footrace, foot race, **run** (a race run on foot) *"she broke the record for the half-mile run"*

**Verb**

- S: (v) **run** (move fast by using one's feet, with one foot off the ground at any given time) *"Don't run--you'll be out of breath"; "The children ran to the store"*
- S: (v) scat, **run**, scarper, turn tail, lam, run away, hightail it, bunk, head for the hills, take to the woods, escape, fly the coop, break away (flee; take to one's heels; cut and run) *"If you see this man, run!"; "The burglars escaped before the police showed up"*

Figure 1.1: WordNet result for the query "run", truncated for brevity.

Since it's inception, other projects built lexical databases, using the same WordNet design. Fellbaum [10] talks about the correct terminology that we abide for the thesis; "As WordNet became synonymous with a particular kind of lexicon design, the proper name shed its capital letters and became a common designator for semantic networks of natural languages". Hence *WordNet* refers to English Princeton WordNet, while *wordnets* created for other languages are not stylized.

## 1.3 Multilingual Wordnets

Authorities list more than 7000[1] living languages but only 40[2] of them have a sizeable presence on the internet. Among this small fraction, English is the dominant language of the web. English in not the centrepiece for natural language processing research because of any linguistic advantage but it is the most abundant language on web.

Distributions like spaCy [3] resorts to lemmatizations such as =*PRON*= to denote pronouns in order to collapse the senses for "I" "you", "them" etc.. The sense and the accompanying word for being the brother of someone's father or mother differs in Turkish while both collapse in "uncle" in English. Studying other languages can provide insight towards concepts that are not present in English.

Translation, information transfer from foreign languages is a valid way of enriching a language's corpora; if a term that denotes a sense does not have a match in the target language, it is a good indication for the linguists of that language to look into their lexicons and work towards expanding it [3]. Further research in the area contributes to more languages having access to tools that will incorporate them into the literature.

We should note that the languages of the wordnets used in the thesis are all present in the 40 languages that have a significant presence on the internet that we have mentioned before. The work on wordnets for languages other than English has been under way since the early days of the predecessor. Research has tackled the issue of lack of wordnets for languages besides English. Yet, against 117000 senses in the English Princeton WordNet, the counterparts, with the exception of FinnWordNet [11] have about a quarter. We have constrained this study to use only the freely available wordnets and not considered wordnets that are gated behind restrictive licenses.

[1] https://www.ethnologue.com/statistics
[2] https://w3techs.com/technologies/history_overview/content_language/
[3] https://spacy.io/

Open Multilingual WordNet [12] set out to discover the effects related to the choice of license for wordnets. Their criteria for usefulness is the number of citations a publication tied to the wordnet gets on literature. They identified two major problems with the current distributions; some projects have picked restrictive licenses, effectively barring access to their tools for research purposes. Other finding is the lack of a standardized form for the wordnets. While on a conceptual level, a database of semantic relations has been derived by others, implementations differed on a software engineering level. This made writing scripts to parse wordnets difficult. Thankfully, Bond & Paik have standardized the wordnets and are currently hosting them from a single source.[4]

With alignment information at hand, we have created our dataset that we will assume to be perfectly aligned; a golden corpus. Among the 34 wordnets available on Open Multilingual WordNet, only 6 of them have gloss information available. Given this thesis will only investigate the ability to map senses using definitions of the sense, we used the subset of Albanian [13], Bulgarian [14], Greek [15], Italian [16], Slovenian [17] and Romanian [18] wordnets. Table 1.1 shows brief statistics about them.

Table 1.1: Summary of the Wordnets used.

| Name of the Project | Language | Number of Definitions | Words Per Definition |
|---|---|---:|---:|
| Albanet | Albanian | 4681 | 11.75 |
| BulTreeBank WordNet | Bulgarian | 4959 | 12.71 |
| Greek Wordnet | Greek | 18136 | 11.24 |
| ItalWordnet | Italian | 12688 | 7.33 |
| Romanian Wordnet | Romanian | 58754 | 9.98 |
| SloWNet | Slovenian | 3144 | 12.68 |

## 1.4 Thesis Goals

In this thesis, our aim is to study the possibility of creating wordnets using dictionary alignment. We will evaluate existing methods for their performance on cross-lingual document retrieval but our documents are dictionary definitions which are short, descriptive snippets of text. At the end of this study, we will answer the following research questions;

1. Is it possible to create wordnet like lexical databases using off-the-shelf methods.
2. How well does the studied techniques perform.

[4] http://compling.hss.ntu.edu.sg/omw/

3. What attributes need to be considered regarding the available data.

## 1.5 Thesis Outline

`Fill later…`

# Chapter 2

# Background Information & Related Work

WordNet generation is broken down into 4 categories

1. Expand model, Vossen [19], fixed synsets are translated from English to target language.
2. Link English entries from machine-readble bilingual dictionaries to English Princeton WordNet senses Knight & Luk [20].
3. Taxonomy parsing Farreres *et al.* [21].
4. Ontology matching Farreres *et al.* [22]

Gordeev *et al.* [23] uses unsupervised cross-lingual embeddings to match cross-lingual product classifications. Working on taxonomy matching, they use out of domain pre-trained embeddings due to small size of their corpora and investigate methods using untranslated and translated text.

Lesk [24] represent words using their gloss. Relied upon traditional dictionaries. Banerjee & Pedersen [25] developed on lesk algorithm and included WordNet definitions. Khodak *et al.* [26] used word embeddings and WordNet.

Metzler *et al.* [27] talked about short text retrieval and lexical matching. They reported that lexical matching is good for finding semantically identical matches.

Sagot & Fišer [9] built a French wordnet.

## 2.1 Word Embeddings

James Somers puts down the modern dictionaries by saying “The definitions are these desiccated little husks of technocratic meaningese, as if a word were no more than its coordinates in semantic space.” [28]. From his perspective as an author, the efficient descriptions of the dictionaries is a bother but we will build the thesis on the idea that we can represent words, senses using their dictionary definitions.

Mikolov *et al.* [29] Word2Vec paper. Xiao & Guo [30] another embedding paper.

Bengio *et al.* [31] root word embedding paper.

Kusner *et al.* [32] is Word Mover’s Distance.

Balikas *et al.* [33] suggested using optimal transport for cross-lingual document retrieval.

Arora *et al.* [34] simple but tough-to-beat baseline for sentence embeddings.

Klementiev *et al.* [35] base paper for cross lingual word embeddings?

Irvine & Callison-Burch [36] used as a guideline on best practices.

Jonker & Volgenant [37] lapjv paper.

# Chapter 3

# Unsupervised Matching

## 3.1 Machine Translation

The first method we have investigated works naively by translating the target language's corpora to English using Google Cloud API. As before, we have created a baseline/golden/basis aligned corpora where English WordNet definitions are aligned to the translated target language definitions. Casting the task to monolingual retrieval, we can establish a baseline using *tf-idf* retrieval. We have chosen *tf-idf* as to ask if the task at hand can be solved by naive tools. In order to get *tf-idf* scores of the documents, first a term-document matrix is created. Documents being definitions and with an average of 10.62 words per definition, the resulting matrix is parse. In a *tf-idf* matrix, for an entry in the matrix $w_{i,j}$, we can give the formula for it as:

$$\textit{tf}_{w,d}\text{-}\textit{idf}_{w} = \sum_{w' \in d} f_{w',d} \cdot \log \frac{N}{df_w}$$

Such that term $w_{i,j}$ depicts the importance of term $t$ with relation to its general importance throughout the corpus. Now we can define the similarity between the documents as the cosine similarity between their *tf-idf* vectors. For the row $w_t$ and $w_p$, cosine similarity between definitions $t, p$ is

$$cos(\theta) =$$

Definitions are then separated into queries and corpora. Query definitions is then matched up against every definition in the corpora and the ten documents that are closest in terms of cosine similarity is retrieved. Within the retrieved documents, if the document with the matched sense id is retrieved in the first result, this is taken as a hit at 1. Mean Reciprocal Rank is also calculated in order to show the success of a retrieval scenario.

Where monolingual retrieval falls short, we leveraged the power of word embeddings to capture the semantic information of the words. A famous example for the inadequacy of *tf-idf* is illustrated by [32]. For two snippets of text; *Obama speaks to the media in Illinois* and *The President greets the press in Chicago* Kusner argues that while they convey the same information, they would be near orthogonal in a bag of words setting. Yet before moving forward with WMD, we wanted to test sentence embeddings.

Edilson A. Corrêa *et al.* [38] used sentence embeddings that were tailored for short text. Their work was on Twitter where the need for word embeddings to capture the essence of the text is crucial given the low amount of data packed in a Twitter document or a tweet. For our purposes, we used sentence embeddings as described in their implementation; Then, with the term-embedding matrix at hand, we have calculated sentence embeddings using;

$$S_{\text{emb}}(S) = \sum_{w_i \in S} \textit{tf}_{w_i,S}\text{-}\textit{idf}_{w_i} \cdot Emb_w(w_i) \tag{3.1}$$

Every word that makes up a definition is scaled by its vector in $\mathbb{R}^n$, then concatenated to form sentence embeddings on $\mathbb{R}^n$.

Given the N vectors from source and target language, we hypothesize that there exists a matching where every source definition vector is perfectly mapped to one target vector. Given that this problem naively iterates over $N!$ matchings, we have looked into an algorithm.

# Chapter 4

# Unsupervised Retrieval

## 4.1 Main Section 1

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# Chapter 5

# Supervised Validation

## 5.1 Main Section 1

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# Chapter 6

# Experiments and Evaluation

## 6.1 Main Section 1

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### 6.1.1 Subsection 1

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# Chapter 7

# Conclusion

## 7.1 Main Section 1

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# Appendix A

# Frequently Asked Questions

## A.1 How do I change the colors of links?

The color of links can be changed to your liking using:

`\hypersetup{urlcolor=red}`, or

`\hypersetup{citecolor=green}`, or

`\hypersetup{allcolor=blue}`.

If you want to completely hide the links, you can use:

`\hypersetup{allcolors=.}`, or even better:

`\hypersetup{hidelinks}`.

If you want to have obvious links in the PDF but not the printed text, use:

`\hypersetup{colorlinks=false}`.

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