Evaluating Utility of Vocabulary to Language Learners

Leonard Paál

Hochschule Karlsruhe

Supervising professor: Jannik Strötgen

Additional supervision by: John Blake (University of Aizu)

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Abstract

[Abstract]

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Chapter 1

Introduction

1.1 Motivation

1.1.1 Role of Vocabulary in Language Acquisition

Learning a second language involves many different skills, often categorized into listening, reading, speaking, and writing. Another categorization may be vocabulary, grammatical skills, the ability to understand known words in various accents, understanding language when spoken at a fast speed. One skill that is required for any of these if the knowledge of vocabulary in the target language. A person with basic grammatical skills but no vocabulary has no ability to express themselves or understand anything which they hear around them. On the other hand, a person familiar with rudimentary vocabulary but no grammatical knowledge may struggle with understanding complex sentences and sound unnatural when speaking, but can at least make sense of short phrases and express themselves. Thus, basic knowledge of vocabulary is clearly one of the most essential skills for using a language. This raises the question of which vocabulary should be learned first when starting out on the journey of language acquisition. This work attempts to contribute to answering this question.
    Note: mention various methods of finding useful vocabulary from viewpoint of learner: textbooks, apps, etc.

1.1.2 Context-specific Language Learning

Learners of languages are typically interested in one or more specific aspects of the language. There is no such thing as an unbiased corpus than can fit every use case. Decisions must be made how much focus is given to everyday conversation, academic writing, writing pertaining to business like job applications etc. Many textbooks group vocabulary by topic, with a new topic being introduced with each lesson that student should ideally be able to converse in after completing the lesson. However, this way of introducing vocabulary has several shortcomings:

- Students spend time learning specific terms about the topic in one lesson while not learning even general vocabulary in other topics until much later.

- Knowing the words from previous lessons becomes a prerequisite for the more advanced material, especially because the terms from earlier lessons are used in example sentences for grammar. Thus, learners interested in learning the use of the language in one context will have a hard time of skipping earlier, less pertinent lessons to them.

Since the advent of computer-aided natural language processing, methods have been suggested to computationally identify useful words: Nation and Waring propose in an 1997 study [10] that the frequency with which a word appears in the target language should be used a metric for its importance to the learner, or utility, and thus teaching high-frequency words should be the focus when teaching beginners. However, focusing on maximum-frequency words to achieve text coverage (e.g., knowledge of 90% of words in a text) may not be as useful as one might at first think, as the most frequent words tend to be generic terms like "but", "from", "time", "world" etc. Knowing only these words is not sufficient for comprehending most texts.

The TF-IDF metric [13] is often employed for finding the keywords in a document and thus a proxy for how important a word is for the overall meaning of the document. It essentially is a frequency normalized against a larger, background corpus and expressed whether the usage frequency in the document is unusual. Using TF-IDF as a measure for utility of a word in a given context is possible, but it suppresses words that may be generally useful.

Thus, there is a need for further exploration as to how word utility can be calculated, using modern NLP methods involving artificial intelligence where necessary. Put more simply, this question may be reduced to:

What order or words, when learned, gives the learner the best set of words to understand and communicate in the language as quickly as possible?

1.1.3 Examples of Contexts and Words

Some examples for contexts that could be interesting to language learners include:

- Reading Wikipedia articles about a specific field (computer science, literature, biographies)

- Watching movies

- Travel to a country where the target language is spoken

- Doing business with a company from a country where the target language is spoken

- Cultural exploration (literature, religion)

- Finding friends from other countries

The different contexts for which learners might be motivated to learn a language differ in how easily corpora can be obtained about to mine patterns from. Movie subtitles and Wikipedia articles are easily obtained from sites such as opensubtitles.org and wikipedia.org. The words that might be relevant for travel are not as easily obtained: One might imagine an ideal scenario to collect data, in which a statistically relevant group of people travelling to the destination to be examined are randomly selected and equipped with microphones and cameras before the travel. During travel, one could record their conversations, conversations with people around them, and materials they attempt to read to navigate their journey such as train schedules, descriptions of tours, restaurant menus, street signs, etc. Lacking the funds to conduct an experiment for every possible language, this paper is interested in finding a methodology to obtain data from readily available corpora and websites online that extracts relevant vocabulary from the source texts. Depending on the context, we can think about which of the following English words might be likely to appear frequently in the texts:

- Convert

- Cash

- Hug

- Dammit

- Y'all

- From

- Nineteen eighty four

- Married

To examine a few examples: Words like "convert" occur frequently when looking at Wikipedia articles [1]. "cash" is likely to be useful for travelers, but in most other contexts, it would not be as relevant. "Y'all" is almost never used in formal writing but used abundantly in everyday speech in the southern United Stated of America and South Africa. "From", meanwhile, will be likely to be one of the most frequently used words regardless of context.

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[1] see "Wikipedia" corpus 2016, drawn from one million lines on https://wortschatz.uni-leipzig.de/en/download/English

1.2 Challenges and Contributions

1.2.1 Challenges/Research Questions

[What is the problem to be solved? - Given a context, find vocabulary maximally useful for understanding texts in it] Criteria for good extraction method:

- Requires little manual effort to generate input data (ideally performable on freely available corpora)

- Requires little computational effort

- Outputs word utilities that align with human intuition

Inherent challenges of text-based language anlysis include:

- ambiguity

- Words having multiple different meanings (polysemy). E.g. *can* can be a verb or a vessel.

1.2.2 Contributions

[Motivation: Useful vocabulary -¿ Need approach to evaluate utility of word] [How this paper address the challenges: Simulate human trying to understand texts with AI] [Distinguish between passive and active utility]

1.3 Outline of Work

Chapter content: explain the logical flow of the thesis chapter to chapter

Chapter 2

Background

This chapter gives context to estimating the utility of vocabulary.

For this, we start by defining the exact aim of the work in chapter 2.1.2. We then go over how this goal links to research about vocabulary acquisition for second language learners in chapter 2.1.

The following three chapters explain the (partially overlapping) fields of Natural Language Processing, Machine Learning, and Explainable AI, tools from all of which will be employed in our approach laid out in chapter 3.

Finally, we examine current approaches for selecting vocabulary for language learners in chapter 2.5, to show what methods are currently employed and how they could be improved.

2.1 Context of the Work

Chapter content: language learning in general, cite reference works and textbooks. Maybe mention context-specific learning resources too, such as academic English

2.1.1 Linguistic motivation

The issue of which words to learn when setting out to acquire a language is not a new one. Every textbook on language which is not completely grammatical must ask address the issue, and proactive learners will doubtless find themselves finding ways to optimize the return on their invested studying time.

The Routledge Handbook of Second Language Acquisition [Insert citation: "The Routledge Handbook of Second Language Acquisition"] gives three criteria for deciding the order in which words are taught to beginners:

1. Frequency

2. Usefulness

3. Easiness

The first criterion, frequency, is easy to justify: Learning words that appear with great frequency will allow the learner to understand the maximum percentage of wrods in texts, and should thus be among the most relevant. The *easiness*, or *learnabiility* of a word is defined as how easy it is for a learner to acquire the word. The author define it with respect to a given learner. Factors influencing the learnability of a word are word length, and whether the learners already knows a cognate of the word: We can imagine a native German speaker attempting to learn English: The word "internationalization" may not be a particularly frequent word in most contexts, but the German will likely recognize the word as a cognate of the German equivalent "Internationalisierung", and acquire the word with ease.

Finally, there is the criterion of *usefulness*. While it is distinguished from frequency, it is not defined what constitutes usefulness.

[Insert citation: " Choosing Words to Teach: A Novel Method for Vocabulary Selection and Its Practical Application "] against picks up the above three criteria in order to group words into clusters which can be used to determine priority in vocabulary learning.

However, again it is not defined what constitutes usefulness suggests no way to measure it beyond "human intuition". In fact, it is put in contrast with frequency, which may be derived from corpus data, whereas usefulness cannot.

The following chapter will attempt to define utility and related concepts more carefully, in order to state the aim of this work more formally.

2.1.2 Statement of Goal

Chapter content: Statement of goal, definition of "utility", context

Generally speaking, this work addresses the problem of evaluating how useful a vocabulary word is to learn in the target language of a language learner. This helps us in generating ordered lists of vocabulary to learn which aid the learner in gaining competency in their target language quickly. Since different language learners learn languages for different reasons, we take into account the learner's motivation to tailor vocabulary specifically to the individual.

To make this goal more specific, we define several concepts that help us speak more precisely about this goal and how it may be accomplished. These concepts are used to throughout this work.

(Language) Context

By a *language context* or just *context*, a subset of situations is meant in which a person interacts with language. Examples of language contexts by topic are: News, football, crocheting.

Examples of language contexts by situation are: Everyday conversation, scientific articles, watching movies.

Contexts can be further subdivided into smaller contexts, or grouped across different lines: "News" could be subdivided into "international politics", "sports", "business", etc.

The concept of a language context is useful to a language learner since it enables them to prioritize learning vocabulary and grammar associated with the context they are interested in: Someone who is learning Arabic to better understand middle-eastern politics will have little use for words which are mostly associated with football.

The context could even determine the complexity of sentences that a learner must be able to understand: Some contexts, like everyday conversation, can be navigated fairly well with short sentences, but political speeches often feature long and structurally complex sentences, with various relative clauses, multiple negations, etc. Thus, learning for one or multiple specific contexts gives the learner a more concrete goal and thus better idea of what they must learn to achieve it.

In contemporary methods and tools for language learning, usually little emphasis is placed on learning for a specific context, or else few contexts are available [Insert citation about: investigage current popular language tools. Classroom cannot cater to individual preferences and apps only allow some personalization].

Utility

In this work, *utility* is defined as the increase of language ability in a given context that a person gains by knowing a word versus not knowing it at all. This means being able to understand more of texts they read in the given context, being able to speak about the subject, etc. It is easy to see that some words will be more useful than others given a context: In the context of international news, learning the word "war" will bring more understanding to the learner than "pear" or "polymorphism".

Proxy Task

Some of the concepts in the realm of language learning cannot be measured directly: This can be because they are psychological in nature ("understanding") or because they are too complex to be objectively measured by numbers ("language ability").

The above section defines word utility as an increase in "language ability", but to analyze this ability with computers, we must make be able to put a number on it, even though we lack both an agreed upon scale or unit of measurement.

To circumvent this issue, so-called *proxy tasks* will be used: Proxy tasks are tasks that test subjects can perform, where the test result (the *proxy measure*) can be used to capture the abstract quantity under study. For example, as a proxy measure for a person's general spelling ability, we could make them choose from multiple spelling variants of a word, and use the accuracy with which they select the correct answers.

This work employs AI models solving NLP tasks as an economic and repeatable substitute for real humans interacting with language, and uses the NLP tasks as proxy tasks to make "language understanding", and thus "utility", measurable concepts that can be computationally maximized.

2.1.3 Summary

With the concepts above defined more precisely, let us state the goal more accurately:

Finding words that have the maximum *utility* given a particular *language context* by means of *proxy tasks*.

With the words filled in, this translates to: Finding words that provide a learner with the most understanding in the learning context they are interested in in the minimum amount of words to learn. Since the understanding of the learner cannot be directly measured, we use tasks that check the learner's understanding as an imperfect but necessary approximation.

The following chapters will go over the fields addressed in achieving this aim, and highlight relevant aspects from them that contribute in later chapters to conceptualizing and implementing a solution.

2.2 Natural Language Processing

Chapter content: [basic concepts, and why they matter to this work. Anything that that the target audience is either not familiar with, or where the function in my method is not obvious]

2.2.1 NLP Task

Humans are generally intelligent and are not trained from childhood on any specific language task exclusively. In contrast, AI models are trained to perform one or several specific tasks. A *NLP task* is a function with a specific input and output format, where at least one of the two formats takes the form of natural language. Typical NLP tasks include:

- Sentiment detection: Given a text, estimate the emotional state of the author.

- Masked Language modeling: Given a text with a word blanked out, estimate what the word should be.

- Machine translation: Given a text, translate the meaning into another language while preserving meaning as faithfully as possible.

In this work, NLP tasks serve as a way for AI models to interaction with language, enabling us to analyze the interaction.

2.2.2 Corpus

A *corpus* is simply a dataset consisting of text data. Recently, many large corpora have been compiled and are freely available to the public. Corpora differ from each other mostly in their source and method of compilation. Depending on their source, some corpora may serve as examples of language being used in a language context, such as news or movie subtitles. In the implementation and evaluation of this work's approach to word utility estimation, several such context-specific corpora will be used.

2.2.3 Tokenizer

Language presents itself in continuous form in most situations: When listening to spoken language, it is not obvious where one word ends and another begins. Likewise, written texts we find online or in books are not necessarily subdivided into its semantic constituents. While words in the written English language are mostly separated by spaces, a writer may choose to create a new hyphenated word sequence on the spot as necessity demands.

Further complicating the issue of where to separate words is the fact that many non-European language do not use spaces in their spelling (e.g. Japanese, Mandarin Chinese) or use spaces for a different purpose (separating syllables in Vietnamese, separating sentences in Thai). For this reason, *tokenizers* are used in Natural

Language Processing to divide continuous texts into their words. [Insert citation: "Daniel Jurafsky & James H. Martin: Speech and Language Processing"] Note: Explain various types of tokenization?

Splitting continuous text into distinct words has several benefits:

- we can make statistics from them (e.g., counting which words occur many times).

- we can assign values to them, such as estimated utility.

- we can mask them in text inputs to AI models to test what effect masking a particular word has on the output.

2.3 Machine Learning

2.3.1 AI Model

While it is assumed the reader is familiar with the concept of AI models, in this work they serve a purpose that might not be obvious: The (pre-trained) AI model is thought of as a test subject in possession of linguistic skills that can be studied. The point is to analyze its skills and make them serviceable to a language learner, similar to how humans can observe experts in their domain and learn from their behavior.

2.3.2 Transformer Attention Mechanism

Many of the recent state-of-the-art AI models performing NLP tasks are built with the *transformer* architecture. [Insert citation: "Attention is all you need"] This is a particular type of deep neural network characterized by an attention layer before the deep neural layers. Said attention layer makes the model "focus" on important parts of the important, while "ignoring" less important ones. This helps the model find patterns in noisy input. [Insert citation: "Attention is all you need"] Attention has been used as one way to make decisions of AI models interpretable [Insert citation: "Understanding Neural Networks through Representation Erasure"] [Insert citation: "Interpretable Neural Models for Natural Language Processing"]. Thus, we will use it as one among several approaches to extract functional knowledge from NLP AI models.

2.4 Explainable AI

Deep neural networks (the recent standard for AI models) stop being readily understandable to humans rather quickly once the number of neurons and layers is increased. Explainable AI is the field of research focused on making the decision-making progress of AI models more transparent and understandable to humans, to enable us to reason about the AI model's decisions. [Insert citation: "Notions of explainability and evaluation approaches for explainable artificial intelligence, Interpretable machine learning: A guide for making black box models explainable"] This can be useful to check, if the decision process contains social biases, or if it is based on wrong patterns learned from skewed training and test data (overfitting). By analyzing the decision process of high-performing AI models, we hope to extract useful information about how the language is processed which can be useful to humans as well.

2.5 State of the Art (of Vocabulary Selection)

2.5.1 Non-computational Methods

How is vocabulary order selected by current language teaching tools: Not context-specific in most cases offers only one order, investigate if there are any automatic approaches besides frequency]

[can present methods for extracting useful words from text] can be similar in either method or goal. goal is finding useful words for language learning method is extracting important words from text via XAI

[6] cites concepts of frequency, usefulness and difficulty of words as widely accepted criteria to decide when to teach it. However, the literature is not clear on how usefulness is defined outside of "human intuition" [6]. Furthermore, usefulness is presented as independent from frequency, making it more unclear still how it may be defined. The advantage of human intuition is that humans can understand the nuances of texts better than computers, especially before the invention of large AI models tackling NLP tasks. Relying on human intuition to evaluate word utility has two main drawbacks compared to computational methods:

- Difficult to put a concrete number on word.

- Evaluating many languages would necessitate human experts for each language, necessitating expensive studies.

2.5.2 Computational Methods

These methods generate vocabulary lists by using corpora and computer-aided language processing to compile vocabulary lists. They are closer related to the methods that this work strives for, and will be used as points of comparison when evaluating our own approaches.

Raw frequency of words in corpus A simple ordering of words by how often they appear in a corpus.

Frequency with stopwords filtered out The same as frequency, but filtering out known stopwords from the resulting lists.

TF-IDF How often the words appear in a target document but divided by their frequency in a more generic corpus. This metric is typically used to employ the most relevant words in documents for identifying keywords that express best its core topic.

2.5.3 Issues with Current Methods

Current methods do not exploit recent developments in AI technology and thus suffer from several shortcomings: In general, all of them essentially only count words without taking into account their relationship between each other:

Frequency: The most frequent words in texts are often words that carry little meaning by themselves, such as "a", "the", "of" in English. While these may appear in many texts, they are not useful in determining their meaning. TF-IDF: This

metric has been used successfully to find the words that give the best hints at a text's topic. However, it does not take into account and semantic relationships between the words in a text. Thus, learning words by aggregating TF-IDFs on multiple texts may aid in identifying the topic of texts, but not at finding out what the message conveyed about the topic is. "not" is a highly frequent word in English and thus will have a low TF-IDF score in most documents. But it is essential to know, as it can completely invert the meaning of a sentence.

Chapter 3

Approach

This chapter describes in detail our approach for word utility evaluation to fulfill the goal stated in chapter 2.1.2.

The problem is first put into terms of mathematical objects in chapter 3.1. We then describe a hypothetical experiment that could be performed to evaluate word utility using human feedback in chapter 3.2 After pointing out the unfeasibility of such a testing method, we suggest ways to perform the experiment with AI models instead of humans as the test subject in chapter 3.3, using the technological building blocks referred to previously in chapter 2.

With a method for utility evaluation established, we then point out why it is in itself not yet sufficient for actually generating useful lists of vocabulary that a human learner could utilize in chapter 3.4. To solve this final problem, 3.5 puts forward a general approach for list generation.

3.1 Problem Statement for Word Utility Evaluation

To repeat the introductory sentence of chapter 2.1.2: The aim of this work is to find words that have the maximum *utility* given a particular *language context* by means of *proxy tasks*. Keeping in mind that this is done in order to sort words into vocabulary lists that can be used by language learners, we can conclude that the output of a proposed solution to this problem would be an **ordered list of words**. The following formula gives a more precise idea of the aim and the variables involved.

Since utility is defined in terms of language ability, we first need a way to put a number on the language ability of a test subject. This is done by means of a proxy task: We can imagine a human test subject taking a language exam as a proxy task to find out their language ability:

$$t : \text{Human} \to [0, 1]$$
$$t(s) \mapsto p$$

where s is the test subject and t is the proxy task, with a possible score p between zero and one.

We can imagine many variables going into this function, such as the time when the test is taken (hopefully the human's performance would increase over time). However, this thesis addresses vocabulary learning, and so the vocabulary of the test subject is provided as an additional parameter into the function

Let W be the set of all words in the language.

$$t : \text{Human}, 2^W \to \mathbb{R}$$
$$t(s, V) \mapsto p$$

where $V \in W$ is the vocabulary of the test subject.

We now have a function from the vocabulary to the score in the proxy task (the proxy metric for language ability). Using the proxy task function, we can define a measure of efficiency of an ordered list of vocabulary l containing elements from W. The efficiency reflects how quickly a learner improves their language ability if they learn words in the order of the list, measured as a proportion p_{aim} of the maximum achievable performance $p_{max} = t(s, W)$ (knowing all words in the language). It is the number of words which must be learned from the vocabulary list to bring the performance above the threshold:

Let

$$l := (w_1, w_2, \ldots, w_n) \quad \text{where } w_i \in W \text{ and } w_i \neq w_j \text{ for } i \neq j.$$
$$V_{l,k} := \{w_i \mid i \leq k\}$$
$$p_{aim} \in [0, 1]$$

Then

$$e_t(s, l, p_{aim}) \mapsto (-1) \cdot \min\{k \mid t(s, V_{l,k}) \geq p_{aim} \cdot t(s, W)\}$$

The term contains a multiplication with -1 such that an efficient list achieves a higher efficiency.

And with this definition of efficiency, we can define the condition for an optimal vocabulary list given a particular p_{aim}:

$$l_{opt,t}(s, p_{aim}) = \arg\max_{l} e(s, l, p_{aim}) \tag{3.1}$$

Finding vocabulary lists that approximate an optimal list according to formula 3.1 is the aim which the rest of this work is dedicated to.

3.2 Experimental Setup: Measuring Word Utility as Ability Improvement in Humans

Chapter content: state utility in terms of language ability improvement aim is not just to evaluate, but also efficiently find lists of vocab give problems that is faced when trying to test this approach with human test subjects: no repeatability, high costs

With the formula 3.1, we now have set our goal more concretely. We are left with the question of how to actually make candidate vocabulary lists, and test them for efficiency. Let us first consider how we could measure the efficiency of one vocabulary list of 3000 words:

We would need to find a human test subject who does not know any words of the target language at the outset. We would then make the subject learn the words from the list one by one, and test their language ability in regular intervals to see if their desired threshold has been reached. This disregards the fact that knowing all words in the language would not necessarily mean the performance would reach 1, but assuming a normal school test that is not an issue.

While this test setup might take a long time to complete depending on the desired threshold, it is still feasible. But if we wish to analyze the same subject's performance learning from a second vocabulary list to compare the lists' efficiencies, there is an unavoidable issue: The test subject cannot completely forget the words they have learned in the first run. The experiment is thus not repeatable. If we increase the number of test subjects so each vocabulary list is learned by a new subject, we introduce differences in capabilities between test subjects and the cost of the experiment also quickly increases.

However, this theoretical test setup could be feasible using a non-human test subject: Using AI models and Explainable AI to analyze their interaction with language, we could not only evaluate, but even compile lists with drastically reduced costs. This approach is laid out in the following chapters.

3.3 AI-Simulated Learner

Chapter content: I view AI models as containers of language knowledge. We can perform studies on it as though it were human, gaining knowledge "from the viewpoint of an entity interacting with language"

This work is interested in finding vocabulary lists that language learners can use to gain linguistic competence in their chosen field in the least possible time. Chapter 3.1 has specified how with the help of a proxy task, we can define this efficiency. Chapter 3.2 has laid out a theoretical approach for how with human test subject, one could test the efficiency of a vocabulary list. However, we have established that the experiment is not easy to set up consistently, as it cannot be repeated with the same test subject on different lists and a large pool of test subjects lowers the comparability of the scores.

To circumvent this issue, this work proposes the following core idea: By replacing the human test subject with an AI model, it could be possible to execute the experiment described in chapter 3.2 consistently and economically:

In recent years AI models such as ChatGPT [Insert citation: "ChatGPT"], Gemini, DeepSeek, BERT have become highly adept at fulfilling language-related tasks such as Language Modeling [Insert citation: "LLMs"], Named Entity Recognition, Sentiment Detection.

It may be said that they possess an understanding of language in a behaviorist sense.

These AI models are trained on one or more specific NLP tasks. If we run the model on a specific corpus and mask some of the words in the input, it is expected that the performance will decrease in comparison to the full input. However, presumable some words will have a larger impact on the performance than others. So to test the efficiency of a vocabulary list, we could let the AI model perform its NLP task on the corpus. At the start, we mask all of the tokens in the input to simulate a language learner who is a complete beginner and thus knows no words in their target language. We can then progressively unmask words in the input, and each time run the AI on the corpus to check the updated (and presumably improved) performance. This will yield a plot of performance over unmasked words which will tell us how quickly the performance improves with unmasked words. A plot with low initial performance increase will betray an inefficient vocabulary list, whereas a quickly increasing performance should correspond to an efficient vocabulary list.

This is a cheap option when compared to using a human test subject and unlike the human, the AI model has no memory of previous tests, meaning we can run the experiment consistently every time.

The experiment described above necessarily requires data to be performed, in the form of a corpus. We can suppose that both the corpus and the NLP task performed by the model will influence how quickly the AI model's performance increases with a given vocabulary list:

For example, to perform Sentiment Detection, words relating to emotion such as "hate", "like", "amazing" will matter more than if the task is related to Information Extraction, such as Temporal Tagging.

The corpus will have a more obvious influence on the performance, since corpora

differ in many aspects such as formality, topic, and format of the text, all of which may be closely influenced by the learning reason of a language learner. Thus, by choosing an appropriate corpus, we can test performance on language that is similar to the language in which a learner wishes to improve their understanding.

Thus, with this model in mind, we can translate some of the concepts introduced in chapters 2.1.2 into technical components to see how we could implement a technical solution to the problem of analyzing the utility of words. Table 3.1 shows the correspondences between the concept and the technical component.

Abstract concept	Implementation
Test subject	AI model
Language ability	Performance in NLP task
Language context	Corpus
Analysis of language interaction	XAI method
Word utility	Impact of word on task performance

Table 3.1: Correspondence of abstract concepts to parts of implementation.

3.4 Evaluating vs. Making Lists of Useful Vocabulary

The previous chapter describes an approach for evaluating the efficiency of vocabulary lists for learning in a specific context. While it can be seen as an improvement on the human setup because of its improved consistency and economy, it describes only the process of evaluation, not generation. Actually finding optimal vocabulary lists is theoretically possible by testing every possible vocabulary list with all words in the language.

In practice, however, this would require an enormous amount of computational resources:

If we wish to find the most efficient list of 1,000 words, and we take the most frequent 20,000 words in the language as candidates for members of this list, there is a total number of $P(20000, 1000) = \frac{20000!}{19000!}$ possible vocabulary lists to be tested. Since every one of these test consists of running the proxy task with a vocabulary which is a subset taken from the first n elements where $n \in [0, 1]$, and all of the subsets will appear in the runs of many vocabulary lists, we can optimize this by running the task with every vocabulary with a cardinality between 0 and 1,000, which would be $\sum_{k=0}^{1000} \binom{20000}{k} \approx \frac{1}{2} \times 2^{20000} = 2^{19999}$ runs of the proxy task. . This is still an unfeasible amount of computation.

It is therefore clear that finding optimal vocabulary list is much too expensive to be done without approximation. As approximations, we suggest XAI to extract information about the linguistic skills of AI models, and the following chapters illustrate this approach.

3.5   Utility extraction with Explainable AI

Chapter content: Advances in XAI, explain various approaches.

The previous chapters have shown the challenges in evaluating the efficiency of vocabulary lists with human test subjects, and suggested a way to use AI models in connection with NLP tasks as a way to make a consistent and repeatable approach. The problem of generating the lists in the first place still remains, however.

The guiding question of this thesis is: *"Which words provide the most language understanding in a particular context?"*. Simulating the learner with AI models in the way described in chapter 3.3 turns this question into: *"Which words improve the performance of the AI model in the NLP task for a given corpus?"*.

This question is very close to the questions that the field of Explainable AI seeks to answer. A typical question of Explainable AI would be: *"Why for a given input, did the model arrive at its output?"*. If the input takes the form of natural language, we can be more specific: *"Which words in the input made the model arrive at its output?"*

By using XAI and answering this questions across the entire corpus, we can find out which words are the most essential for the AI model to perform its task in the corpus. If the words found in this way are close to those that would provide the most utility to a human learner as well, they could be used to create very efficient vocabulary lists as well.

We therefore propose a framework to extract useful words which has the following main components:

- Corpus

- (Pretrained) AI model

- NLP task

- XAI method

Note: Insert diagram of components interactions with each other

In the next chapter, we will tackle the implementation of this approach. We will present various choices for these components, and argue for some to be used over others, with the aim of making the utility estimated by the framework align as much as possible with utility to human learners.

3.6 TO BE SORTED OR DELETED

Let us examine examples of how utility may be defined: In the question "Would you like some coffee?", the most important part is "coffee". If we replaced the entire sentence with "coffee?", the meaning becomes less clear, but it is still possible to guess what is meant. If, however, we replace the sentence with "would?", there is so little information in the sentence that it becomes impossible to guess the meaning. To identify which words are important to understand the question, we could ask a human to point them out. However, this is not very quantifiable and the answer is likely to be influenced by bias. We could try removing some of the words in the sentence and see if a human hearing the question can still answer appropriately. While this removes some of the bias, there are still issues with this approach: Going through all possible permutations of the sentence would take a great amount of time to perform, and the same test subject cannot process one permutation without being influenced by the past experiences: If we go through "would?", "you?", "like?", "some?", "coffee?" in sequence, the test subject would have full knowledge of the sentence by the time the last item is asked. These problems can be alleviated by using AI models: They are cheaper to perform tests on than humans, and can be employed in such a way as to answer the question without being influenced by the previous questions each time.

Note: Explain approach where a model is trained on small set of words and performance is evaluated. But too costly.

While the models achieving state-of-the-art performance (neural networks) are black boxes for the most part, they are easier to understand than human decisions and the field of Explainable AI has produced various approaches to gauge the importance of inputs to the model. Explainable AI has the explanation of the decisions of AI models as its aim. This means that when analyzing the decisions of AI models by reducing them to human-understandable rules or by observing which words are the most important for the AI to fulfill its tasks, we are not technically observing rules of objective truth, but only the behavior which the AI has learned to perform its task. If we try to extract truthful knowledge about language from the AI, we are relying on the assumption that the AI has learned rules that correspond to linguistic reality. However, in the case of state-of-the-art models, we know the performance of such models to meet certain standards, which supports the above assumption.

Chapter 4

Implementation

Chapter 3 has formalized the problem and put forward out an approach for evaluating how efficiently a vocabulary list may help a human language learner acquire competency, by using the performance of AI models in an NLP task on a corpus as a proxy metric for language ability. An general approach has also been proposed in chapter 3.5 for actually compiling vocabulary lists that approach maximal efficiency.

In this chapter, we will describe possible implementations of this approach, first setting criteria for the selection of its components and then suggestion concrete options.

4.1 Data Pipeline

4.2 NLP Tasks

The choice of NLP tasks employed to test a XAI-based approach for word utility estimation is a crucial step: Since we are trying to estimate the utility a word a word has to language understanding, the NLP tasks should reflect language understanding as much as possible. A good place to start looking for such tasks are those which are typically employed for pre-training NLP models: Pre-training tasks are used to first endow the AI model with a general understanding of the language, before using transfer learning to specialize it for a more specific downstream task. Such tasks must necessarily be general and require general language understanding, since training the model with them is supposed to provide a solid basis for a wide variety of NLP tasks. Another benefit of using pre-training tasks is that their training is unsupervised, meaning there is no need to manually label data. Note: Look at various pre-training tasks, preferably those used by state-of-the-art AI models Note: include free availability for AI models in their justification

4.2.1 NLP Pre-Training Tasks Used by State-of-the-Art AI Models

This section takes a look at the pretraining process of recent state-of-the-art LLM models which have made public their training process. Both the NLP tasks and the kind of data is considered.

GPT-4 [11]

Task: Language modeling (see next section).

Data: Not disclosed in detail, according to the original paper, the model was trained "using both publicly available data (such as internet data) and data licensed from third-party providers".

GPT-3 [3] GPT-3 is a model that does not rely on transfer learning to apply its linguistic understanding to new tasks; instead, it uses zero-shot and few-shot learning to perform tasks it was not specifically trained for.

Task: Language modeling (same as GPT-2 [14])

Data: Common Crawl, WebText2, Books1, Books2, Wikipedia Note: link sources?

LLama 3.3 [1]

Task: Meta did not make public the training process for Llama 3.3.

Data: "data from publicly available sources"

4.2.2 Tasks Considered

Next Sentence Prediction In this task, the AI model takes as input two sentences and predicts a probability for the second sentence being the successor of the first sentence in their source text. Advantages for this task for our purposes is that such a dataset is easy to generate, as it merely requires a corpus of sentences that follow from each other, which is easily obtained from Wikipedia articles, film subtitles, or any other continuous text.

Text summarization This task involves summarizing a given text, in other words, writing a shorter version of the input text while still conveying as much of the information from the original text as possible. Summarizing texts seems to require a high level of "understanding" of the text and would thus seem to be good choice for testing whether ablating certain words from the text would have detrimental effect on the model performance. Unfortunately, this task requires hand-labeled datasets and is thus not a good candidate if we aim to find approaches which can be implemented in many different languages, as there is a dearth in data in many of the less-studied languages of the world.

Masked language modeling (aka. "cloze task")

Causal language modeling (aka. Next token prediction)

Sentence order prediction

Sentence embeddings Sentence embeddings take the approach of transforming words into meaningful vectors and extend it to whole sentences. This "task" differs from the others in that we do not measure differences in performance when the input is perturbed; but rather a distance between the embedding vectors themselves. This justification for such an approach is that sentences whose meaning is very different should end up further apart from each other in the vector space once embedded. This brings several advantages: This approach can be performed on any corpus containing distinct sentences. These corpus does not have to be document-level, and sentences need not be consecutive. To make this a task on which XAI methods can be applied, we can define a distance from the original token

4.2.3 Sentence Embedding Methods

LASER [2]

BERT [15]

4.2.4 Data Required for Each NLP Task

The various NLP tasks employed require certain types of corpora to be employed properly:

xt sentence prediction Requires a corpus that contains consecutive sentences. Furthermore, NSP typically predicts whether two sentences follow each other in a document, not a dialogue (see the data on BERT training [8]). This excludes movie subtitles from the possible corpora for this task.

4.3 XAI Methods

The XAI methods used in this work are the following:

- Attention as Explanation Advantages: Model only needs to be run once per sentence. Longer sentences do not lead to a much longer calculations Disadvantages: Justification as explanation controversial.

- Single Token Ablation

The following lays out how each of these methods works to achieve the goal of word utility estimation.

Performance difference of AI for NLP tasks Here, a Large Language Model (LLM) or a more specific language processing model is made to run NLP tasks such as text summarization, sentiment detection or question-answering. To find out which words help the AI model the most in performing its tasks, words are methodically omitted from texts and the AI's performance is recorded. This metric attempts to approximate utility by finding words which, when missing, cause the greatest performance loss in the NLP tasks. Evaluation metrics like Shapley values [18] may be used to measure the impact of missing words

Transformer attention The transformer architecture is based on a mechanism called *self-attention*. It allocates the neural network's processing to important parts of the input and thus provides some degree of explainability "out of the box".

Difference in internal vector representation for AI reading text This approach words similarly to the above involving an AI model, but instead of measuring the changes in the quality of its output, it measures how much changing the input to the model changes its the internal vector state: AI stores data in vector format, and when performing NLP tasks on texts, there is an internal vector representation. By using various distance metrics, it may be possible to find out which words have the greatest impact on the model's understanding of a text. Most of these approaches can be done both for individual words and word sequences (n-grams). While individual words are the easiest to examine, sometimes n-grams are insightful for finding sequences of words whose meaning is more than the sum of their parts (idioms and collocations) and which therefore must be learned in separately from their constituents (meaningful English n-grams include e.g. "kick the bucket", "such that", "such as").

This also raises the question of what is considered a "word". A phrase like "such as" can be considered two words if the definition of a word is simply "something separated by a space" or one word if the definition is "a phrase whose meaning cannot be arrived at trivially from knowing the definition of its parts". In Natural Language Processing, tokenizers break down texts into words, but they typically use the first definition for a word in the case of English. Many non-European language do not use spaces in their spelling (e.g. Japanese, Mandarin Chinese) or use spaces to separate a different unit of text (syllables in Vietnamese, sentences in Thai), making this definition of a word unpractical. In most languages, words can appear in various different

forms: Verbs in Spanish are conjugated according to the time and originator of an action, Nouns in German are declined depending on their number and grammatical case. This adds another variable for compiling word lists: Whether the list should consider any different combination of letters as a different word, or whether different forms of the same headword should be viewed as only one word.

4.4 Interdependencies Between Components Used

While the components described above can mostly be used in any combination, there are some important restrictions to keep in mind:

Attention as XAI can only be used on transformers

Tokenization (and thus selection of word candidates) is only independent on model use
  As a direct consequence of this, other XAI mechanisms like attention as explanation are only useful for our purposes if the AI model uses a tokenization approach that somewhat corresponds to human notions of words. If a model uses tokenization approaches where a token is a combination of any three letters, any list obtained that tries to order the tokens by utility, while meaningful, will not be useful for human vocabulary learning. Note that in such cases, we can postprocess the data obtained, by merging the tokens to human-readable words and taking the average or maximum attention score of the AI model's tokens.

4.5 AI Models

- NSP-model ABC

- LLAMA?

Note: tests of performance tests of models used with corpora used (e.g., if NSP prediction model is reliable)

4.6 Tokenizers

[explanation of why tokenizers are important, explain various possible definitions of "word"] [explain why morphosyntactically rich languages necessitate word splitting to some extend]

In some XAI models, we are free to choose any tokenizer we like. We can choose, for instance, to only use full words, or word parts in English. In input perturbation XAI approaches, we can choose to mask any part of the input with the help of tokenizers. For decomposition approaches, the model is not looked at as a black box but instead examined using model-specific methods such as attention or Layer-based Relevance Propagation. In such approaches, only the calculations made by the model itself are available for analysis, which means we are not free to choose our own word-splitting approach independent from the model. This is because these models are trained using a specific tokenizer in the preprocessing, and changing the preprocessing makes the model function incorrectly.

4.7 Input Data

4.7.1 Selection Criteria

For the purposes of this paper, it was desirable that the corpora used be:

- representative of what language learners strive for

- available in many languages

- for background corpora: Document-level

- freely accessible

4.7.2 Corpora Used

OpenSubtitles Parallel Corpus This set of corpora contains parallel corpora: Corpora which has text segments in one language aligned with the presumed translation of the segment in a second language. Its sentences are generated from subtitles from the popular subtitle sharing platform *OpenSubtitles* (https://www.opensubtitles.org/) and undergo various preprocessing and filtering steps as described in [9]. These include:

1. Enforcing universal UTF-8 character encoding.

2. Splitting and joining of sentences from their original subtitles blocks (the segments which appear on screen when watching the movie with its subtitle). One such block may contain multiple sentences, or only a partial one. There is thus a n-to-m-relationship between the blocks and sentences.

3. Checking and correcting possible spelling issues, especially ones arising from OCR (Optical character recognition) errors.

4. From available subtitles, identifying the subtitle pair which is most likely to be accurate in its alignments and free from errors such spelling, taking into account metadata such as user ratings of subtitles.

One advantageous aspect of this corpus is that is contains many sentences that are sequential, which means we can generate a Next Sentence Prediction dataset from it (add hedging here since not all lines in corpus are sequential and even within the same movies there may will be pauses in the subs). This corpus has been used to train machine translation models such as OPUS-MT [17], a freely available set of transformer models for translation, including between low-resource languages. Note: Not completely correct, the pipeline uses data from OPUS, not necessarily or specifically from OpenSubs While it is possible to reconstruct which movies the subtitle lines came from from information contained in the corpus, it is unfortunately not clear how these movies were selected in the first place.

Leipzig Wortschatz Corpora Available in x languages

But: data quality issues, methodology might be outdated

[5]

CCMatrix / NLLB

The full process, as illustrated by the authors, can be seen in figure 4.1 As of 2025, the latest version of the corpus (v2018) contains aligned subtitles of 62 languages between each other.
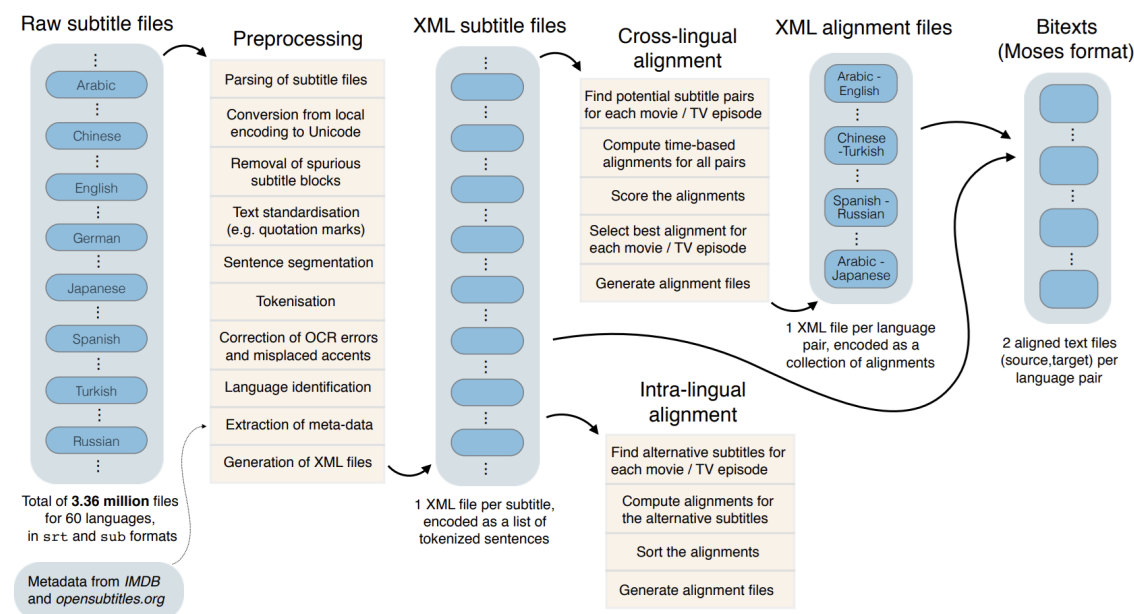

Figure 4.1: The pipeline producing the OpenSubtitles parallel corpus

4.7.3 Data Augmentation

Data Augmentation was not used to gain additional data. While in recent years data augmentation methods have become popular for training AI models in NLP, most of these would have either no or a detrimental effect on the methods employed in this paper: Some of these methods include [12]:

Character level Introducing character swaps to data is a method used to train the model to noise in the data, but in our case, would only add noise to the results.

Word level There exist techniques to switch words for synonyms or swap words in the sentences to create noise. As with noise on the word level, adding words in inappropriate places is undesired for our use case. Swapping words for synonyms would also prove detrimental, as this would skew the statistics away from the natural word distribution found in the human-generated source texts.

Higher level techniques suffer from the same issues. For this reason, the data is left in its "natural state" for our purposes.

Chapter 5

Evaluation

5.1 Evaluation Measures

The various utility extraction approaches produce ranked lists as outputs. To compare these, we employ both quantitative and qualitative comparison approaches, described in the following chapters.

5.1.1 List Similarities

In order to compare the results provided by the various approaches, metrics are needed that can be consistently calculated across the different approaches. While a human may be able to qualitatively analyze lists and gain a rough idea of their similarity, computed metrics provide an instantaneous (if simplified) outlook on similarities. A metric shall be defined as a function which takes as parameters two word lists of equal length which are word lists ordered descendingly by supposed relevance, and outputs a real number giving either a distance or similarity between the lists.

Considerations of the choice of metric are:

Handling of lists with partial overlap. Metrics must be able to handle elements which occur in only one of the two lists. Thus, a metric which solely compares ranks of elements is not viable.

Start of lists is more impactful than end. Since the beginning of lists contains the words which are ranked as most important, changes at the top should impact the metric more than changes at the bottom. This includes (1) Equal differences in rank should be counted as more important if they occur further up the list. A word that is rank 1 in list A but rank 101 in list B says more about the similarity than if a word is rank 2000 in list A but rank 2100 in list B. Likewise, if a word is absent from list B, it implies a greater difference if that word is at rank 1 in list A than if it were at rank 1000.

Metrics Used

Sequential rank agreement (modified) [4]: This metric is based on the deviations of some subset of the lists in the upper ranks. It is important to note that this metric has an additional parameter "depth" which determines how many elements (from the top of the list) are considered. It is therefore more helpful to view its results at various depths. The original formula for this metric in the case of two lists is:

$$a_d := a \text{ from start to rank } d$$

$$S_d := a_d \cup b_d$$

$$SRA_d(a, b) := \lambda \cdot \frac{\sum_{x \in S_d} \sigma^2 \left((r_b(x)) - (r_a(x)) \right)}{|S_d|}$$

where λ is a normalization factor ensuring that $\max(SRA) = 1$. In its proposed form, this metric can only compare lists which contain the same set of unique

elements, just in different orders. In order to make it work on lists where this is not the case, one can set the "rank" of nonexisting elements to a value greater than the length of the lists, such as $2|a|$. Another drawback of the metric is that the standard deviation of two numbers does not depend on their absolute value, only their difference. However, to satisfy number 3 of the stated requirements, we can take the deviation of the logarithm of the ranks instead of the deviation of the ranks themselves, resulting in the formula

$$r'(x) := \begin{cases} \text{rank}_b(x) & \text{if } x \in b, \\ 2 \cdot |a| & \text{otherwise.} \end{cases}$$

$$SRA_d^{mod}(a,b) := \lambda \cdot \frac{\sum_{x \in S_d} \sigma^2 \left(\log(r'_b(x)) - \log(r'_a(x)) \right)}{|S_d|}$$

For this modified version, λ can be calculated with:

$$\lambda = \frac{1}{SRA_d(a, a^*)},$$

where a^* is a list such that $a \cap a^* = \emptyset$.

Discounted Cumulative Gain : This formula outputs a value between 0 and 1, with 1 being given if both lists are identical, 0 when they have no elements in common, and values in between when there is partial overlap between elements and/or their order is different. $DCG_p = \sum_{i=1}^{p} \frac{rel_i}{\log_2(i+1)} = rel_1 + \sum_{i=2}^{p} \frac{rel_i}{\log_2(i+1)}$

$$rel_i := \begin{cases} \frac{1}{rank_b(el_i)+1} & \text{if } el_i \in b \\ 0 & \text{otherwise} \end{cases}$$

Metrics Rejected

Kendall rank correlation [7]: This metric is bounded between 0 and 1 and compares the ranks of the elements of two lists. However, it cannot handle elements that only occur in one of the two lists, and thus is not suitable for our purposes. It also does not distinguish between differences in the upper and lower parts of the lists.

Spearman's footrule [16]: Rejected for the same reasons as Kendall rank correlation.

Tests of Applicability

[Results of preliminary tests of various metrics on own lists such as rank switching ,replacement at bottom and top of list etc.]

5.2 Baselines

It may be useful to compare the lists generated by the various approaches with existing word lists from educational materials: Textbooks often feature chapters with word lists, or sentences which can be converted to word lists with a tokenizer. The purpose is to have a point of comparison, to see if generated lists agree with existing lists, and find reasons for differences.

5.2.1 Existing Lists

- Language learning textbooks

- Language learning applications

  - Duolingo: While Duolingo is the most popular language learning application as of 2024, it does not publish its word lists or course contents that is free of cost and easily convertible to a format that can be processed with NLP tools.
  - Rosetta Stone: Rosetta Stone publishes Course contents on its website. While the contents take the form of sentences, these can be converted to word lists by using a tokenizer on the contents and creating a list in the order in which they appear in the texts.

5.2.2 Existing Methods

To get an impression of how well the XAI-based methods perform, it will be informative to test established methods such

- Frequency: The frequency of the word in the context-specific corpus.

- Frequency without stopwords: The frequency of the word in the context-specific corpus, but with known stopwords filtered out.

- TF-IDF: The frequency of a word in the context-specific corpus, normalized against a background corpus.

5.2.3 AI Prompts

In recent years, Large Language Models have become a popular tools for language learners to find new words to learn about specific areas. For this purpose, we run the following prompt to ChatGPT 3 for each context to get a sense of how well my method performs against this easy method. Note: Prompt and results

5.3 Results

Chapter content: Discussion/Analysis [Interpretation of the results] Could you combine approaches with each other or baselines to combine strength, what are the strengths/weakness of each approach

5.4 Discussion

Chapter 6

Outlook

- Sentence importance evaluation

- Capturing text as coherent unit instead of sentences which are independent from each other

- Active vs passive utility: Ideas for active utility estimation

- Compound splitting

Chapter 7

Appendix

7.1 Abbreviations

NSP Next sentence prediction

NLP Natural language processing

LLM Large language model

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