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Automated Detection of Syntactic Ambiguity Using Shallow Parsing and Web Data

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Abstract:

Technical documents are mostly written in natural languages and they are highly ambiguity-prone due to the fact that ambiguity is an inevitable feature of natural languages. Many researchers have urged technical documents to be free from ambiguity to avoid unwanted and, in some cases, disastrous consequences ambiguity and misunderstanding can have in technical context. Therefore the need for ambiguity detection tools to assist writers with ambiguity detection and resolution seems indispensable.

The purpose of this thesis work is to propose an automated approach in detection and resolution of syntactic ambiguity. AmbiGO is the name of the prototyping web application that has been developed for this thesis which is freely available on the web. The hope is that a developed version of AmbiGO will assist users with ambiguity detection and resolution. Currently AmbiGO is capable of detecting and resolving three types of syntactic ambiguity, namely analytical, coordination and PP attachment types. AmbiGO uses syntactic parsing to detect ambiguity patterns and retrieves frequency counts from Google for each possible reading as a segregate for semantic analysis. Such semantic analysis through Google frequency counts has significantly improved the precision score of the tool's output in all three ambiguity detection functions.

AmbiGO is available at this URL: <http://omidemon.pythonanywhere.com/>

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There is no greater impediment to the advancement of knowledge than the ambiguity of words”- Thomas Reid

1. Introduction

Ambiguity is generally defined as “the capability of being understood in two or more possible senses or ways” (Berry et al, 2003) and appears in different means of communication and senses. The Necker cube in Figure 1 is an example of visual ambiguity in which the visual perception flips between two different 3-D cubes.

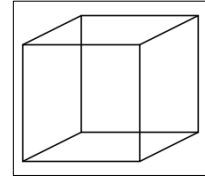


Figure 1: Necker cube

Ambiguity is an inevitable feature of languages which can be demonstrated using the Context-Free Grammars (CFG) mathematical model. According to CFG, grammar G in a natural language L consists of (N, T, P, S) tuple where N is a set of non-terminals or syntactic categories, T is a finite set of terminals or vocabularies, S is the start symbol that represents the language, and P is the finite set of rules that produces infinite number of sentences (Hopcroft et al, 2001). However if grammar G leads to derivation of more than one parse trees, the grammar is considered as ambiguous (Learn Automata Theory, 2017). For example, in English grammar, a prepositional phrase (PP) can attach to both verb (V) or noun phrase (NP) in a sentence and accordingly, both of the following production rules are valid:

$P \rightarrow \text{Verb PP} \mid \text{Noun PP}$

Therefore the following sentence has two derivations:

- “Police shot the rioters with guns”
 - ✓ Derivation 1: shot with guns
 - ✓ Derivation 2: rioters with guns

Which makes the meaning of the sentence ambiguous.

Ambiguity can be a positive aspect of natural languages, as in puns in news headlines or punch lines of jokes which make them more interesting to read or hear. As Milan Kundera puts it, “The greater the ambiguity, the greater the pleasure”. However, it is not always true and ambiguity can have undesirable and disastrous outcomes, for example, when it comes to technical or legal contexts.

The present thesis aims at investigating and developing an automated ambiguity tool which is capable of detection and resolution of syntactic ambiguity in written English language and henceforth, ambiguity refers to the linguistic phenomenon in textual data.

1.1 Motivation

According to Gricean maxim of manner, ambiguity should be avoided in natural language (Grice, 1975) due to the miscommunication and misinterpretation it causes. The history is full of examples of disasters resulted by uncertainty and miscommunication. The collision involving a landing airplane and a snow plow in Sioux City, Iowa, December 1983 is an example of lexical ambiguity in which the operator of the snow plow, had been told to 'clear the runway' for the landing of the aircraft, misinterpreted the command as an order to remove the snow from the runway (Porter, 2008).

According to a survey conducted in the University of Trento, 71.8% of technical documents are written in common every-day natural languages (Mitch et al, 2004) which makes them ambiguity-prone. Don Gause names 'too much unrecognized disambiguation' as one of the five important sources of failure in technical context (Gause, 1989). Britton also emphasizes the importance of ambiguity avoidance in technical writing by instructing technical authors to "convey one meaning and only one meaning" which "must be sharp, clear, and precise and the reader must be given no choice of meanings". "[The reader] must not be allowed to interpret a passage in any way but that intended by the writer" he adds (Britton, 1965). It is of utter importance for technical and legal documents to be interpreted in the same way by different users with similar background (Harwell et al, 1993), or to be accurately perceived by a large majority of the reading audience (Gopen & Swan, 1990).

The importance of ambiguity avoidance in technical or legal documents has been the main motivation for this thesis work and the ambiguity tool, AmbiGO, which has been developed for the purpose of this theses. To date, there is no ambiguity tool freely available on the net or in the market and the current tools are mainly developed for academic or commercial purposes while AmbiGO is freely available on the net and can be developed further with more ambiguity functions and detection cases. Another advantage of AmbiGO over the current ambiguity detection tools is that in addition to detecting potentially ambiguous cases, AmbiGO is also capable of resolving the detected cases with a relatively high precision using large context such as web search statistics.

Apart from that, detection and resolution of syntactic ambiguity is essential for many automated natural language processing functions such as Machine Translation, Question Answering, Information Extraction, Information Retrieval, Automatic Speech Recognition and etc. which can improve their performance (Olteanu and Moldovan, 2005).

1.2 Research questions

The first question in this thesis work was to find out detection of which ambiguity type is more tangible and achievable using syntactic shallow-parsing among different types of ambiguity e.g. lexical, syntactic, semantic and pragmatic.

The first question in this thesis was to examine to what extent and with what precision the detection and resolution of syntactic ambiguity is possible through syntactic parsing.

Another question was to see how much using web search statistics as a source of semantic knowledge will help to improve the precision of the detection of the potentially ambiguous cases and the resolution of the detected cases.

1.3 Contributions

The main contribution here is the ambiguity detection tool, so-called AmbiGO, developed for the purpose of this thesis. Using data from WWW to validate the detection results and also to resolve the detected cases is also another innovative approach in this field.

A theoretical finding of this thesis is regarding attachment ambiguity, where we hypothesize that prepositional phrases (PP) do not attach to the linking verbs in a sentence which resolves related PP ambiguity cases.

1.4 Delimitations

Initially, the scope of this thesis included detection of all types of linguistic ambiguity, e.g. lexical, syntactic, semantic and pragmatic. However, after doing some development and testing it became clear that detection and resolution of syntactic ambiguity is easier to achieve through syntactic parsing and therefore the focus was narrowed down towards the subtypes of syntactic ambiguity such as analytical, coordination and prepositional attachment.

Chapter 2 of this thesis reviews the syntactic types of ambiguity as well as some related ambiguity detection and resolution tools and approaches. Chapter 3 presents the implementation of the prototype ambiguity detection tool AmbiGO. Chapter 4 presents the evaluation results and discussion on some of the interesting cases and finally Chapter 5 concludes the findings of this thesis.

2 Background

2.1 What is Ambiguity?

To gain a better understanding of the nature and sources of ambiguity, let's take a brief look at some definitions. According to Merriam-Webster Dictionary, ambiguity can be defined as: *1) the capability of being understood in two or more possible senses or ways* and, *2) uncertainty* (Merriam-Webster). Berry et al refer to the first aspect as the ambiguity derived from linguistic features such as poorly constructed sentences or syntactical error. "Uncertainty, on the other hand, refers to the lack of semantic information and grounding between the writer and reader" (Berry et al, 2003). They further classify ambiguity into lexical, syntactic, semantic and pragmatic types (ibid) where lexical ambiguity refers to words with similar forms (written and spoken) but different meanings such as homonymy and polysemy, and syntactic to ambiguity derived from structure and syntax of a sentence. Semantic and pragmatic, on the other hand, deal with the meaning at sentence and context level respectively.

Here the focus is on syntactic ambiguity since detection of syntactic ambiguity is possible via syntactic shallow-parsing at sentence level which is in line with the scope of this thesis. Detection of semantic and pragmatic ambiguities, on the other hand, requires a deep-level analysis of meaning at context and discourse level which is beyond the scope of this thesis.

We will have a look on syntactic ambiguity in more details below.

2.2 Syntactic Ambiguity

Syntactic ambiguity, also called structural ambiguity, occurs when a sentence has more than one meaningful structure or more than one parse (Berry et al, 2006). Analytical, prepositional phrase attachment and coordination ambiguities are among the subtypes of syntactic ambiguity which have been studied in this thesis and thus, will be discussed here:

2.2.1 Analytical ambiguity

Analytical ambiguity occurs when the role of the constituents within a phrase or sentence is ambiguous (Berry et al, 2006) which is common in compound noun phrases such as the following example:

C2E1: English grammar teacher

which can be interpreted in two ways:

C2E2: English teacher of grammar

C2E3: Teacher of English grammar

The third possible reading can also be the combination of the both readings as in:

C2E4: English teacher of English grammar

This option is, however, not considered in this study.

2.2.2 Coordination ambiguity

Coordination ambiguity occurs when one conjunction is used with a modifier (Berry et al, 2006):

C2E5: Young men and women

This can be interpreted as 'young men and women' or 'young men and young women'

2.2.3 Attachment ambiguity

Attachment ambiguity occurs when a particular syntactic constituent of a sentence such as prepositional phrase or relative clause can be possibly attached to two different parts of a sentence. Prepositional phrase (PP) attachment is an example of this type of ambiguity because PP can modify either a verb or a noun phrase in a sentence (Berry et al, 2006). PP attachment ambiguity (PPAA) is a significant and frequent source of ambiguity and detection and resolution of PPAA cases challenging via automated tools and in some cases, it requires world knowledge and general reasoning capabilities (Clark, 2013) which makes it even difficult for human to disambiguate PPAA cases. According to one experiment, human precision in disambiguating PPAA is 93.2% (Ratnaparkhi et al. 1994).

The degree of ambiguity varies in different cases based on the domain knowledge and common sense. For example, in the following sentence there is a PPAA:

C2E6: I saw a boy with a telescope.

C2E7: I saw a tree with a telescope.

C2E6 is ambiguous in meaning since it is equally reasonable to see a boy holding a telescope or seeing a boy through a telescope, while disambiguation of C2E7 is easy via general reasoning by discarding the concept of a tree holding a telescope. This is where semantic analysis comes to play, which is missing in syntactic parsing.

The following sentence is another example of an unresolved cases of PPAA:

C2E8: *Police shot the rioters with guns.*

Where the prepositional phrase ‘*with gun*’ to the noun ‘*rioters*’ or the verb phrase ‘*shot the rioters*’, which results in the following interpretation:

C2E9: Police used their guns to shoot the rioters

C2E10: Police shot the rioters who were carrying guns

In the next chapter, we will discuss the detection methods of PPAA as well as the surrogate we used in this study to compensate for the lack of semantic analysis.

2.3 Related ambiguity detection tools and approaches

Development of computational tools for automated ambiguity detection has been a strand of research in recent years and several automated ambiguity detection approaches have been developed recently using machine learning, statistical and probabilistic methods, eye movement detection and alike which are, however, not under the focus of this these and, therefore, will not be discussed here. It is also worth mentioning that there are many researches and tools developed for the purpose of ambiguity detection in formal languages such as different programming languages. Despite the similarity in purpose, ambiguity detection in formal languages engages different methodology and approach than the scope of this thesis work and therefore, will not be discussed here. The focus, however, is on the detection tools of ambiguity in natural languages using syntactic shallow-parsing and web data which are closer to the scope of our ambiguity detection tool (AmbiGO) which is developed for the purpose of this thesis work. Among the related works, the following researches and developments are worth mentioning.

1. Gleich et al’s developed an industrial and fit-for-purpose ambiguity detection tool using natural language processing (NLP) techniques such as part-of-speech (POS) tagging and Regular Expressions (RE) to detect ambiguity in English and German requirement specifications and also to educate the technical writers on the potential sources of ambiguity. Berry et al’s Ambiguity Handbook and Siemens-internal guidelines for requirements writing were used as the main source of ambiguity definition and recognition (Gleich et. al., 2009). The tool they have developed is capable of detecting 39 ambiguity cases, mostly on single word level, using lexical and syntactic detection which has been claimed to have precision and recall scores of 95% and 86% respectively. Despite the similar approach, the ambiguity patterns which will be discussed in this project are not covered in Gleich et al’s tool which make the comparison of the results irrelevant.

2. Nigam et al. have also made a similar effort in developing an ambiguity detection tool for detection of lexical and syntactic ambiguity cases in software requirement specifications (Nigam et al, 2012). Their tool is similar to the scope of this thesis in a way that NLP methods such as text matching and POS tagger have been used as well, however, Nigam et al’s detection tool is only capable of detecting ambiguity on word level and no ambiguity pattern were defined which is

different from the scope of our project. Their tool also provides some sort of ambiguity percentage statistics to the user based on the detection results in form of charts and highlighted text. They further tested the tool on four different software requirement specifications and provided the ambiguity percentage for lexical and syntactic ambiguity types for each test material. Unfortunately, no precision or recall score have been provided in their paper.

3. Lami et. al. have used syntactic parsing to develop an automated ambiguity detection tool, called QuARS, which detects potential linguistic defects that can cause ambiguity in textual data (Lami et al, 2001). The approach used in QuARS is to apply Lexical and Syntax parsing using a domain dictionary. The parsed data is processed in a stage called Indicator Detector which looks for language defects such as vagueness, subjectivity, underspecification, multicapitality and etc. The output of the Indicator Detector is presented through a log file and diagrams. The output also contains readability metrics based on the Coleman-Liau readability formula i.e. the number of defective sentences divided by the total number of sentences (ibid).

4. Using web data as the source of semantic knowledge has been used in research before and among those it is worth mentioning the work of Olteanu and Moldovan on disambiguation of PP attachment (Olteanu and Moldovan, 2005). They highlight the importance of using such semantic knowledge base by stating: "Lexical and syntactic information alone is not sufficient to resolve the PP-attachment (PPA) problem; often semantic and/or contextual information is necessary" (ibid). In their approach, Olteanu and Moldovan used a Support Vector Model containing the feature sets obtained from candidate syntax trees generated by a parser, manually annotated semantic information as well as unsupervised information obtained from the web and used statistical models to estimate the frequency ratio of the prepositional phrase attaching the verb or the noun of the sentence and this way, disambiguate the case. They achieved accuracy of 93.62% and 92.85% on Penn Treebank and FrameNet datasets respectively (ibid).

2.4 Comparison with AmbiGO

The approach of AmbiGO is similar to those discussed above in the sense that it uses NLP techniques such as syntactic analysis for detection of ambiguity, but there are some features that give AmbiGO advantage over the current ambiguity detection tools. First is the fact that AmbiGO is open-source and not-for-profit tool available on the web which makes it portable and easy to access while, to date, the current available ambiguity detection tool has been mainly developed for industrial or academic purposes. The architecture of AmbiGO is also designed in a way that more ambiguity detection functions can be easily added to the tool using shallow-parsing ambiguity patterns to cover more ambiguity cases and types.

Disambiguation is also an important feature of an ambiguity tool because detecting an ambiguity case is not enough and the ambiguity tool should be able to help user with ambiguity resolution suggestions. This way, the results of the ambiguity tool will be of pedagogical value and helpful in improving the quality of the output. Most of the ambiguity tools, however, are not capable of ambiguity resolution, while AmbiGO has the advantage of resolving and disambiguating in addition to ambiguity detection using web data as a source of semantic knowledge. This ultimately improves the precision of the final results.

Similar to Olteanu and Moldovan's approach, AmbiGO uses web data for validation and resolution of the detected ambiguity cases, however, the difference is Oltenau et al's approach uses other sources of semantic knowledge in addition to the web data and applies smoothing algorithms to normalize the retrieved data from the web while AmbiGO uses simpler methods and algorithms in handling the retrieved data from the web and no smoothing on the results or cross-checking with other semantic sources is used in AmbiGo. The advantage of AmbiGO, on the other hand, lies in its capability of detecting cases of PPA ambiguity as well as disambiguation while Oltenau et al's approach is merely designed for disambiguation of already detected PPA ambiguity cases. Furthermore, AmbiGO covers more types of ambiguity such as analytical and coordination ambiguities, which are missing in Oltenau et al's approach. However, the precision score obtained for AmbiGO is lower than what has been reported for Olteanu and Moldovan's approach.

The next chapter describes AmbiGO, the prototyping web-based ambiguity tool which has been developed for the purpose of this thesis work in more details.

3 Implementation of *AmbiGO*

3.1 Introduction

This chapter introduces the ambiguity detection and resolution prototyping tool, *AmbiGO*, which is capable of detecting and resolving syntactic types of ambiguity described in section 2.2. The hope is that the output of a fully developed version of *AmbiGO* could assist users to detect ambiguities in textual data.

This version of *AmbiGO* focuses on detection of syntactic ambiguity only rather than different types for the following reasons: (1) as mentioned earlier, detection and resolution of syntactic ambiguity types are more achievable with the approach of this thesis and also (2) to prioritize precision over coverage by focusing on lesser ambiguity types but with a relatively higher precision score.

Developed in Python (python.org) and powered by NLTK (nltk.org) and Google Custom Search API (developers.google.com/web-search), *AmbiGO* uses heuristic methods such as syntactic shallow-parsing to detect potential cases of syntactic ambiguity at the sentence level and uses the World Wide Web (WWW) as a surrogate for semantic analysis to validate and resolve the detected ambiguity cases. A demo of *AmbiGO* is available at the following URL:

<http://omidemon.pythonanywhere.com/>

The back-end source code of *AmbiGO* is freely available on Github under the terms of the GNU General Public License (GPL) as published by the Free Software Foundation version 3, at the following URL (except the Google API credentials):

https://github.com/omidemon/AmbiGO/blob/master/AmbiGO_v1.0.py

PythonAnywhere (pythonanywhere.com) was chosen as the host for *AmbiGO* for the following reasons: the basic plan is free of charge, it supports Python in a user-friendly manner with several Python libraries, including NLTK, already installed and ready to use off-the-shelf, and supports the ability to code and store the scripts in a cloud. The web platform which is used to run the back-

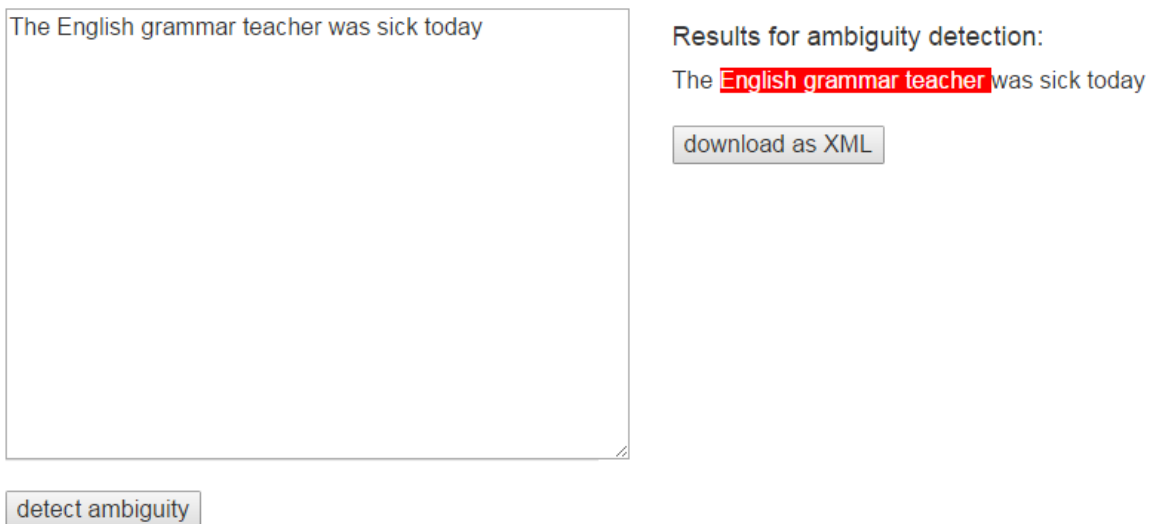
end Python scripts for this project is Flask (flask.pocoo.org) which is also a very strong and convenient platform to develop Python-based web apps.

3.2 Overview of AmbiGO's functionality

AmbiGO consists of two modules; a web interface and a processing module. The interaction and functionality of different parts of AmbiGO will be explained in the following sections.

3.2.1 The web interface

The home page of AmbiGO consists of *input* and *output sections*. The input section is a text area in which the user inserts the text as well as an output section where the user can see the detected ambiguity cases in form of highlighted text. Picture 3-1 illustrates what the web interface looks like.



3-1 AmbiGO input and output sections

The user initiates the detection process by inserting a piece of text in the textbox and clicking the 'detect ambiguity' button which sends the input text to the processing module and triggers the ambiguity detection function. Having processed the raw input, the processing module sends back the *output* to the web interface where the detected ambiguity cases are shown to the user in highlighted text. Hovering over the highlighted text, the user can also receive information such as ambiguity type and possible readings as well as ambiguity percentage and, if applicable, the most probable reading as the resolution of the detected case. Such information will be illustrated in more details in the following sections.

3.2.2 The processing module

The processing module is a Python script which processes the input from the web interface and returns the processed output back to the web interface to be displayed to the user. The process of ambiguity detection includes the following steps:

Parsing:

Initially the script breaks down the input text into separate sentences using the NLTK sentence tokenization function. Next, each sentence is tokenized into separate words and a POS tagger is applied on each word to determine the parts-of-speech of each word in the sentence, e.g. noun, verb, adjective, etc. For now, the built-in NLTK's POS tagger is used for this task even though the results of this tagger are not completely accurate which unfortunately negatively affects the final results in some instances.

Preliminary Ambiguity Detection:

In the next stage, the ambiguity function parses and analyzes the POS-annotated data against pre-defined syntactic ambiguity patterns in a process similar to shallow-parsing to identify potentially ambiguous structures and expressions using chunking or Regular Expressions.

In this step, using an off-the-shelf parser instead of our shallow-parsing approach could also be helpful in some cases such as PP Attachment ambiguity detection where ambiguity follows a certain CFG production rule, but it may not apply to other types of ambiguity. The reason for using shallow-parsing in this project was the wider coverage on smaller constituents such as analytical and coordination ambiguity types and consequently, to have a unified architecture for all ambiguity functions throughout the entire script. Defining ambiguity detection rules is also easy using shallow-parsing rules and the tool can be developed further to cover detection of more ambiguity types in the future. According to the test results which are provided in the following chapter, detection of ambiguity patterns using our shallow-parsing approach has been quite successful and there was no need for another approach such as CFG parsing.

Google Hits Processing (GHP) module:

The preliminary ambiguity detection merely relies on syntactic clues and shallow parsing. However, ignoring the semantic features can result in incorrect detections. In other words, a structure may look 'syntactically' ambiguous but after applying common sense and semantic analysis, only one reading remains valid and the structure becomes semantically unambiguous. To compensate for that lack of semantic analysis and to reduce amount of false positive results, AmbiGO was enabled with the GHP module which is designed in a way that it takes both possible readings for each detected ambiguity case, makes an exact search term of each reading in Google, and returns the frequency count (hits) for each reading. The function then estimates the degree of ambiguity or ambiguity percentage for each detected pattern based on the number of hits of each reading.

Although the Google search API seems to be a good solution here, it has some drawbacks; Using Regular Expressions in Google search is not possible and doing an open text search results in a huge amount false positive and irrelevant hits. Therefore, the search query must be restricted to the exact search term. How the Google search API processes queries is also a question mark and it is not clear if additional information such as user preference or location are involved in query retrieval.

An alternative for using Google as the source of semantic knowledge is Wikipedia corpus (<https://corpus.byu.edu/wiki/>). For this project, however, we used the Google Search API since it is easier to develop applications using the features Google APIs provide to the developers. Google data is also much larger than Wikipedia which gives us a bigger source of semantic knowledge.

To carry out a better analysis on the retrieved frequency count, an evaluation function was added to AmbiGO which takes the frequency counts for each query and calculates the Ambiguity Percentage (AP) using the following formula:

$$AP = (\text{Query with lower frequency count} / \text{Query with higher frequency count}) * 100$$

Per this formula, the closer the frequency counts are, the higher is the chance of being ambiguous and vice versa. For example, if case X has readings Xa and Xb with frequency counts of 100K and 96K respectively in Google, the ambiguity percentage would be calculated as:

$$AP(X) = (96K / 100K) * 100 = 96\%$$

which is quite high because both possible readings are frequent in Google. But if case Y has Ya = 100K and Yb = 15K, therefore the ambiguity percentage would be:

$$AP(Y) = (15K / 100K) * 100 = 15\%$$

which is a low probability due to the huge difference between the number of Google hits between two readings. In such cases where the difference between the cases are high and consequently AP is low, AmbiGO discards the reading with the lower frequency count and suggest the other reading to the user as the most probable reading to resolve the ambiguity. On the other hand, if both readings have equally high number of frequency counts, AmbiGO considers the whole case as ambiguous and suggests both readings as valid readings of the detected case. The color of the highlighted case can be red or orange, for unresolved or resolved ambiguity cases respectively. Currently, 50% is considered in AmbiGO as the limit between low and high ambiguity percentages which was conventionally chosen as a default value and can be changed in future.

The Google search can also function as a sanity check which compensates for the inefficiency of NLTK's POS tagger, where false part-of-speech tags will be discarded due to low frequency counts in Google. Examples will be provided in the next chapter.

This method has improved the precision of the tool and some statistics and examples will be provided in the next chapter to demonstrate such improvement.

Annotation:

In the last step, the script annotates the ambiguity case with corresponding ambiguity labels in form of HTML tags and sends it back to the web interface where the HTML-annotated data is processed and displayed to the user in a user-friendly manner. The following HTML-annotated example is the detection result for the sentence 'the English teacher was sick today':

<span style='background:red; color:white' title='syntactic ambiguity, type analytical. This combination is ambiguous and has two valid readings, -teacher of English grammar- or -

English teacher of grammar-. Ambiguity Percentage: 74%'> English grammar teacher
 is sick today.

Each ambiguity detection function of AmbiGO is explained in the following section.

3.3 Ambiguity Detection Functions in AmbiGO

AmbiGO is capable of detecting analytical, coordination and PP attachment types of syntactic ambiguity. The detection and validation process of each function is explained in the following section.

3.3.1 Analytical

Analytical ambiguity occurs when an adjective precedes two consecutive nouns. To detect any case of analytical ambiguity, AmbiGO first looks for occurrences of an Adjective followed by two consecutive nouns in a sentence according to the following RE pattern:

Analytical: {<JJ><NN.*><NN.*>}

The following example is a potential analytical ambiguity case with two readings

C3E1: English grammar teacher

Reading1: teacher of English grammar

Reading2: English teacher of grammar¹

Once the preliminary detection is done, the GHP module fetches the frequency count for both R1 and R2 from Google Custom Search API. Here choosing the right preposition to glue the chunks of the detected case is important because Google Search does not support Regular Expressions. Using free text search also returns an unreliable and inaccurate frequency counts. For example, in C3E1 case, 'of' is a suitable preposition for producing possible readings while in

C3E2: Midnight anonymous calls

'at' is the suitable preposition.

To avoid such problem with the preposition choice, AmbiGO uses a chunk of the reading instead of the whole reading based on the following patterns:

Query 1 = Adj N1

Query 2 = Adj N2

In C3E2 case, the queries are as

Query1: English grammar (2.09m hits)

Query2: English teacher (2.47m hits)

Which result in ambiguity percentage of

AP (C3E1) = 84%

In this example both readings have roughly equally high number of frequency counts in Google and consequently the AP is high, therefore the tool marks this example as an unresolved case of ambiguity, highlighted in red, and provides both readings as valid readings. The output for C3E1 example is presented below:

English grammar teacher

'syntactic ambiguity, type analytical. This combination is ambiguous and has two valid readings, -teacher of English grammar- or -English teacher of grammar-. Ambiguity Percentage: 84%'

Such cases are highly ambiguous and cannot be disambiguated without considering the entire context. However not all the occurrences of this pattern are ambiguous and it may be a false positive detection as in the following example:

C3E3: modern economy teacher

With possible readings:

Reading1: teacher of modern economy

Reading2: modern teacher of economy

which results in the following queries:

Query1: modern teacher (22k hits)

Query2: modern economy (104k hits)

AP (C3E3) = 21%

As we can see, Query1 has much less frequency hits than Query2 therefore the tool resolves the case by discarding the second reading and suggesting the first one to the user as the only valid reading:

modern economy teacher

'syntactic ambiguity, type analytical. This combination is ambiguous and has two readings, -teacher of modern economy- and -modern teacher of economy-, but the valid reading is -teacher of modern economy-. Ambiguity Percentage: 21%'

3.3.2 Coordination

Coordination ambiguity follows a certain pattern of an adjective followed by more than one noun phrases, connected by a conjunction, using the RE pattern of:

Coordination: {<JJ><NN.*><CC><NN.*>}

An example of this ambiguity type is the following case:

C3E4: Young men and women

Reading1: Young men and women

Reading2: Young men and young women

Like the previous function, AmbiGO implements a sanity check through the GHP module to determine which of the possible readings are valid. Here also a chunk of the readings is used as a query with the general pattern of Q1=Adj N1 and Q2=Adj N2:

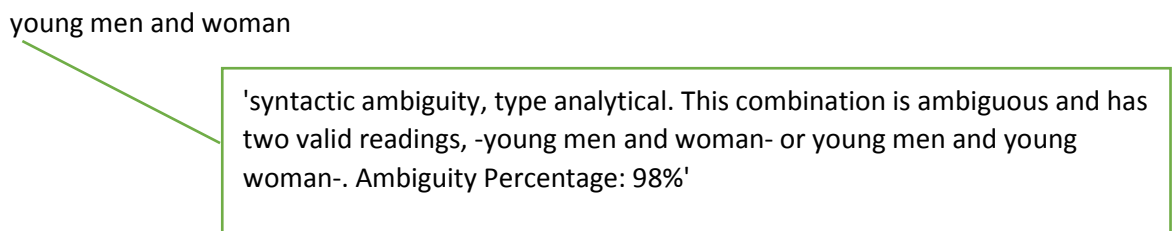
Query1: young men (4.9m hits)

Query2: young women (5.04m hits)

AP (C3E4) = 98 %

In this case both Query1 and Query2 return equally high number of frequency hits which makes the structure highly ambiguous:

young men and woman



'syntactic ambiguity, type analytical. This combination is ambiguous and has two valid readings, -young men and woman- or young men and young woman-. Ambiguity Percentage: 98%'

On the contrary, the next example also seems syntactically ambiguous since it follows the coordination ambiguity pattern:

C3E5: Real estate and vehicles

Which has the following detection results:

Reading1: real estate and vehicles

Reading2: real estate and real vehicles

Query1: real estate (185m hits)

Query2: real vehicle (1.3k hits)

AP (C3E5) = 0%

After considering the number of frequency hits, it can be concluded that Reading2 is not valid and consequently will be ruled out by the tool.

real estate and vehicles

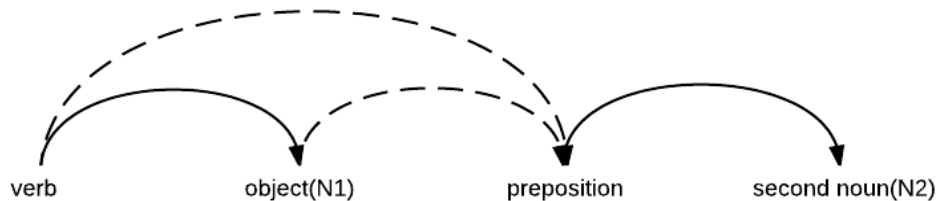
'syntactic ambiguity, type analytical. This combination is ambiguous and has two readings, -real estate and vehicles- and -real estate and real vehicles-, but the valid reading is -real estate and vehicles-. Ambiguity Percentage: 0%'

3.3.3 Attachment

Despite the challenges in resolving a PPAA, detecting a potential one is possible through syntactic clues. Generally, there are four main elements in a sentence which form PPAA, known as 4 head words (Clark, 2013):

- V: the verb of the sentence
- N1: the object of the verb
- P: preposition
- N2: the object of preposition

The following figure illustrates how these 4 head words interact in a PPAA where the dotted lines show the possible attachment of the preposition (Suster, 2012).



3.2 - 4 head words involved in PP attachment

Per this formula, the sentence “police shot with guns” is not a case of PPAA due to lack of N1 while the sentence “Police shot the rioters with guns” is.

Accordingly, the first thing AmbiGO looks for to detect any case of PPAA is the occurrence of these 4 head words in a sentence using a regular expression which is presented below:

PP Attachment: {<VB.*><DT>?<JJ>*<NN.*><IN><DT>?<JJ>*<NN.*>}

Here <VB.*> matches all tenses of verb and <DT>?<JJ>*<NN.*> matches a noun phrase with or without a determiner and any number of adjectives followed by a noun. <IN> also matches any preposition.

The main verb of the sentence also plays an important role in this pattern. For example, the sentence:

C3E5: My favorite drink is (V) coffee (N1) with (P) milk (N2)

contains all the 4 head words but still the sentence is not ambiguous in the meaning since the PP (with milk) modifies the object (coffee) and not the verb (is).

The reason is the fact that 'to be' verbs are counted as *linking verbs* which join an adjective or noun complement to a subject. Therefore, the role of the linking verb here is to connect the noun phrase 'coffee with milk' to the subject 'my favorite drink'. This is a general rule regarding the linking verbs in PPAA cases which to our knowledge has not been cited before this thesis.

To examine this hypothesis, a small test has been conducted on Brown's news corpus to find the sentences containing the [*linking Verb, N1, P, N2*] pattern using the above-mentioned list of linking verbs. Among the 4623 sentences analyzed, 13 sentences with this pattern were detected. After manually analyzing the ambiguity of each sample, almost all the samples proved this hypothesis that PP does not attach to the linking verb.

The following examples are taken from the test samples:

C3E6: He will be succeeded by Ivan Allen Jr., who became a candidate in the Sept. 13 primary after Mayor Hartsfield announced that he would not run for reelection.

C3E7: I feel a certain loss of status when I am driven up in front of work in a car driven by my wife, who is only a woman.

These two sentences follow the PPAA pattern however not ambiguous in meaning. In C3E6, 'who became in the Sept. 13' does not make sense while 'became a candidate in the Sept. 13 is the correct parse of this sentence.

Similarly, in C3E7, the prepositional phrase 'I feel of status when I am driving...' is ungrammatical and does not make sense and the only valid reading is 'I feel a certain loss of status when...'

To avoid detection of similar PPAA cases, a list of the 9 most common linking verbs according to the British Council website (learnenglish.britishcouncil.org, 2017) were provided in AmbiGO to avoid detection of similar structures as ambiguous. This list includes:

"be", "seem", "become", "sound", "remain", "feel", "appear", "look"

C3E6 and C3E7 are the examples where this hypothesis is used to eliminate the falsely detected ambiguity cases.

Like other ambiguity detection functions in AmbiGO, the GHP module comes to play to fill in the gap of semantic analysis. In this approach, the tool fetches the frequency counts for the chunks 'Noun PP' and 'Verb PP' as possible readings and determines which has stronger binding. Same as before, it resolves the ambiguity if the APP is below 50% by discarding the less frequent reading or marks both readings as valid for the cases with APP above 50%. This process is illustrated in the following examples:

C3E8: I saw a boy with a telescope

Query1: N1 P N2 > a boy with a telescope (1.3k hits)

Query2: V P N2 > saw with a telescope (652 hits)

AP (C3E8) = 52%

Which leaves the ambiguity unresolved and the tool suggests the both readings as valid ones:

I saw a boy with a telescope

'syntactic ambiguity, type analytical. Prepositional phrase can attach to both Noun and Verb like -saw with a telescope- or -a boy with a telescope-. But the valid attachment is -a boy with a telescope-. Ambiguity Percentage: 52%'

While in this example:

C3E9: I saw a tree with a telescope

- Query1: 'a tree with a telescope' (2 hits)

- Query2: 'saw with a telescope' (652 hits)

AP (C3E9) = 0%

Where the tool discards Query1 and suggests Query2 as the valid reading for this detected case to resolve the potential syntactic ambiguity.

I saw a tree with a telescope

'syntactic ambiguity, type analytical. Prepositional phrase can attach to both Noun and Verb like -saw with a telescope- or -a tree with a telescope-. But the valid attachment is -saw with a telescope-. Ambiguity Percentage: 0%'

The following examples are also interesting cases of PPA ambiguity:

C3E10: I eat pizza with a fork.

C3E11: I eat pizza with anchovies.

Semantically it is clear that 'with fork' attaches to the verb 'eat' and 'with anchovies' to the noun 'pizza', but for an automated ambiguity tool with the lack of semantic analysis, it is not possible to find the correct attachment. The output of AmbiGO is interesting for C3E10 since it recognizes both readings as valid and reports the case as an unresolved ambiguity:

syntactic ambiguity, type analytical. Prepositional phrase can attach to both Noun and Verb like -eat with a fork- or -pizza with a fork-. Ambiguity Percentage: 58%

The reason for that is the high frequency count for the phrase 'pizza with fork' on the web which is almost as frequent as 'eat with fork'. However, using 'sushi' instead of 'pizza' gives a more reasonable output:

C3E12: I eat sushi with a fork.

'syntactic ambiguity, type analytical. Prepositional phrase can attach to both Noun and Verb like -eat with a fork- or -sushi with a fork-, but the valid attachment seems to be -eat with a fork-. Ambiguity Percentage: 5%'

Considering this example, it can be conceded that the results of the GHP module can be affected by unreliable frequency hits of some phrases or words to display the incorrect ambiguity resolution.

The tool has also usefully resolved the attachment resolution for C3E11:

'syntactic ambiguity, type analytical. Prepositional phrase can attach to both Noun and Verb like -eat with anchovies- or -pizza with anchovies-, but the valid attachment seems to be -pizza with anchovies-. Ambiguity Percentage: 0%'

Having discussed the functionality of AmbiGO, we will look at the testing methodology and evaluation results of AmbiGO in the following chapter.

4 Testing and Evaluation

This chapter describes the testing material and methodology. Quantitative analysis on each function of AmbiGO is presented here as well as qualitative analysis on some of the interesting cases and observations.

4.1 Testing material and methodology

To evaluate the performance of AmbiGO in real context, each ambiguity function was used to detect 50 cases for each type of ambiguity. Among the results, the invalid detections which were caused by wrong POS tagging were excluded from the evaluation because the performance of the NLTK's POS tagger is out of AmbiGO's scope. The remaining valid results were considered for the evaluation. The news genre of the Brown corpus, was a satisfactory testing material since it contains a well-established and formal language which is close to the technical written data as the target group of this thesis project.

As mentioned in the previous chapter, the purpose of adding the Google Hits Processor (GHP) was to do some sort of a sanity check in addition to the syntactic analysis in order to filter out the false detections which consequently improves the performance of the tool. To determine the effect of this module, the performance of AmbiGO was evaluated in two tests: Test 1, excluding the GHP and Test 2, including it.

Test 1 was merely based on syntactic clues, e.g. according to the ambiguity patterns defined in each function regardless of any semantic analysis. Therefore, it can be referred to as 'detection before semantic analysis'. Even though most of the detected cases followed the correct ambiguity pattern i.e. were syntactically ambiguous, not all of them were ambiguous in meaning i.e. semantically ambiguous.

Test 2, on the other hand, was designed to determine how the GHP has improved the results of the tool in Test 1 by using the semantic information, i.e. frequency counts in WWW as reported by Google search API, on each syntactic detected case from Test 1 in the following tasks:

1. To validate the correct ambiguity case where both readings have relatively high frequency counts in Google

Or

2. To resolve potential syntactic ambiguity by ruling out the invalid reading where one reading has high frequency count and the other reading has a low frequency count and the more frequent reading will be presented as the valid reading by the tool

4.2 Quantitative analysis of the results

In Test 1, each detected case was marked either as a 'true positive (tp)' if the detected case was truly ambiguous in meaning, or as a 'false positive (fp)' if the detected case was not ambiguous in meaning and incorrectly marked as ambiguous. The ground truth for evaluating the status of each case has been the human judgement of only one person who is the author of the thesis. The testing material and results are provided as appendix.

Having collected the test results, precision score was calculated for both Test 1 and Test 2. Here, the precision score can be defined as how successful the tool has performed in detecting ambiguity cases and can be calculated using the following formula:

$$\text{Precision} = \frac{\text{correct detections of ambiguity (tp)}}{\text{total detected cases (tp + fp)}}$$

Using the precision formula, the precision score for each ambiguity function in Test 1 is summarized in Table 1:

	Total cases	True positive (tp)	False positive (fp)	Precision in Test1
Analytical	42	2	40	5%
Coordination	25	3	22	12%
Attachment	20	1	19	5%
Average (Test 1)				7%

Table 1 - Results and precision scores for each ambiguity function in Test 1

According to Table 1, the tool had a low performance in correct detection of ambiguity cases in Test 1 (excluding the GHP) and only a few ambiguity cases were detected correctly.

The output of the tool in Test 2 contained resolution results derived from the GHP. Therefore each detected case in Test was evaluated into the following categories:

True positive (tp): if the syntactically detected case is semantically ambiguous and AmbiGO has correctly marked it as ambiguous.

True negative (tn): If the syntactically detected case is not semantically ambiguous and AmbiGO has correctly resolved it by discarding the invalid readings.

False negative (fn): If the syntactically detected case is semantically ambiguous but AmbiGO has mistakenly discarded it by either resolved the valid reading or ruling out the ambiguity.

False positive (fp): If the syntactically detected case is not semantically ambiguous but AmbiGO has mistakenly marked it as ambiguous.

In order to distinguish between the false positive cases in Test 1 and 2, we refer to the false positive cases in Test 2 as 'fp2'. The results of Test 2 is shown in Table 2.

Using the number of true and false negatives discovered by comparing the results from Test 1 and Test 2, recall and accuracy of AmbiGo in Test 2 can also be calculated. Here, recall tells us among the results, how many of the relevant items, e.g. ambiguity cases, are detected and can be calculated using the following formula:

$$\text{Recall} = \frac{\text{correct detections of ambiguity (tp)}}{\text{total number of ambiguity cases (tp + fn)}}$$

Having both precision and recall in hand, the F-measure which is the geometric mean of these two scores can also be calculate using the following formula:

$$\text{F-measure} = 2 * \frac{\text{precision} * \text{recall}}{\text{precision} + \text{recall}}$$

Accuracy is formulated as how many of the incorrect ambiguous cases detected by the tool in Test 1 were correctly resolved or discarded in Test 2:

$$\text{Accuracy} = \frac{\text{correct detection ore resolution of ambiguity (tp+tn)}}{\text{total detected cases (tp+fp+tn+fn)}}$$

Using this formula, the accuracy score for each ambiguity function is presented in Table 2.

	Total cases	True positive (tp)	True negative (tn)	False positive (fp)	False negative (fn)	Precision (Test 2)	Recall	F-measure	Accuracy
Analytical	42	2	29	1	10	67%	15%	25%	73%
Coordination	25	3	12	0	10	100%	23%	38%	60%
Attachment	20	1	15	0	4	100%	17%	29%	76%
Average (Test2)	-	-	-	-	-	89%	18%	30%	70%

Table 2 - Scores for each ambiguity function in Test 2

According to the data presented in Table 2, the performance of the tool did improve in Test 2 thanks to GHP where many of the false positive cases in Test 1 were resolved in Test 2 and turned from false positive to true negative. Therefore the precision score has been significantly improved for every singly detection function and therefore the average has been improved from 7% to 89%. The recall scores, on the other hand, tell us still many of the ambiguity cases either have not been detected or have been incorrectly resolved by the tool which results in relatively low average recall score of 18% in comparison to the precision score.

However, we should keep this in mind that these results are inventory because the dataset used for these tests is too little. In order to draw a solid conclusion we need a much bigger test data. It is also important to stress that the recall and accuracy scores presented here are not *'real scores'* since the amount of false negative cases i.e. all cases of ambiguity not even found by syntactic analysis in Test 1, are not known. In order to calculate the real accuracy, we need to have access to some sort of a gold standard where all the true negative ambiguity cases are annotated.

4.3 Qualitative analysis of the results

To gain a better understanding of how each detection function was evaluated, qualitative analysis on some example cases as well as discussion on some of the interesting cases and findings are presented in the following sections.

4.3.1 Analytical

Although the combination of "Adjective-Noun-Noun" is highly ambiguity-prone, not all the cases are ambiguous and many can be resolved using general reasoning and semantic analysis. The GHP module played a significant role in improving the results of the analytical detection function as the precision has increased from 5% to 71% in Test 2 by resolving many of the false detections after discarding the low-frequent and invalid reading i.e. turning a 'false positive' in Test 1 to a 'true negative' in Test 2 which increases the precision. Here is an example of such cases:

C4E1: High school certificate

This case seems syntactically ambiguous since it follows the ambiguity pattern, resulting in the following readings:

Reading 1: certificate of high school

Reading 2: high certificate of school

But the GHP has successfully managed to resolve the ambiguity by discarding the invalid reading e.g. Reading 2:

AmbiGO output: "This combination is syntactically ambiguous and has two readings, -certificate of high school- and -high certificate of school-, after semantic analysis, the valid reading is -certificate of high school-. Ambiguity Percentage: 0%"

Below are some more examples of true negative cases which the tool has successfully resolved:

C4E2: Social security system

AmbiGO output: "This combination is syntactically ambiguous and has two readings, -system of social security- and -social system of security-, after semantic analysis, the valid reading is -system of social security-. Ambiguity Percentage: 13%"

C4E3: Public relations director

AmbiGO output: "This combination is syntactically ambiguous and has two readings, -director of Public relations- and -Public director of relations-, after semantic analysis, the valid reading is -director of Public relations-. Ambiguity Percentage: 0%"

C4E4: Last minute decision

AmbiGO output: "This combination is syntactically ambiguous and has two readings, -decision of last minute- and -last decision of minute-, after semantic analysis, the valid reading is -decision of last minute-. Ambiguity Percentage: 0%"

C4E5: First year student

AmbiGO output: "This combination is syntactically ambiguous and has two readings, -student of first year- and -first student of year-, after semantic analysis, the valid reading is -student of first year-. Ambiguity Percentage: 2%"

C4E6: Heavy court costs

AmbiGO output: "This combination is syntactically ambiguous and has two readings, -costs of heavy court- and -heavy costs of court-, after semantic analysis, the valid reading is -heavy costs of court-. Ambiguity Probability: 10%"

As we can see, AmbiGO has successfully resolved the ambiguity in these cases while in the C4E7 example, the ambiguity is still open and unresolved:

C4E7: General assistance program

AmbiGO output: "This combination is ambiguous and has two possible readings: -program of general assistance- or -general program of assistance-. Ambiguity Percentage: 96%"

Among the false negative examples, we can mention the following case:

C4E8: Local police station

AmbiGO output: "This combination is syntactically ambiguous and has two readings: -station of local police- and -local station of police-, after semantic analysis, the valid reading is -station of local police-. Ambiguity Percentage: 13%"

Here both readings seem to be valid and therefore the ambiguity should remain unresolved.

4.3.2 Coordination

The performance of the coordination ambiguity function has also been improved to some extent using the GHP with the improvement from 12% to 51% in precision score.

Some of the true positive cases are mentioned below with the possible readings:

C4E9: Democratic district and county

AmbiGO output: "This combination is ambiguous and has two valid readings, - Democratic district and county- or -Democratic district and Democratic county-. Ambiguity Percentage: 97%"

And the following example is a true negative case which was successfully handled by the tool using the GHP module:

C4E10: High school and college

AmbiGO output: "This combination is syntactically ambiguous and has two readings: -high school and college- and -high school and high college-, after semantic analysis, the valid reading is -high school and college-. Ambiguity Percentage: 0%"

The following example can be considered as a false negative case:

C4E11: Local business and industry

AmbiGO output: "This combination is syntactically ambiguous and has two readings: -local business and industry- and -local business and local industry-, after semantic analysis, the valid reading is -local business and industry-. Ambiguity Percentage: 1%"

where both "local business" and "local industry" are valid readings but the tool preferred only one as the only valid reading.

4.3.3 PP Attachment

The precision score of the attachment function has been improved significantly using the GHP, from 5% to 76%. This case is an example of a correctly resolved (true negative) case:

C4E12: Dallas may get to hear a debate on horse race parimutuels.

AmbiGO output: "Prepositional phrases can attach to both Noun and Verb like - hear on horse- or -a debate on horse-. The valid attachment is -a debate on horse parimutuels -. Ambiguity Percentage: 25% "

While the following example is a false positive case:

C4E13: Fifty-three of the 150 representatives immediately joined the board as co-signers of the proposal

AmbiGO output: *“Prepositional phrases can attach to both Noun and Verb like - joined as co-signers- or –the board as co-signers-. Ambiguity Percentage: 50%”*

Which is not semantically ambiguous since ‘*joined as co-signers*’ is the valid reading and the tool should have resolved the ambiguity by discarding the invalid reading.

Lexical ambiguity can also be a problem while using Google search engine as in example C4E14:

C4E14: Retailers would sign a certificate of correctness

AmbiGO output: *“Prepositional phrases can attach to both Noun and Verb like - sign of correctness- or -a certificate of correctness-. Ambiguity Percentage: 48%”*

In which the tool should have discarded the first reading since it is not grammatical, but the tool failed to do that and considered both readings valid with high frequency count and therefore labels the case as ambiguous.

The reason for this false detection is the lexical ambiguity type homonymy where it can be considered both as a verb and a noun which results in high frequency counts of ‘sign of correctness’ as a noun in Google search. Changing ‘sign’ to some other verb without lexical ambiguity results in the following correct resolution by AmbiGO:

C4E15: Retailers would submit a certificate of correctness

AmbiGO output: *“Prepositional phrases can attach to both Noun and Verb like - submit of correctness- or -a certificate of correctness-. The valid reading is -a certificate of correctness-. Ambiguity Percentage: 0%”*

Another interesting observation is the following example where the ambiguity has been incorrectly missed by AmbiGO:

C4E16: These actions should protect the servants from criticisms.

The reason for this wrong detection is that term ‘protect from criticisms’ has no frequency in Google and consequently the case is considered as unambiguous while ‘protect from criticism’ has relatively high number of frequencies and helps resolving the ambiguity as in the following example:

C4E17: These actions should protect the servants from criticism.

AmbiGO output: *“Prepositional phrases can attach to both Noun and Verb like - protect from criticism- or -the servants from criticism-. The valid reading is - protect from criticism-. Ambiguity Percentage: 0%”*

In this case lemmatization of ‘criticisms’ could have helped but applying lemmatization to all words in the sentence will interrupt the correct POS tagging or inaccurate Google search query because the exact term search in Google is highly dependent on the word form. Apart from that,

according to Clark, “morphological analysis such as lemmatization gives only a small improvement (0.4%)” in automated detection of PPA (Clark, 2013). So, lemmatization has not been considered in this approach.

The next chapter will conclude the implementation and evaluation of AmbiGO based on the findings and the test results of this thesis work.

5 Conclusion

5.1 Summary

In this thesis, we focused on developing an open-source and web-based ambiguity detection and resolution tool, so-called AmbiGO, to detect three different types of syntactic ambiguity, namely analytical, coordination and PP attachment ambiguities, at the sentence level using syntactic analysis and shallow parsing. As a surrogate for semantic analysis, AmbiGO takes frequency counts in WWW for each possible reading into consideration using Google Custom Search API.

AmbiGO has also undergone a small test and the results for each ambiguity function and also the average is summarized in Table 3. However these results are inventory due to the fact that the dataset for testing was too little and a manually-annotated ambiguity gold standard was missing to know the exact amount of false negative cases.

	Precision	Recall	F-measure	Accuracy
Analytical	67%	15%	25%	71%
Coordination	100%	23%	38%	51%
Attachment	100%	17%	29%	76%
Average	89%	18%	30%	70%

Table 3 - Accuracy score for each ambiguity function

5.2 Understandings and contributions

Even though detection of syntactically ambiguous structures are easy using syntactic clues, the results contain a great deal of false positive results. The reason for that can be either incorrect POS tagging or, in a bigger picture, the common sense or the shared knowledge hidden beneath the syntactic level or in other words, on the semantic level. In order to compensate for such shortcoming, AmbiGO was enabled with GHP module as a source of semantic knowledge. This feature was proven to be successful and improved the precision of the tool. It can be concluded that using frequency counts in WWW can be very useful in not only detection, but also resolving ambiguity cases. This has significantly improved the precision score of the tool on each ambiguity detection function.

Another significant finding of this thesis was the hypothesis regarding the linking verbs in PPAA cases. According to this hypothesis, the propositional phrase does not attach to linking verbs and only attaches to action verbs. Therefore, in a sentence containing a linking verb, a noun and a proposition phrase, the propositional phrase can only attach to the noun and consequently the sentence is not ambiguous. This hypothesis was also tested and the results were demonstrated in Chapter 3. To our knowledge, this hypothesis has not been discussed or cited before.

5.3 Lessons learned and possible improvements:

After evaluating AmbiGO's output, the following observations were made which should be taken into consideration in using WWW as a source of semantic knowledge:

- Normalization:
The amount of data in WWW is massive and unstructured which sometimes lead to incorrect logic in terms of frequency counts. Case C3E10 is an example where high frequency count of a phrase has led to an incorrect ambiguity resolution by AmbiGO. As an improvement, some algorithms can be added to the script to 'normalize' the retrieved data against the frequency counts of every single word in the entire query to have a more reliable input from Google. Such normalization algorithms, however, have not been included in the current version of AmbiGO.
- Lemmatization:
It has also been noticed in some cases lemmatization, e.g. using the present tense of the verb or singular form of a noun in the query, helps to retrieve more reliable input from Google. Case C4E16 is an example of possible improvement using lemmatization.
- Lexical ambiguity:
As explained in case C4E14, the lexical ambiguity in the word 'sign' has caused incorrect ambiguity resolution by AmbiGO.

These topics can be good subjects for future improvement to AmbiGO. The tool can also be empowered by adding more functions and ambiguity detection patterns to AmbiGO's already-built infrastructure to cover a more variety of ambiguity cases and types.

And finally, as mention in Chapter 4, the precision and accuracy presented in section 4.2 were not reliable due to a small testing dataset and also the lack of a gold standard with all known ambiguity cases. In order to have a more accurate precision and accuracy. Therefore testing AmbiGO with a more reliable testing material will result in more accurate precision and accuracy scores.

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Summary

Legend

True Positive (TP)	the detected case is ambiguous and AmbiGo correctly marks it as ambiguous
False Positive (FP)	the detected case is UNambiguous and AmbiGo wrongly marks it as ambiguous
True Negative (TN)	the detected case is UNambiguous and AmbiGo correctly resolves it with a valid reading
False Negative (FN)	the detected case is ambiguous and AmbiGo wrongly resolves it with a valid reading

precision	$TP / (TP+FP)$
recall (test 2 only)	$TP / (TP+FN)$
f-score (test 2 only)	$2 * (prec * recall) / (prec + recall)$
accuracy (test 2 only)	$(TP + TN) / (TP+FP+TN+FN)$

	Analytical	Coordination	Attachment	average
TP	2	3	1	
FP	1	0	0	
TN	30	12	15	
FN	11	10	5	
total	44	25	21	
Test 1 Precision	5%	12%	5%	7%
Test 2 Precision	67%	100%	100%	89%
Recall	15%	23%	17%	18%
F-score	25%	38%	29%	30%
Accuracy	73%	60%	76%	70%

Analytical

detected case	AmbiGO output	human judgement	comment
general assistance program	possible readings: -program of general assistance- or -general program of assistance-. AP: 96% general assistance program	tp	
amicable property settlement	possible readings: -settlement of amicable property- and -amicable settlement of property-, the valid reading is -amicable settlement of property-. AP: 0% amicable property settlement	tn	
general election ballot	possible readings: -ballot of general election- and -general ballot of election-, the valid reading is -ballot of general election-. AP: 0% general election ballot	tn	
public relations director	possible readings: -director of public relations- and -public director of relations-, the valid reading is -director of public relations-. AP: 0% public relations director	tn	
rural road construction	possible readings: -construction of rural road- and -rural construction of road-, the valid reading is -construction of rural road-. AP: 12% rural road construction	fn	
future Legislature sessions	possible readings: -sessions of future Legislature- and -future sessions of Legislature-, the valid reading is -future sessions of Legislature-. AP: 3% future Legislature sessions	tn	
rural roads bonds	possible readings: -bonds of rural roads- and -rural bonds of roads-, the valid reading is -bonds of rural roads-. AP: 0% rural roads bonds	tn	
new school superintendent	possible readings: -superintendent of new school- and -new superintendent of school-, the valid reading is -superintendent of new school-. AP: 1% new school superintendent	tn	
local option proposal	possible readings: -proposal of local option- and -local proposal of option-, the valid reading is -proposal of local option-. AP: 1% local option proposal	tn	
miscellaneous excise taxes	possible readings: -taxes of miscellaneous excise- and -miscellaneous taxes of excise-, the valid reading is -miscellaneous taxes of excise-. AP: 3% miscellaneous excise taxes	tn	
real estate brokers	possible readings: -brokers of real estate- and -real brokers of estate-, the valid reading is -brokers of real estate-. AP: 0% real estate brokers	tn	
public utility companies	possible readings: -companies of public utility- and -public companies of utility-, the valid reading is -companies of public utility-. AP: 7% public utility companies	tn	
local water project	possible readings: -project of local water- and -local project of water-, the valid reading is -project of local water-. AP: 31% local water project	fn	
social security system	possible readings: -system of social security- and -social system of security-, the valid reading is -system of social security-. AP: 13% social security system	tn	
federal housing chief	possible readings: -chief of federal housing- and -federal chief of housing-, the valid reading is -chief of federal housing-. AP: 3% federal housing chief	tn	
paid-for nursing home	possible readings: -home of paid-for nursing- and -paid-for home of nursing-, the valid reading is -paid-for home of nursing-. AP: 5% paid-for nursing home	fn	
annual tax boost	possible readings: -boost of annual tax- and -annual boost of tax-, the valid reading is -boost of annual tax-. AP: 0% annual tax boost	tn	
social security costs	possible readings: -costs of social security- and -social costs of security-, the valid reading is -costs of social security-. AP: 2% social security costs	tn	
Similar payroll tax	possible readings: -tax of Similar payroll- and -Similar tax of payroll-, the valid reading is -Similar tax of payroll-. AP: 2% Similar payroll tax	fn	
aged care plan	aged care plan	-	incorrect POS tagging
medical care program	possible readings: -program of medical care- and -medical program of care-, the valid reading is -program of medical care-. AP: 1% medical care program	tn	
last minute decisions	possible readings: -decisions of last minute- and -last decisions of minute-, the valid reading is -decisions of last minute-. AP: 0% last minute decisions	tn	
4-year college requirement	possible readings: -requirement of 4-year college- and -4-year requirement of college-, the valid reading is -requirement of 4-year college-. AP: 0% 4-year college requirement	tn	
high school teaching	possible readings: -teaching of high school- and -high teaching of school-, the valid reading is -teaching of high school-. AP: 0% high school teaching	tn	
foreign policy decisions	possible readings: -decisions of foreign policy- and -foreign decisions of policy-, the valid reading is -decisions of foreign policy-. AP: 0% foreign policy decisions	tn	
economic aid policies	possible readings: -policies of economic aid- and -economic policies of aid-, the valid reading is -economic policies of aid-. AP: 12% economic aid policies	fn	
international control commission	possible readings: -commission of international control- and -international commission of control-, the valid reading is -international commission of control-. AP: 12% international control commission	fn	
international inspection system	possible readings: -system of international inspection- and -international system of inspection-, the valid reading is -international system of inspection-. AP: 2% international inspection system	tn	
global danger points	possible readings: -points of global danger- or -global points of danger-. AP: 58% global danger points	tp	
special town meeting	possible readings: -meeting of special town- and -special meeting of town-, the valid reading is -special meeting of town-. AP: 10% special town meeting	tn	
free enterprise track	possible readings: -track of free enterprise- and -free track of enterprise-, the valid reading is -track of free enterprise-. AP: 26% free enterprise track	tn	
common decency charge	possible readings: -charge of common decency- and -common charge of decency-, the valid reading is -charge of common decency-. AP: 9% common decency charge	fn	
local police station	possible readings: -station of local police- and -local station of police-, the valid reading is -station of local police-. AP: 13% local police station	fn	
full-time CD director	possible readings: -director of full-time CD- and -full-time director of CD-, the valid reading is -full-time director of CD-. AP: 4% full-time CD director	fn	
previous grand juries	possible readings: -juries of previous grand- and -previous juries of grand-, the valid reading is -juries of previous grand-. AP: 0% previous grand juries	fn	
friendly test suit	friendly test suit	-	incorrect POS tagging

anonymous midnight phone-calls	possible readings: -phone-calls of anonymous midnight- and -anonymous phone-calls of midnight-, the valid reading is -anonymous phone-calls of midnight-. AP: 2%	tn	
county-wide day schools	anonymous midnight phone-calls possible readings: -schools of county-wide day- or -county-wide schools of day-. AP: 83% county-wide day schools	fp	
big cities Thursday	possible readings: -Thursday of big cities- and -big Thursday of cities-, the valid reading is -Thursday of big cities-. AP: 0% big cities Thursday	-	incorrect POS tagging
national child health	possible readings: -health of national child- and -national health of child-, the valid reading is -national health of child-. AP: 6% national child health	tn	
direct government research	possible readings: -research of direct government- or -direct research of government-. AP: 69% direct government research	fn	
first year students	possible readings: -students of first year- and -first students of year-, the valid reading is -students of first year-. AP: 1% first year students	tn	
extended hospital stay	readings, -stay of extended hospital- and -extended stay of hospital-, the valid reading is -extended stay of hospital-. Ambiguity Percentage: 1%	tn	
other White House	possible readings: -House of other White- or -other House of White-. AP: 63% other White House	-	incorrect POS tagging
last eight years	possible readings: -years of last eight- and -last years of eight-, the valid reading is -last years of eight-. AP: 23% last eight years	-	incorrect POS tagging
new ad hoc	possible readings: -hoc of new ad- and -new hoc of ad-, the valid reading is -hoc of new ad-. AP: 0% new ad hoc	-	incorrect POS tagging
heavy court costs	possible readings: -costs of heavy court- and -heavy costs of court-, the valid reading is -heavy costs of court-. AP: 11% heavy court costs	tn	
several Superior Court	possible readings: -Court of several Superior- and -several Court of Superior-, the valid reading is -several Court of Superior-. AP: 19% several Superior Court	tn	
former Fire Chief	possible readings: -Chief of former Fire- and -former Chief of Fire-, the valid reading is -former Chief of Fire-. AP: 4% former Fire Chief	tn	
nuclear test ban	possible readings: -ban of nuclear test- and -nuclear ban of test-, the valid reading is -ban of nuclear test-. AP: 1% nuclear test ban	tn	

Coordination

detected case	AmbiGO output	human judgement	comment
medical intern or extern	possible readings: -medical intern or extern- and -medical intern or medical extern-, the valid reading is -medical intern or extern-. AP: 1% medical intern or extern	fn	
social security or railroad	possible readings: -social security or railroad- and -social security or social railroad-, the valid reading is -social security or railroad-. AP: 0% social security or railroad	tn	
social security and railroad	possible readings: -social security and railroad- and -social security and social railroad-, the valid reading is -social security and railroad-. AP: 0% social security and railroad	tn	
Democratic rank and file	possible readings: -Democratic rank and file- and -Democratic rank and Democratic file-, the valid reading is -Democratic rank and file-. AP: 11% Democratic rank and file	tn	
major conflict or opposition	possible readings: -major conflict or opposition- and -major conflict or major opposition-, the valid reading is -major conflict or opposition-. AP: 33% major conflict or opposition	fn	
cordial understanding and relaxation	possible readings: -cordial understanding and relaxation- and -cordial understanding and cordial relaxation-, the valid reading is -cordial understanding and relaxation-. AP: 0% cordial understanding and relaxation	tn	
annual dinner and show	Possible readings: -annual dinner and show- or -annual dinner and annual show-. AP: 80% annual dinner and show	tp	
other uncles and aunts	possible readings: -other uncles and aunts- and -other uncles and other aunts-, the valid reading is -other uncles and other aunts-. AP: 48% other uncles and aunts	tn	
such variety and beauty	possible readings: -such variety and beauty- and -such variety and such beauty-, the valid reading is -such variety and such beauty-. AP: 12% such variety and beauty	-	incorrect POS tagging
key streets and cars	possible readings: -key streets and cars- and -key streets and key cars-, the valid reading is -key streets and key cars-. AP: 26% key streets and cars	tn	
such neighbors and friends	possible readings: -such neighbors and friends- and -such neighbors and such friends-, the valid reading is -such neighbors and such friends-. AP: 10% such neighbors and friends	-	incorrect POS tagging
educational program and facilities	possible readings: -educational program and facilities- and -educational program and educational facilities-, the valid reading is -educational program and facilities-. AP: 39% educational program and facilities	fn	
young wildlife and livestock	possible readings: -young wildlife and livestock- and -young wildlife and young livestock-, the valid reading is -young wildlife and livestock-. AP: 25% young wildlife and livestock	fn	
legislative session and defend	possible readings: -legislative session and defend- and -legislative session and legislative defend-, the valid reading is -legislative session and defend-. AP: 0% legislative session and defend	tn	
theatrical producer and band	possible readings: -theatrical producer and band- and -theatrical producer and theatrical band-, the valid reading is -theatrical producer and band-. AP: 4% theatrical producer and band	fn	
local business and industry	possible readings: -local business and industry- and -local business and local industry-, the valid reading is -local business and industry-. AP: 1% local business and industry	fn	
interstate transportation and conspiracy	possible readings: -interstate transportation and conspiracy- and -interstate transportation and interstate conspiracy-, the valid reading is -interstate transportation and conspiracy-. AP: 0% interstate transportation and conspiracy	tn	
nuclear weapons and jolt	possible readings: -nuclear weapons and jolt- and -nuclear weapons and nuclear jolt-, the valid reading is -nuclear weapons and jolt-. AP: 0% nuclear weapons and jolt	tn	
new orders and sales	possible readings: -new orders and sales- and -new orders and new sales-, the valid reading is -new orders and new sales-. AP: 41% new orders and sales	tn	
slow-baked ham and sprinkle	possible readings: -slow-baked ham and sprinkle- and -slow-baked ham and slow-baked sprinkle-, the valid reading is -slow-baked ham and sprinkle-. AP: 0% slow-baked ham and sprinkle	-	incorrect POS tagging
critical eyes and tongues	possible readings: -critical eyes and tongues- and -critical eyes and critical tongues-, the valid reading is -critical eyes and tongues-. AP: 0% critical eyes and tongues	fn	
high school and college	possible readings: -high school and college- and -high school and high college-, the valid reading is -high school and college-. AP: 0% high school and college	tn	
young men and women	Possible readings: -young men and women- or -young men and young women-. AP: 99% young men and women	tp	
various paintings and sculptures	possible readings: -various paintings and sculptures- and -various paintings and various sculptures-, the valid reading is -various paintings and sculptures-. AP: 42% various paintings and sculptures	fn	
Soviet tanks and artillery	possible readings: -Soviet tanks and artillery- and -Soviet tanks and Soviet artillery-, the valid reading is -Soviet tanks and artillery-. AP: 20% Soviet tanks and artillery	fn	
first-class paintings and sculptures	first-class paintings and sculptures	-	incorrect POS tagging

new enthusiasm and reliance	Possible readings: -new enthusiasm and reliance- or -new enthusiasm and new reliance-. AP: 62% new enthusiasm and reliance	tp
new products and methods	possible readings: -new products and methods- and -new products and new methods-, the valid reading is -new products and methods-. AP: 3% new products and methods	fn
public understanding and support	possible readings: -public understanding and support- and -public understanding and public support-, the valid reading is -public understanding and public support-. AP: 34% public understanding and support	tn

PP Attachment

detected case	AmbiGO output	human judgement	comment
considering the widespread interest in the election , the number of voters and the size of this city	possible attachments: -considering in the election- or -the widespread interest in the election-. the valid attachemnt is -the widespread interest in the election-. AP: 37% considering the widespread interest in the election , the number of voters and the size of this city	tn	
The grand jury took a swipe at the State Welfare Department	possible attachments: -took at the State- or -a swipe at the State-. the valid attachemnt is -a swipe at the State-. AP: 0% The grand jury took a swipe at the State Welfare Department	tn	
has seen fit to distribute these funds through the welfare departments	possible attachments: -distribute through the welfare- or -these funds through the welfare-. the valid attachemnt is -these funds through the welfare-. AP: 0% has seen fit to distribute these funds through the welfare departments	fn	
Fulton County should receive some portion of these available funds	possible attachments: -receive of these available funds- or -some portion of these available funds-. the valid attachemnt is -some portion of these available funds-. AP: 0% Fulton County should receive some portion of these available funds	tn	
Mayor William B. Hartsfield filed suit for divorce from his wife	possible attachments: -filed for divorce- or -suit for divorce-. the valid attachemnt is -filed for divorce-. AP: 6% Mayor William B. Hartsfield filed suit for divorce from his wife	fn	
a meeting held Tuesday night in Blue Ridge brought enthusiastic responses from the audience	possible attachments: -brought from the audience- or -enthusiastic responses from the audience-. the valid attachemnt is -enthusiastic responses from the audience-. AP: 2% a meeting held Tuesday night in Blue Ridge brought enthusiastic responses from the audience	tn	
in the event Congress does provide this increase in federal funds	possible attachments: -provide in federal funds- or -this increase in federal funds-. the valid attachemnt is -this increase in federal funds-. AP: 0% in the event Congress does provide this increase in federal funds	tn	
I didn't Smell a drop of liquor	possible attachments: -smell of liquor- or -a drop of liquor-. the valid attachemnt is -smell of liquor-. AP: 41% I did n't smell a drop of liquor	fn	
It was marked by controversy , anonymous midnight phone calls and veiled threats of violence	possible attachemnts -veiled of violence- or -threats of violence-. But according to Google the valid attachment is -threats of violence-. Ambiguity Percentage: 0%'	tn	
Daniel personally led the fight for the measure	possible attachments: -led for the measure- or -the fight for the measure-. the valid attachemnt is -the fight for the measure-. AP: 25% Daniel personally led the fight for the measure	tn	
If you destroy confidence in banks , you do something to the economy	possible attachments: -destroy in banks- or -confidence in banks-. the valid attachemnt is -confidence in banks-. AP: 0% If you destroy confidence in banks , you do something to the economy	tn	
Operating budget for the day schools	possible attachments: -Operating for the day- or -budget for the day-. the valid attachemnt is -budget for the day-. AP: 3% Operating budget for the day schools	-	incorrect POS tagging
Dallas may get to hear a debate on horse race parimutuels	possible attachments: -hear on horse- or -a debate on horse-. the valid attachemnt is -a debate on horse-. AP: 25% Dallas may get to hear a debate on horse race parimutuels	tn	
One validated acts of school districts	possible attachments: -validated of school- or -acts of school-. the valid attachemnt is -acts of school-. AP: 0% One validated acts of school districts	-	incorrect POS tagging
Without dissent , senators passed a bill by Sen. A. R. Schwartz of Galveston	possible attachments: -passed by Sen.- or -a bill by Sen.-. the valid attachemnt is -passed by Sen.-. AP: 38% Without dissent , senators passed a bill by Sen. A. R. Schwartz of Galveston	fn	
17,000 retailers who pay a group of miscellaneous excise taxes by eliminating the requirement that each return be notarized	possible attachments: -eliminating that each return- or -the requirement that each return-. but the valid attachment seems to be -the requirement that each return-. Ambiguity Percentage: 0%'	fn	
Instead , retailers would sign a certificate of correctness of El Paso , to acquire sites for underground storage	possible attachments: -sign of correctness- or -a certificate of correctness-. the valid attachemnt is -sign of correctness-. AP: 47% Instead , retailers would sign a certificate of correctness	tn	
reservoirs for gas	possible attachments: -acquire for underground- or -sites for underground-. the valid attachemnt is -sites for underground-. AP: 0% of El Paso , to acquire sites for underground storage reservoirs for gas	tn	
the State Affairs Committee a bill which would order the referendum on the April 4 ballot	possible attachments: -order on the April- or -the referendum on the April-. the valid attachemnt is -the referendum on the April-. AP: 0% the State Affairs Committee a bill which would order the referendum on the April 4 ballot	tn	
Opponents generally argued that the ballot couldn't give enough information about tax proposals	possible attachments: -give about tax- or -enough information about tax-. the valid attachemnt is -enough information about tax-. AP: 20% Opponents generally argued that the ballot could n't give enough information about tax proposals	tn	
Cotten felt could better be spent providing water for rural Texas	possible attachments: -providing for rural Texas- or -water for rural Texas-. the valid attachemnt is -water for rural Texas-. AP: 0% Cotten felt could better be spent providing water for rural Texas	tn	
Fifty-three of the 150 representatives immediately joined Grover as co-signers of the proposal	possible attachments: -joined as co-signers- or -Grover as co-signers-. AP: 50% Fifty-three of the 150 representatives immediately joined Grover as co-signers of the proposal	tp	
Dr. Clark holds an earned Doctor of Education degree	possible attachments: -holds of Education- or -an earned Doctor of Education-. the valid attachemnt is -an earned Doctor of Education-. AP: 11% Dr. Clark holds an earned Doctor of Education degree	tn	