Scope Quantifier Ambiguity Recognition and Resolution in Natural Language Processing

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Abstract. The following approach to scope ambiguity will specifically focus on quantifiers, such as 'every' and 'some', and a machine learning approach to their identification, as well as their resolution. By implementing HPSG (Head-driven phrase structure grammar) and Centering Theory, as well as exploring inherent language processing techniques, such as presupposition accommodation, coreference resolution, and discourse representation theory, this approach aims to avoid over-generalization and increase the accuracy by which machine learning replicates the processing of scope ambiguity and resolves its semantic role in a similar manner to humans. Constructed using the third generation programming language C++, the program, using a restricted lexicon and data gathered from the web, analyzes manually labeled data sets, parses the data sets into a syntactically accurate tree form, processes the features of the anaphora, quantifiers, and noun phrases in order to correctly identify the scope, and conducts supervised learning with the results, offering an alternative and combinational methodology to scope quantifier ambiguity and how it is addressed in NLP.

I. Introduction

Scope quantifier ambiguity resolution is a generally subconscious cognitive process in which humans are able to solve for ambiguity in utterances lead by scope quantifiers. This ambiguity generally stems from the quantifiers themselves, which sit in the determiner position syntactically, and correlate to the manner in which the scope is defined between the quantifiers and the following quantified terms (Kurtzman & MacDonald, 1993). Specificity of quantifiers often affects the ambiguity of the utterances, though this is not wholly the reason for ambiguity with scope quantifiers (Ioup, 1975). For example, the phrase "Every cat walked in and it sat down" shows scope quantifier ambiguity between 'every cat', and whether or not 'it' refers to not only a singular cat – or other- type walking in and sitting down, or alternatively every cat walking in and thus every cat sitting down, as represented respectively in (1a) and (1b).

(1a). $\forall x[cat(x) \rightarrow (walked\ in(x))] \wedge sat(y)$

#(1b). $\forall x[cat(x) \rightarrow (walked\ in(x) \wedge sat\ down(x))]$

In 1a, it follows that 'every cat' is of a wide scope, while 'it' is of a narrow scope. In this case, the wide scope property of 'every cat' allows for every cat to preside over the entire utterance, while the narrow scope of 'it' limits what 'it' refers to (Brasoveanu, 2011). 1b, contrastingly, defines 'every cat' as a narrow scope, while 'it' takes the property of a wide scope. In this case, the wide scope of 'it' allows the scope to extend to 'every cat', which has a narrow scope, and thus specific referents, and in return the semantic properties are extended from 'every cat' to 'it' (Brasoveanu, 2011). Here, we see the semantic interpretation of 'it' mirror that of 'every cat', whereas in 1a, the identity and semantic relations of 'it' are ambiguous and may be interpreted differently based on gender or numeric semantic features that are either defaulted by the listener, or decided based on preceding and following context clues (Kurtzman & MacDonald, 1993).

Due to the relatively subconscious resolution of these ambiguities in natural language, the cognitive layout is not very well understood. As a result, replicating this process computationally proves to be a problem in the natural language processing community and has yet to find a universal solution to the problem. Depending on the utterance, it may be that scope quantifier ambiguity is more or less complicated by other semantic features provided by context (Micham, D., Catlin, J., VanDerveer, J, & Loveland, K., 1980). Additionally, there is no one universal language in which scope quantifier ambiguities can be solved as a whole. Many approaches have been taken, including coreference resolution, HPSG (head-phrase structure grammar), and centering theory, and while advances have been made these proposals individually have fallen short in one way or another. By combining these processes, along with computational parsers to resolve syntactic parts of speech, and databases to provide semantic features that mimic that of a natural language lexicon, this program's algorithms aim to propose a solution in order to advance the resolution of scope quantifier ambiguity in natural language processing.

II. Related Syntactic Approaches

Syntactically, pronoun resolution is crucial to the resolution of scope quantifier ambiguity. Pronoun resolution alone in natural language is not a simple process, but seems so due to the cognitive process by which it occurs. There exists a hierarchy to pronoun resolution, where subjects are often preferred over objects, closer syntactic positioning is preferred over further distancing, and a list of logical entities is needed to choose from in order to provide an antecedent to the pronoun (Hobbs, 1976). Moreover, "focus elements" are preferred, or rather elements determined from previous specifying questions- in general coreference resolution is equal parts, if not more, inferencing from context and questioning, rather than from explicit declarations, such as positions (Hobbs, 1976). Somewhat expectedly, the best performing models of coreferencing are those with a heuristic approach (Hobbs, 1976; Lappin & Leass, 1994; Mitkov, 1998), or rather one that is focused less in a psychological approach. Grosz and Sidner (Grosz, 1977; Sidner, 1979) created an approach concentrated on focusing effects (Anderson, Garrod, & Sanford, 1977; Sanford & Garrod, 1994), which plays a large part in coreference resolution and read times in humans.

Of the available pronoun resolution approaches to scope quantifier ambiguity, the most productive approach is Centering Theory, proposed by the (Grosz, Joshi, & Weinstein, 1995) study, *Centering: A Framework for Modeling the Local Coherence of Discourse*. Centering Theory depends on the types of referents, as well as the syntactic structure of serially occurring sentences, and utilizes these properties into order to resolve the assignments of anaphora to their antecedents. According to Centering Theory's proposals, each utterance contains one backward looking center and a set of forward looking centers (Grosz, Joshi, & Weinstein, 1995). The backward looking center is constrained by the previous utterance's center looking forward tied to the pronoun, whereas the list of entities that make up the forward looking centers of the designated utterance depend only on the utterance's entities itself- not the previous utterances (Grosz, Joshi, & Weinstein, 1995). Backward looking centers relate to forward looking centers in a sense of 'directly realizing 'or a sense of 'realizing' one another (Grosz, Joshi, & Weinstein, 1995; Kehler, 1997). If the backward looking center is of a direct relation to the forward looking center, it is directly realized. Alternatively, when a backward looking center is first introduced, or its existence is indirectly related to the forward looking center, the relation is simply 'realized' (Grosz, Joshi, & Weinstein, 1995). The realization of the centers is a property that is applied when the utterances of a discourse undergo the most important aspect of Centering Theory- shifting.

Utterances within a given discourse undergo one of four types of shifting, respectively: continue, retain, smooth-shift, and rough-shift. According the BFP algorithm, proposed by Brennan, Friedman, and Pollard in their 1987 research, the progressive likelihood of the decided forward looking cener of each shift determines which center looking forward belongs to the pronoun in the utterance (Kehler, 1997). Continue's result is preferred as the forward looking center over retain, retain is preferred over smooth-shift, and smooth-shift's result of forward looking center is preferred over rough-shift (Kehler 1997). Moreover, forward looking center's that have continued type of shifts are also more preferred, potentially overriding the preferred center looking forward type of shift itself. For example, a forward looking center continually shifted under smooth-shift will be more inclined to be the preferred forward looking center if smooth shift is possible for calculation, even if continue is the more likely result. The result of Centering Theory's application using the BFP algorithm is shown in (Grosz, Joshi, & Weinstein, 1995):

(2a). Terry really goofs sometimes.

(2b). Yesterday was a beautiful day and he was excited about trying out his
new sailboat.

(2c). He wanted Tony to join him on a sailing expedition.

(2d). He called him at 6AM.

(2e). He was sick and furious at being woken up so early.

In (2a), Terry is the original forward looking center entity. In (2b), Terry is both the forward looking center as well as the backward looking center. Moving into (2c), it is found that Terry is continuing to hold the position of forward looking center, while Tony is introduced as the new backward looking center. The forward looking center and backward looking center positions are held through (2d). However, between (2d) and (2e), the subject referent changed its referred entity- in this case, he in (2d) referred to Terry, but in 2e he refers to Tony. In addition, the forward looking center and backward looking center positions are switched. This is understood under the shift calculations per utterance from (2c) to (2d), and (2d) to (2e).

The following representations of shifting in Centering Theory, (3a) and (3b), as proposed by the BFP algorithm are marked by Cb as the backward looking center, Cp as the forward looking center as decided through previous shifts between utterances, and Ui as the list of forward looking center entities per utterance (Grosz, Joshi, & Weinstein, 1995). An increment of 1 indicates the next sentence in serial to the utterance, while a lack of numerical increment indicates the current utterance (Kehler 1997).

(3a). {[Cb(Ui+1)= =Cp(Ui+1)]^[[Cb(Ui+1)= =Cb(Ui)] || [Cb(Ui)]]= =?}
Continue Coherence

(3b). {![Cb(Ui+1)= =Cp(Ui+1)]^[[Cb(Ui+1)= =Cb(Ui)] || [Cb(Ui)]= = ?]}
Retain Coherence

(3c). {[Cb(Ui+1)= =Cp(Ui+1)] ^![Cb(Ui+1)= =Cb(Ui)]}
Smooth Shift Coherence

(3d). {![Cb(Ui+1)= =Cp(Ui+1) ^ ![Cb(Ui+1)= =Cb(Ui)]}
Rough Shift Coherence

In regards to discourse coherence as a whole, centering theory as a syntactic approach is not enough to determine the correct referents per pronoun. The BFP algorithm alone focuses solely on the syntactic placement, as well as the morphological structure and other Centering Theory constraints, of the centers to correctly calculate a forward looking center (Grosz, Joshi, & Weinstein, 1995). However, Centering Theory openly states that there are many semantic features that must be included in the calculations in order to correctly determine the forward looking center of each utterance (Grosz, Joshi, & Weinstein, 1995). This type of claim can be seen easily in the shift between examples 2d and 2e, where with added context, the pronouns in the examples could possibly refer to entities beyond the entities in the utterances. Alternatively, it is the properties of the verbs that solidify whether a proposed forward looking center is logical in discourse coherence, not just syntactically correct and semantically appropriate (Pollard & Sag, 1994). While (Grosz, Joshi, & Weinstein, 1995)'s claim is both correct and attainable, computationally this poses problems. While semantic features are integrated into natural language, computationally a database would need to be created in order to maintain all features of any given word in a lexicon, as well as position of speech properties (Veronis & Ide, 1992). Additionally, beyond centering theory, context plays a large role in discourse coherence, and neither BFP, nor Centering Theory as a whole compensate for it.

Due to these problems, it is impossible to approach scope quantifier ambiguity, a problem that relies heavily on semantic features and context, with Centering Theory alone.

III. Related Semantic Approaches

Incorporating semantic features into scope quantifier ambiguity is significantly harder than syntactic approaches. Moreover, because the semantic features of natural language are built in, and often times seem implicit due to the cognitive processing (Hatch & Brown, 1995), semantic features computationally are inexistent. They must be created and learned via user input empirically, as seen in (Gildea & Jurafsky, 2002), *Automatic Labeling of Semantic Roles*. These semantic features additionally extend beyond simple gender features, or numeric properties, though both features are crucial to pronoun resolution and thus also scope quantifier ambiguity. Rather, semantic features must be able to compensate for instances such as in sentences (1a) and (1b), changing the phrase "every cat walked in and it sat down" to two alternative phrases:

(4a). ∀x[cat(x) -> (walked in(x))] ^ ɩx[(cat(x) ^ big(x)) -> (sat down(x))]

*(4b). ∀x[cat(x) -> (walked in(x))] ^ ɩx[cat(x) -> (sat down(x))]

Where 4a denotes "every cat walked in and the big cat, presupposed that there is one and only one big cat, sat down" and 4b denotes "every cat walked in and the (some specific, but unspecified cat) sat down". 4b is an illogical sentence due to semantic features, despite that syntactically it is undeniably correct.

This particular example can be solved in natural language through a proposed theory called Presupposition Accommodation. Presupposition Accommodation, addressed by (Stalnaker, 1999) *In Context and Content,* states that in some circumstances the speaker speaks as if the auditor has prior background knowledge to what the speaker is referring to, for various reasons, even if the speaker knows that the auditor does not. Because the speaker is aware that the auditor does not share the same background knowledge, the speaker presupposes enough information that the auditor is able to infer the meaning from the context of the conversation (Stalnaker, 1999). This could be done for the sake of time and explanation, as is the case for sentence (4a). While 'every cat walked in' does not explicitly state the types of cats walking in, 'the pretty cat' can be implicitly reasoned to exist because no other contrasting data was given. The types of cats could be infinite, and thus it is reasonable that out of every cat, there exists one that is pretty. However, sentences 4b states that while 'every cat walked in', 'the cat' sat down. 'The cat' is underspecified and contrasted by 'every cat', since there is more than one and 'the cat' lacks the features to differentiate a specified cat from another. Thus 'the cat' is unable to be implicitly resolved and the sentence, again though syntactically correct, is semantically illogical.

The most important semantic approach to scope quantifier ambiguity, however, is that of Head-Driven Phrase Structure Grammar. As proposed in Daniel Flickinger's 1987 dissertation *Lexical Rules in the Hierarchal Lexicon*, Head-Driven Phrase Structure Grammar (hereon known as HPSG), proposes the idea that items in the natural language lexicon are not simply entries. Instead, HPSG proposes that lexical entries are structured with a hierarchal set of features (Pollard & Sag, 1994). These features extend out to every position of speech and word type, and the idea of HPSG has developed into a large community within NLP. While HPSG is highly focused on syntactic value, it provides a basis for semantic features to be built upon as well.

HPSG defines lexical entries' syntactic properties into a set of features, with both atomic and category values, and subcategorization specifications, including complements and adjuncts (Flickinger, 1987). Furthermore, atomic values may be Binary, Inverted, Vform, Complete, Lexical, Cat (category), and Case (Flickinger, 1987). Entries are even more broadly categorized by the classes and superclasses. A superclass of Part-of-Speech includes Major and Minor superclasses, which further deviate to nouns, verbs, adjectives, and prepositions to the major superclass, and determiners, conjunctions and complementizers to the minor superclass (Flickinger, 1987). Complementation follows as the second super class on the hierarchal level of Part-of-Speech, and divides entries into Complete or Incomplete, meaning the entry either does or does not require arguments, respectively (Flickinger, 1987). The subcategories of category values, subcategorization, complements, and adjuncts range so numerous that the expanded upon features are limited to that of determiners and adjectives for the sake of scope quantifier ambiguity. Flickinger's description for Adjective classes are limited, and provide no other features outside of belonging to the Major superclass, and containing the CAT atomic feature. Determiners, alternatively, belong to the Minor superclass, with the CAT atomic feature and as well as the Determiner types and Agreement feature (Pollard & Sag, 1994).

The semantic features of Flickinger's work alone are restricted to thematic roles, and offer much to be expanded upon (Flickinger 1987). Regardless, the semantic representations of the lexical entry are included within the lexical representation and its hierarchy in HPSG, and will proceed to be the main component in the development of computational resolution for scope quantifier ambiguity.

IV. Methods

Furthermore, in addition to the natural language approaches to scope quantifier ambiguity previously mentioned, this approach adds an additional entry to the HPSG lexical structure of Adjectives. Adjectives, such as 'every' and 'some', among other quantifiers, fit into the position of determiners syntactically. Because of this, I felt it best in this proposal to classify the quantifiers traditionally as adjectives, with the atomic feature of a determiner type, allowing the quantifiers to take on the properties of determiners without changing their part of speech classification. Additionally, I created a new feature on the equivalent level of subcategorization specifications and features, called a scope feature. This feature is limited to adjectives, and further more to quantifier adjectives. Ideally the hierarchy for this feature would be narrowed down using the semantic

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Universal Quantifiers:
Superclass :: MAJOR
Atomic features :: CAT Adjective, DType
Complements::
  Subject Features:: CAT Noun, CASE NOMINATIVE, SINGULAR, GENDER
Scope::
  Scope Features:: Universal-Universal, Subject, SINGULAR Subj
  Scope Features:: Universal-Anaphor, GENDER Subj, Subject
  Scope Features:: Universal-Existential, Subject
  Scope Features:: Universal-Numeric, Subject
  Scope Features:: Universal-Semi, Subject
  Scope Features:: Universal-Determiner, Subject

Existential Quantifiers:
Superclass :: MAJOR
Atomic features :: CAT Adjective, DType
Complements::
  Subject Features:: CAT Noun, CASE NOMINATIVE, PLURAL, GENDER
  Subject Features:: CAT Noun, CASE NOMINATIVE, SINGULAR, GENDER
Scope::
  Scope Features:: Existential- Numeric, Subject
  Scope Features:: Existential-Semi, Subject
  Scope Features:: Existential-Determiner, Subject

Semi-Universal Quantifiers:
Superclass :: MAJOR
Atomic features :: CAT Adjective, DType
Complements::
  Subject Features:: CAT Noun, CASE NOMINATIVE, PLURAL, GENDER
Scope::
  Scope Features:: Semi-Numeric, Subject
  Scope Features:: Semi-Determiner, Subject

Numeric Quantifiers:
Superclass :: MAJOR
Atomic features :: CAT Adjective, DType
Complements::
  Subject Features:: CAT Noun, CASE NOMINATIVE, PLURAL, GENDER
  Subject Features:: CAT Noun, CASE NOMINATIVE, SINGULAR, GENDER
Scope::
  Scope Features:: Numeric-Numeric, Subject,  AGREEMENT PLURAL Subj
      || AGREEMENT SINGULAR Subj
  Scope Features:: Numeric-Universal, Subject
  Scope Features:: Numeric-Anaphor, GENDER Subj, Subject, SINGULAR Subj
  Scope Features:: Numeric-Semi, Subject
  Scope Features:: Numeric-Determiner, Subject

Determiner Quantifiers:
Superclass :: MAJOR
Atomic features :: CAT Adjective, DType
Complements::
  Subject Features:: CAT Noun, CASE NOMINATIVE, SINGULAR, GENDER
  Subject Features:: CAT Noun, CASE NOMINATIVE, PLURAL, GENDER
  Determiner Features:: SINGULAR
  Determiner Features:: PLURAL
Scope::
  Scope Features:: Determiner- Determiner, Subject, GENDER, AGREEMENT
SINGULAR
     Subj/Det || AGREEMENT PLURAL Subj/Det
  Scope Features:: Determiner- Anaphor, Subject, GENDER, AGREEMENT
SINGULAR
     Subj || AGREEMENT PLURAL Subj

Anaphor Quantifiers:
Superclass :: MAJOR
Atomic features :: CAT Adjective, DType
Complements::
  Subject Features:: CAT Noun, CASE NOMINATIVE, PLURAL, GENDER
  Subject Features:: CAT Noun, CASE NOMINATIVE, SINGULAR, GENDER
Scope::
  Scope Features:: Anaphor- Anaphor, Subject, GENDER
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Figure 1.

representation within HPSG's lexical representation, as well as only possibly linking to adjectives with that of the binary positive for determiner types. With this, the scope feature should limit to quantifiers in the position of determiners, such as in our primary example, "Every cat walked in and it sat down". The fully proposed HPSG entry for adjectives, including the scope quantifier features (scope feature, as well as determiner type) is illustrated in Figure 1. In order to qualify for compatible scope features, the quantifiers must be of matching 'scope types' within the scope features. For instance, in Figure 1 under Universal Quantifiers, two scopes of universal type and existential type that refer to the same subject and all of its features qualifies towards a positive match in scope between the two quantifiers. Types of quantifiers include Universal, Existential, Semi-Universal, Numeric, Determiner, and Anaphora (or alternatively NULL) quantifiers, while properties of the scope feature vary between each quantifier. If a feature is unlisted, it is assumed binary -, whereas listed implies binary positive.

Another complication posed towards the approach to scope quantifier ambiguity computationally is the overgeneralization of computational algorithms to solve for problems (Pham & Triantaphyllou, 2008). In the case of natural language, problems with ambiguity of any type are identified and solved accordingly. However, computationally it is common that an algorithm will overgeneralize and assume a solution that may not make sense, solely because it is more likely than others (Pham & Triantaphyllou, 2008). However, in terms of scope quantifier ambiguity, there is not necessarily a binary solution. Rather, there is a definite solution, an ambiguous solution, or no solution at all.

In order to overcome this complication, this proposal utilizes the method of most coreference resolution approaches- assigning feature values to each particular feature, at varying rates, and calculating using smoothing to resolve whether or not the smoothed value has a high enough significant distance from a control group to be considered likely, ambiguous, or unlikely. Smoothing is utilized via the chi-squared test, $X^2 = \sum(Y\text{-}Z)^2/(Z)$ (Franke, Ho, & Christie, 2012), and values to matching scope features in Figure 1 provide positive values, while incompatible features such as gender mismatches are met with negative values.

This proposal also includes its own parser, which identified parts of speech tagged from a manually labeled data set, and created syntactic trees to later be reparsed for the Centering Theory algorithm. Finally, a specific algorithm was developed to integrate Presupposition Accommodation, by assuming the generality and specificity of the quantifiers and leading antecedent nouns and the following anaphora. The program was developed in C++, in 1461 LoC, and developed using the IDE Geany. No additional libraries to the standard library was used, and the program itself is not utilized for machine learning. To do so, the program must be written to read an additional file that would track the number of equivalent quantifier scope occurrences, write to the file when discovering a new one, and add this occurrence number as a positive binary value to the value calculations. While this process is relatively simple, not enough time was available to integrate this feature.

V. Results

The program with its given specifications and abilities was an overall success. While the program does not conduct machine learning, code can easily be added in a separate cpp file to do so, as the structure of the program is meant to be built upon. The output of the program is represented for the sake of this proposal in discourse representation using (Kamp, Genebith, & Reyle, 2003; Kamp, 1981) Discourse Representation Theory (hereby DRT).

For the first input, the program was to read from a manually parsed file containing the discourse in (5), while the output given is represented in (6). The computational results correlate with the DRT mapping of Figure 2. The second input was read manually from another parsed file, containing the discourse in (7), while the output is shown in (8). The computational results correlate with the DRT mapping of Figure 3 and Figure 4. The parts of speech tagged were made up of [N] for nouns and pronouns, [P] for prepositions, [V] for verbs, [C] for conjunctions, [A] for adjectives, [T] for adverbs, and [D] for determiners. The output was to list first the type of scope, definite or ambiguous, and print out the scope quantifiers that were labeled as such. Given a quantifier, it is automatically assumed that the discourse that followed it would be included in the scope as well. The output then additionally prints out the fully parsed tree obtained from the manually labeled input, all sentences containing a newline separator.

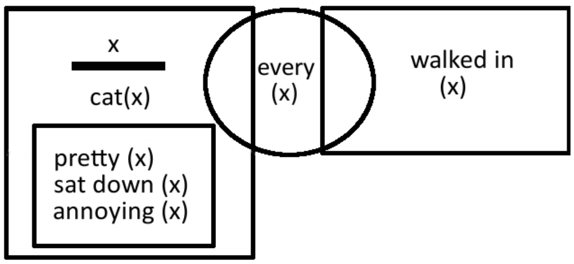

Figure 2.

(5).
Every[D] cat[N] walked[V] in[P] and[C] the[D] pretty[A] cat[N] sat[V] down[P].
She[N] was[V] very[T] annoying[A].

(6).
Definite Scope Quantifier: every cat
Definite Scope: every cat , she , the pretty cat

Sentences: [DP][VP][PP][DP][NP][VP][PP]::[S]
[DP]Every[D]cat[N][VP]walked[V][PP]in[P][DP]the[D]pretty[A]cat[N]
[VP]sat[V][PP]down[P]
Sentences:
[NP][VP][TP]::[S]
[NP]She[N][VP]was[V]very[T]annoying[A]

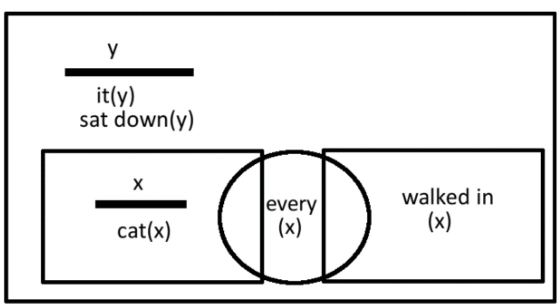

Figure 3.

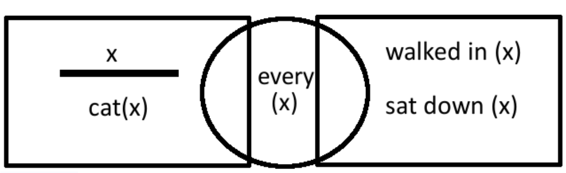

Figure 4.

(7).
Every[D] cat[N] walked[V] in[P] and[C] it[N] sat[V] down[P].
She[N] was[V] very[T] annoying[A].

(8).
Ambiguous Scope Quantifier: every cat
Ambiguous Scope: every cat , it

Sentences:
[DP][VP][PP][NP][VP][PP]::[S]
[DP]Every[D]cat[N][VP]walked[V][PP]in[P][NP]it[N][VP]sat[V]
[PP]down[P]
Sentences:
[NP][VP][TP]::[S]
[NP]She[N][VP]was[V]very[T]annoying[A]

Given ambiguous results, such as those from (8), the DRT provides the ambiguous reading with both interpretations (see Figure 3 and Figure 4). Otherwise the scope is represented with a single discourse representation.

In Figure 2, along with (5) and (6), it was found that the program correctly interpreted that “Every cat” and “the pretty cat”, and “She”, three scopes that incorporate together presupposition accommodation, gender features, coreferencing, and scope quantifier ambiguity, are all one in the same scope, with the leading quantifier scope of “Every”. In Figure 3 and Figure 4, as well as (7) and (8), the program was able to correctly determine that “Every cat” and “it” had an ambiguous interpretation of scope, and that “She” was in fact not within that scope. Therefore the anaphora scope quantifier “she” and its following discourse was removed from the ambiguous scope entirely, while the leading scope quantifier was determined to be “Every”. This particular discourse, which integrated coreferencing, semantic and syntactic features, and scope quantifier ambiguity, was the leading example for this research.

Tests were run on a total of 6 similar sentences, incorporating all approaches of presupposition accommodation, coreferencing, Centering Theory, and scope quantifier ambiguity. All tests were proved equally correct in interpretation with a 100% accuracy, however, several limitations arose.

Because the data had to be manually labeled, it was impossible to judge the aspect of machine learning and its success rate. Therefore at this time it is undiscernible as to how much input is needed in order for the program to reach 100% accuracy in applications. Moreover, the scope quantifiers had to also be of manual input, and thus if an additional scope quantifier was to be used, it would need to be added to the built in database. The program is optimized for syntax, morphology, and semantic features of American English, and thus other language input would require adjustment of the entire program. Lastly, the tests were only run on syntax that was simple and in similar structures. More complicated syntax was not accounted for, and may affect results without optimization.

VI. Conclusion

There are many ways in which to improve the results and overall usage of the program itself. Incorporating other languages, additional scope quantifiers, a computational mapping of discourse representation, machine learning, and a larger corpus and database would allow for this program to be utilized for more advanced applications. It may also be the case that additional approaches should be used, possibly those more heavily semantic incorporating and morphologically based. Better smoothing techniques and SVM are always advisable to improve, or rather disprove, accuracy rates, and once given a property of machine learning, further testing would help to improve the artificial intelligence and increase processing time. Using external NLP libraries with built in tools for natural language processing, such as MLPack, may also help to increase processing time and improve the parsing algorithms within the program itself.

Naturally, as more studies arise in the analysis of scope quantifier ambiguity and the understanding of how it is processed in natural language improves, computational approaches to scope quantifier ambiguity will also be able to improve. As it stands, this is one of many approaches to mapping out the intangible processing by humans through computational means, and leaves much room to be improved upon, while hopefully being utilized for the future.

VII. References

Anderson, A., Garrod, S. C., and Sanford, A. J. 1983. The accessibility of pronominal antecedents as a function of episode shifts in narrative text. *Quarterly Journal of Experimental Psychology*. *35*(3): 427-440.

Brasoveanu, A. (2011). Scope and the Grammar of Choice. *International Review of Pragmatics.* 3: 194-227.

Flickinger, D. (1987). Lexical Rules in the Hierarchical Lexicon. Doctoral dissertation, Stanford University, Stanford, CA.

Franke, T., Ho T., and Christie, C. (2011). The Chi-Square Test: Often Used and More Often Misinterpreted. *American Journal of Evaluation*, 33(3): 448-458.

Gildea, D. and Jurafsky, D. (2002). Automatic Labeling of Semantic Roles. *Computational Linguistics.* 28(3): 245-288.

Grosz, B. J. 1977. The representation and use of focus in a system for understanding dialogs. In *IJCAI* 67:76.

Grosz, B. J., Weinstein, S., and Joshi, A. K. (1995). Centering: A framework for modeling the local coherence of discourse. *Computational linguistics*. 21(2): 203-225.

Hatch, E. and Brown, C. (1995). "Vocabulary, Semanics, and Language Education". Cambridge, Cambridge University Press.

Hobbs, J. (1976). ``Pronoun Resolution''. Research Report, City University of New York, New York.

Ioup, G. (1975). Some universals for quantifier scope. In J. P. Kimball (Ed.), "Syntax and Semantics". New York, Academic Press: 37-58.

Kamp, H. (1981). A theory of truth and semantic representation. *In Formal Methods in the Study of Language*. Mathematical Centre Tracts 135, eds.

J.A.G. Groenendijk, T.M.V. Janssen and M.B.J. Stokhof, 277-322. Amsterdam: Mathematical Centre. Reprinted in Portner and Partee, eds., 2002, 189-222.

Kamp, H., van Genabith, J., and Reyle, U. (2003). "Discourse representation theory". In D. Gabbay & F. Guenthner (Eds.), "Handbook of philosophical logic" 10: 125-394.

Kehler, Andrew. (1997). Current Theories of Centering for Pronoun Interpretation: A Critical Evaluation. *Computational Linguistics (Squibs and Discussions)*, 23(3): 467-475.

Kurtzman, H. and MacDonald, M. (1993). Resolution of Scope Quantifier Ambiguities. *Cognition*, 48(3): 243-279.

Lappin, S., and Leass, H. J. 1994. An algorithm for pronominal anaphora resolution. *Computational Linguistics*. *20*(4), 535-561.

Micham, D. L., Catlin, J., VanDerveer, N. J., and Loveland, K. A. (1980). Lexical and Structural Cues to Quantifier Scope Relations. *Journal of Psycholinguistic Research*, 9(4): 367-377.

Mitkov, R. 1998. Robust pronoun resolution with limited knowledge. In *Proceedings of the 36th Annual Meeting of the Association for Computational Linguistics and 17th International Conference on Computational Linguistics.* 2: 869-875.

Pham, H. and Triantaphyllou, E. (2008). The impact of overfitting and overgeneralization on the classification accuracy in data mining. In "Soft Computing for Knowledge Discovery and Data Mining". Boston: 391-431.

Pollard, C. and Sag, I. A. (1994). "Head-Driven Phrase Structure Grammar". Chicago, IL: University of Chicago Press

Garrod S. and Sanford, AJ. (1994). Resolving sentences in a discourse context: How discourse representation affects language understanding. Gernsbacher M, editor. "Handbook of Psycholinguistics". New York: Academic Press: 675–698.

Stalnaker, R. (1999). "In Context and Content". Oxford University Press: 47-62.

Veronis J. and Ide N. (1992). A feature-based model for lexical databases. "14th International Conference on Computational Linguistics (COLING'92)". Nantes, France: 588-594.