Automatic Resolution of Anaphora in English

Michel Denber

Eastman Kodak Co.
Imaging Science Division
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Abstract

An algorithm is described for the automatic resolution of inter-sentential anaphoric references in English sentences. Anaphora are backward references to nouns which have previously been mentioned in the input text stream, such as *his* in the sentence *John started his car*.

The method is based on constraint matching and makes use of both syntactic and morphological information about the sentence structure and real-world knowledge about the semantics of the sentence elements gained from several different sources to generate features for use in matching.

The ability to perform anaphora resolution is important in multimedia image retrieval for improving the completeness of image query and caption understanding, leading to better matches in retrieved images. For example, given the query

A man and a woman.

He is standing, she is sitting.

a simple word-matching retrieval algorithm would return images containing all combinations of men and women both standing and sitting. However, if the anaphoric referents to *he* and *she* could be resolved, the accuracy of the results returned could be improved by knowing who was doing what. As the number of images stored electronically with captions continues to increase, this ability will become increasingly important.

1 Introduction

1.1 Definitions

The linguistic term *anaphora* is an exotic name that refers to a common phenomenon. Like Molière's Monsieur Jourdain who discovered with astonishment that he had been speaking in prose without even realizing it [Moli], everyone uses anaphora on a daily basis whether they know it or not. The etymology of the term goes back to Ancient Greek with *anaphora* (αναφορα) a compound word consisting of the separate words ανα- *back, upstream, back in an upward direction* and φορα - *the act of carrying* and denoting *the act of carrying back upstream* [thanks to R. Mitkov for this definition]. Anaphora are forms of reference in written or spoken speech in which a word, most commonly a pronoun is used in place of a previously mentioned item (most often a noun or noun phrase) where both refer to the same entity. For example, in the sentence,

Kathy always took her camera with her.

her refers to Kathy (in both instances).

Much as is the case with visual interpretation of images, humans normally perform anaphoric resolution completely unconsciously and usually with high accuracy. However, there are cases in which the referent is ambiguous. For example:

While Jack was talking, Joe finished his beer.

Here *his* may refer to either *Jack* or *Joe,* largely depending on the context of the situation.

The automatic resolution of anaphora by computer is arguably one of the most difficult problems in natural language processing because it depends heavily on both linguistic knowledge (how sentences are constructed) and world knowledge ("common sense" facts about how the world works).

This paper presents an algorithm for automatically resolving two forms of two-sentence intersentential pronominal anaphora, i.e. ones in which the anaphoric co-referents appear in the sentence directly preceding the one containing the anaphora themselves, in American English. Although the operation of the algorithm is described in detail, the primary point here is to serve as a sort of roadmap of the entire topic so that someone revisiting this issue in the future can have some idea of the problems that might be encountered and the extent of the difficulties involved as well as some history of what has come before.

1.2 Motivation

Anaphora resolution is obviously useful in a speech or text understanding system in order to help the machine understand what is going on. Indeed, it can be said that an understanding of the co-referents in anaphora *is* a good part of what is going on in a realistic spoken or written discourse or text.

Similarly, anaphora resolution can assist the process of image retrieval by natural language query. This application resembles speech processing in the need for interactive response. It would be of interest to customers such as stock photography houses interested in offering users natural language image query that works better than simple keyword search, museums wanting to improve access by researchers or the general public to their collections, as well as individual consumers captioning their own snapshots for digital storage. For example, the query

A lake with the sun reflected in it.

was posed to the search engine at the Publisher's Depot Web site. Of the 12 images returned on the first page, only three were relevant to the query. When the query was rephrased as

*A lake with the sun reflected in **lake**.*

the number of relevant images increased from three to eight.

Consider as well the example caption,

A picture of a bride and groom.

He is putting the ring on her finger.

A search engine which performs straight keyword matching will return all images that contain the words *bride, groom, ring,* and *finger*. While this combination will most likely return an image with the desired content (assuming one exists in the database) it will also return other unrelated images, such as

*The reverend points his **finger** towards the **ring** on the altar between the **bride** and **groom**.*

which contains all of the keywords but describes a rather different image.

If on the other hand, one could resolve the anaphora *he* and *her*, the original caption could be restated as

Groom is putting the ring on bride's finger.

In this form, a semantic association can be made associating *ring* with *groom* and *finger* with *bride*. This would help improve the accuracy of retrieved images. Research has shown that anaphora resolution does in fact improve both recall and precision performance in largescale database queries [Pirk]. While this may not make much difference if only a dozen or so images are found, it starts to become more important as the size of the database grows. For example, users may be satisfied even if 50% of 12 images are irrelevant, but may be considerably less satisfied if they have to search through several hundred images looking for the relevant 50%.

1.3 Prior art

To my knowledge, this is the first instance of work specifically on anaphora resolution within Kodak. It was intended to complement work done by Archna Bhandari for performing natural language query of image captions, and which is based on Fillmore's case grammar [Fill] but does not specifically address anaphora resolution. The program presented here does not attempt to match queries with captions, it only associates anaphora with their antecedants. The "de-anaphorized" text can then be used as input to the query-caption matcher to (hopefully) improve the accuracy of the match as described in the preceding section.

Work on anaphora resolution in the open literature tends to fall into three domains: *artificial intelligence* (as a specialty of computer science, including computational linguistics and natural language processing), *classical linguistics* (as distinguished from computational linguistics), and *cognitive psychology* [Lust 82, Sanf]. Psychologists tend to be interested in this topic because of what they can learn about how the brain processes language. Linguists are interested simply because anaphora resolution is a classical problem in the field. For our purposes we are primarily interested in the AI/computational linguistics approach.

The various approaches to anaphora resolution differ largely in the depth of linguistic analysis being performed, that is the extent to which the system tries to understand the contents of the input text. At one extreme is the work of Kennedy and Boguraev [Kenn] which is purely morpho-syntactical in nature. This has the advantage of being fast and relatively easy to implement. A middle ground is found in Lappin and Leass' RAP program [Lapp] which is also based on surface processing but employs a more extensive syntactic analysis. At the other extreme are discourse-understanding systems [Alla] which attempt to build a model of what information is being converyed in the input. These can be quite complex and use a variety of techniques including various corpora, statistical techniques [Daga], fuzzy logic and neural networks [Conn] most commonly associated with artificial intelligence work. Some systems, notably by Mitkov [Mitk94] try to gain advantage by combining different approaches. Two key components widely found in most of the existing work are the use of a separate parser or tagger (which performs a limited version of parsing) and the use of an external lexicon most commonly to provide basic lexical information but sometimes also to derive semantic clues. Although a variety of taggers are in use, the *WordNet* system from Princeton University is by far the most popular lexicon in the field.

A number of linguistic ideas are often applied to computational anaphora resolution, including centering theory [Kehl 93], the notion of c-commanding [Alla], and discourse representation theory (DRT) [Fisc].

Most of applications targeted in the existing work deal with natural language processing for question-answering systems, machine translation, and data mining. In fact, no references were found for systems specifically addressing image query and caption matching. However, interest in anaphora resolution is currently quite high and several conferences devoted entirely to anaphora resolution have been held in the last two years (cited extensively in the references).

The following major companies are known to have interests in anaphora resolution: Apple [Kenn], BBN, IBM, Kurzweil, Microsoft (which has a group of more than 30 researchers devoted to natural language), NEC, Quarterdeck, Sony, SRI [Kehl], and Xerox [Dalr]. They are motivated by interests in text and/or speech understanding for applications including multimedia image retrieval, data mining, document understanding, and machine translation of natural languages. In addition, numerous small companies are active in this area for the same reasons.

Very frequently cited works in the literature include those by Hobbs [78], Lappin and Leass, Luperfoy, and Sidner.

It is interesting to note that as of this writing there are no U.S. patents issued that contain the string *anaphor**. The patent situation is treated separately in Section 7.

1.4 Types of anaphora

Although there is no unanimous agreement in the literature as to how they should be categorized, the (more extensive than most) approach taken here is to define six main types of anaphora, plus one "catchall" class. The succinctness of the taxonomy belies the complexity of the problem. The classes are:

1.4.1 Pronominal

Pronominal anaphora are the most commonly encountered in general usage. This category includes three subclasses:

- Personal: *he, she, it, his, hers, its, they, them, their, theirs*
- Demonstrative: *this, that, these, those, others*
- Reflexive: *himself, herself, itself, themselves*

Within these groups, the personal pronouns constitute the great majority of anaphora in general texts. The demonstrative pronouns are quite variable. They can be anaphoric as in,

*The car wouldn't start because of **this**.*

but are probably more often seen as cataphoric (see below) as in

***This** is a ruby laser.*

1.4.2 Quantifier

One (two, three…n), each, some, many, most, all, every, none, a little, a few, a lot (of them)

This form can occur as both subject and object:

***One** was green.*
*She chose the blue **one**.*

1.4.3 Ordinal

(*The) first, second, etc., former, latter*

These forms are anaphoric depending on context. For example, in

*His horse came in **first**.*

first is not an anaphor while in *The **first** was easy.*, it is. However, this appears to be encountered relatively less often than the equivalent *The first **one** was easy.* (which becomes a *one*-anaphora).

1.4.4 Question

Also called *wh-anaphora*, includes the pronouns

who, what, which, where, when

as in

*Even before the butler confessed, everyone knew **who** did it.*

*Main Street is **where** the action is.*

1.4.5 Event anaphora

Anaphora need not have only a single noun as a referent. This is distinct from the common generalization of the referent to a complete noun phrase. Consider for example,

In 1969 America landed a man on the moon.

***It** was NASA's shining moment.*

The first sentence contains four nouns (*1969, America, man, moon*) but *it* refers to the entire *event "the moon landing"* or *"landing a man on the moon"* rather than either any single one of them or to the NP *a man*. These types of anaphora require a deeper understanding of the semantics of the sentences involved to resolve properly than is available simply from a syntactic and lexical analysis and are therefore also beyond the scope of this paper. To the extent that the referent is really a paraphrase of the actual antecendent text (as in this example), this problem also borders on ellipsis (see below).

1.4.6 Pleonastic *it*

This is an interesting case of a pronoun which does not refer to anything. (*It* is raining. *It* is summer. *It* seems that… *It* just so happens that… *It's* late… *It's* 3 'o'clock., *It's* about time.) This form is also called *non-referential* or *expletive it* and is considered in further detail in Section 2. In the literature, pleonastic pronouns are commonly not considered to be anaphora (precisely on the grounds that they *don't* have referents), but it seems that they need to be recognized in a system that handles anaphora, if only to know not to look for a referent for them. Therefore, they are included as a separate category here. Actually, one could even make the case that pleonasms do have referents of a sort, such as "*the time*" or "*the weather*", however, this point is debateable.

1.4.7 Special cases

These forms tend toward the idiomatic and there is not always even agreement as to their status as anaphora. Two common examples include

Do so, and *respectively.*

There are also *temporal anaphora* (as distinct from the time pleonasms given above) which are important in discourse representation. These are touched on in section 2.7.2.2.

In addition, anaphora may be *intrasentential*, where the referent is in the same sentence as the anaphor (*Jack tried to start his car*.) or *intersentential* where the anaphor refers to a noun in the previous sentence (*Jack got in his car. He tried to start it*.). Anaphora may even refer back more than one sentence in a discourse, although the more widely separated the elements are, the less likely it becomes that they may be co-referents. It is expected that this situation is also less likely to be encountered in a query/caption system where the individual textual units tend to be short.

1.5 Related constructions

There are other types of linguistic constructions that appear similar to anaphora but are not strictly classified as such. For example, a sentence may contain a forward reference, as in

When he replaced the water pump, Joe scraped his knuckles

where *he* refers to the subsequent mention of *Joe*. Technically, this type of construction is called *cataphora*, although in the linguistics literature anaphora is sometimes presumed to include cataphora (however, because they involve different analysis strategies, we will not do so here). In this example both pronouns refer to *Joe* but *he* is cataphoric and *his* is anaphoric. Both anaphora and cataphora are forms of *endophora* (within-context references). For completeness, it should be mentioned that there are also *exophora*, which are “universal” or commonly understood referents (possibly in a particular context assumed to be shared between the speaker or author and the audience) such as *the sun*, *the PC*, or *the President*. One copier company attempted to exophorize itself by adopting the slogan “the Document Company”.

Next, *ellipsis* is a linguistic form which resembles anaphora except that here it is the *absence* of something that refers to something else. For example, in

Uneven stitches will result if the upper thread tension does not match the lower.

there is an elided *thread tension* at the end of the sentence. This example can be converted to an anaphor by adding *one*, as in

Uneven stitches will result if the upper thread tension does not match the lower ***one****.*

One quite common example of anaphora and cataphora in ellipses involves *this* as in

This is a picture of uncle Joe.

where *This is* contains an elided *picture (This* ***picture*** *is a picture of uncle Joe.)*

In any case, elliptical constructions are quite difficult to recognize and beyond the scope of this paper.

Finally, for completeness we examine forms like

It's beginning to feel a lot like Christmas.

Which at first glance appear to be pleonastic since *it* generally has no direct antecedant. However, here *it* really does appear to refer to something, if only an abstraction or particular seasonal gestalt. This is more of an "elliptical pleonasm" than a true anaphor.

With this understanding of the anaphora resolution problem, we now examine a method of solving it by computer in the next section, with a specific focus on intersentential anaphora for use in image query and caption analysis (implying a limited amount of text)..

2 The algorithm

2.1 Design

The algorithm implemented here is called *AM*, for *Anaphora Matcher*. It is designed to handle inter-sentential anaphora over a two sentence context. Currently it can handle two types of anaphora: *personal pronouns* and *pleonastic its*. These were selected since the former is by far the most common category, while the latter could cause considerable confusion in sentence meaning if it was attempted to find resolvants for it. Also since *it* appears in both categories, no treatment of personal pronouns is complete without also considering pleonastic *its*. A two-sentence "window" is reasonable for anaphora resolution in the domain of image queries and captions since it is expected that few of these types of expressions would exceed two sentences in length. The algorithm could be extended beyond two sentences by keeping information from previous sentences in context (the "history list" idea [Alla]) or simply by considering the input two sentences at a time. In any case, most anaphora do not refer back more than one sentence. Multi-sentence intersentential anaphora resolution also has been studied using centering theory [Kehl 93] however, this type of approach increases the complexity of the solution and is beyond out scope.

AM is based on *constraint-matching*, using both syntactic information about the sentence as well as real-world semantic knowledge obtained from several sources. The idea is based on the way humans perform at least some forms of anaphora resolution. For example, in the sentence

Joe and Melissa walked in the room and she sat down.

the most likely interpretation is that *she* refers to *Melissa* and cannot refer to *Joe* because there would be a gender constraint mismatch in that case. Some algorithms attempt to solve the anaphora problem purely syntactically [Lapp]. While there may be good reasons for doing this, it greatly increases the difficulty of an already difficult problem and there is no reason to be so restrictive if the computational resources are available to perform more in-depth analysis. By using all of the information available, we can generate better matches. AM uses three different external sources of information in its processing:

1. AM makes use of a commercially available natural language tagger called *engcg* (for *Eng*lish *C*onstraint *G*rammar) based on the theory of constraint grammar [Karl].. engcg is one of a number of so-called "super taggers" now available and classifies each word in an English sentence according to its part of speech (noun, verb, etc.), morphological features (singular, plural, etc.), and syntactic role (subject, object, etc.). It is not strictly a parser in the sense that it does not partition a sentence into the traditional noun phrase/verb phrase groupings, however, it does provide important information for use in anaphora resolution.

2. AM also uses the freely available *WordNet* lexical database system [Fell] to obtain real-world knowledge about the words in the input sentences. WordNet is basically a

combination dictionary/thesaurus organized hierarchically. It provides not only definitions and synonyms, but part-of and kind-of relationships between words as well as frequency data which can be useful for determining the more likely alternative in cases of ambiguity. WordNet is quite popular in current natural language processing research.

3. AM uses a set of three lists of proper names from the MIT Media Lab as part of a knowledge representation database package there [Haas]. These categorize proper names as either male names, female names, or place names.

2.2 Detailed procedure

The algorithm takes as its input two English sentences provided as a single string and returns as output a list of any of the following: the co-referents in the first sentence of any anaphora in the second sentence, "none" if no anaphora were present, or "pleonastic" if an *it* was recognized as such. Steps 1 and 2 below pre-process the input. Steps 3 through 7 deal with assigning constraints to the possible referents. Steps 8 and 9 apply constraints to the anaphora, and step 10 is the actual matching operation. It proceeds as follows:

1. The two-sentence input is provided as a single string. The first step is to divide this string into two sentences. This is done by searching the string for a sentence delimiter in the form of ".", "!", or "?". Everything up to that point is considered to be the first sentence (S1) and the rest of the string is considered to be the second sentence (S2).

2. The first input sentence (S1) is passed to engcg for syntactic analysis. A list is made of all nouns in the sentence using the part of speech tags returned by engcg. This becomes the possible solution set for any anaphora in S2. Since AM is specifically designed to handle intersentential anaphora, S2 is not searched for resolvants (although some might exist there).

3. For each noun found in S1, it is examined to see if it is a noun-noun modifier (i.e. a noun acting as an adjective as in *the* ***log*** *cabin*, *the* ***wood*** *elephant*) by checking its part of speech. This is done by making a list of the part of speech of each word in the input and searching for the pattern $\mathbf{N_a}^{+}\ \mathbf{N}$ (a string of two or more consecutive nouns). All of the $\mathbf{N_a}$ nouns are removed from consideration as they are considered ineligible as anaphoric antecedents.

4. Each remaining noun is tagged for number (singular or plural) and syntactic function (subject or object), again using information provided by engcg.

5. Each noun is tested for capitalization and one of step 6 or 7 is executed as a result.

6. If a noun is capitalized, it is assumed to be proper and an attempt is made to determine if it is a place name or a personal name by looking for it in a set of name and place lists. For personal names, an attempt is made to tag them with the correct gender using gender-typed name lists following the procedure described in detail in section 2.4 below. This information is added only if a name exists uniquely in one list and not the others, i.e. rather than risk guessing wrong, ambiguous names are

simply left untagged. Note that the test "capitalized implies proper noun, else common noun" is only a heuristic. One can easily imagine circumstances in which it would not hold. However, in the absence of any better way to distinguish proper nouns (which is a difficult problem in its own right) this will have to do.

7. If a noun is not capitalized, it is assumed to be common and WordNet is searched for its *hypernyms* (*kind-of* relationships). This yields information concerning the noun's classification as animate or inanimate as well as possibly its gender. If such information is found, the appropriate tags are added to the noun's constraint list. The animate/inanimate tag is set by searching WordNet for the word *creature* or *object*. The gender tag is set by searching for *male* or *female*. Nouns with the object tag also receive the neuter gender tag.

8. The second sentence (S2) in the input is sent to engcg for analysis. In this sentence, all of the second- and third-person pronouns are collected as the anaphora which must be resolved. Each of the pronouns which AM knows about has an associated list of constraints defined within the program (for example, *he* has the constraints *masculine* and *singular*).

9. Using the results of engcg, syntactic constraints are added to each pronoun specifying their role in the sentence as subject or object (assuming engcg returned that information which is not always the case). One could imagine using more of the case grammar tags and applying various weights to them to provide dynamic constraints as is done by Bhandari. Although this approach has in fact been used by some authors [Carb][Fisc], it appeared to introduce additional complexity with an uncertain payoff and was not pursued.

10. The list of pronouns as collected in step 8 is examined. Any *it* is first tested for being pleonastic. For any other pronoun, as well as non-pleonatic *its*, its constraint list is matched against that of each noun in S1. The noun which matches the greatest number of constraints is considered to be the antecedent of the pronoun. In the event of a tie, the noun which matches in the subject/object constraint is judged the winner. If this does not break the tie, or in the case of a tie where that the noun or pronoun was not assigned a syntactic category by engcg, the first noun encountered in S1 is used. Syntactic role agreement was used as a tie-breaker rather than earlier in the matching process because it was deemed to be less reliable as an indicator of co-reference than the other constraints used. Matching a noun does not remove it from the list of candidates for matching subsequent pronouns, since it is common for more than one anaphor to refer to the same noun.

The aim of this algorithm is to maximize the amount of information available to make a decision while minimizing the consequences of missing or conflicting information. For example, if a proper name is encountered which could be either a male or female name, then the gender constraint is simply omitted. This reduces the amount of information available but does not affect the operation of the matching procedure. In this type of situation, a human observer would have the same problem.

2.3 Number agreement

Number agreement refers to the grammatical constraint found in many natural languages including English requiring that certain pronouns (such as *he, she*, and *it*) only be used with singular nouns and others (*they*) only with plural nouns. English pronouns must also agree in number with verbs although this fact is not exploited here. The number constraint is important because it is always known for pronouns and is usually easy to determine for antecedents. The engcg parser is quite good (but not perfect) at assigning the proper number classification to nouns. For nouns that are ambiguous in number, such as *deer* or *fish*, engcg returns the tag "SG/PL". However, in these cases a human would also be unable to distinguish them; the computer can do no better. Of course, the use of number agreement as a constraint in AM assumes that the input will follow the grammatical rules of English.

The remainder of this section discusses number agreement problems that are not addressed by AM. One common problem involves the process of set formation. For example in the sentence pair

The man and the woman sat down to eat.

They *ordered steak.*

they is a plural pronoun but both possible antecedents (*man* and *woman*) are singular. The correct answer is "man and woman". The same problem arises with *or*:

Tom had to choose vi ***or*** *emacs but he hated* ***them*** *both.*

It can also happen without any conjunction at all:

Joe took the boys to the ball game.

They *had a good time.*

Here *they* refers to both *Joe* and *boys*, at least in the most common interpretation (collective reading).

Sometimes number agreement fails. This happens with certain nouns that look plural but act singular, as in

Nancy took the kids to the ***movies****.*

They argued over which ***one*** *to see.*

Movies is plural, but it is the correct antecedent to *one*, which is singular. Other members of this class include *the races, the fights,* and *the falls.*. One possible solution is to regard *movies* and "***the*** *movies*" as two different entities with the latter being treated as a singular construction.

In addition, sometimes people will deliberately violate number agreement by using *they* in order to avoid using a gender-typing pronoun as in

When the ***user*** *starts the program,* ***they*** *will be asked for a password.*

In this case, *they* is used to replace the phrase *he or she*. Although this is not considered good usage, it does occur in practice.

2.4 Gender agreement

Gender agreement refers to the linguistic requirement that a pronoun and co-referring noun match in grammatical gender. In English this is restricted to proper names, where *he* and *she* are used to refer to males and females respectively and *it* is reserved for inanimate objects or animals of undetermined gender.

Therefore, proper names can be useful clues as potential antecedents in that they often contain constraints on gender and animacy. Unfortunately, they also present a surprising number of problems because of potential ambiguities. Proper names can be recognized in English by virtue of being capitalized. This is the extent to which AM deal with proper names. Unfortunately, the first word of a sentence is normally always capitalized, so if that word is a noun it can't be identified as proper that way. This same problem extends to some words such as *Count*, which can be a title or a verb when it occurs at the start of a sentence. Also, older legacy databases are often found to have been entered entirely in upper-case characters.

This is important because WordNet contains no proper names and one wants to avoid sending it one since it is not uncommon for proper names also to be common nouns which could return misleading information. For example, in WordNet *Bob* returns data about hairstyles, and *Jack* returns data about devices for lifting cars, neither of which have the desired gender attributes for those names. There is also considerable overlap between girls' names and flower names (*daisy*, *heather*, *ivy*, *rose*, etc.) for example. Ultimately of course, names can be anything as in Frank Zappa's daughter *Moon Unit*, the artist formerly known as Prince, various nicknames, etc.

Some proper names can be ambiguous in gender (e.g.; *Chris*, *Pat*, *Tracy*). In addition, some names differ in gender in different languages. This needs to be considered since foreign names can easily appear in English sentences. For example, *Jan* is a boy's name in Polish and a girl's name in English; *Jean* is a girl's name in English and a boy's name in French. There is further ambiguity between person names and other proper nouns such as place names or organization names. For example, *Troy* can be both a boy's first name and a city (in fact one of several different cities). Other names may be ambiguous with non-place proper names. For example, *April* is both a girl's name and a month of the year. Table 1 summarizes the possible intersections in the name lists used by AM.

	male names	female names	place names
male names	2947	374	159
female names		5001	97
place names			4788

Table 1 : Proper name intersections

When it is not possible to unambiguously resolve a proper name for gender, no gender tag is attached to it.

Proper names also have a scoping problem which causes referent ambiguity. For example, in

Sol Hurok was an impressario.

He brought the Bolshoi to America.

one would like to resolve *he* with *"Sol Hurok"* rather than *Sol* or *Hurok*. A heuristic for this might be to check the word following any proper name. If it is either a proper name or a proper noun of undetermined type, group it with the preceding name as two-name compound noun. This would also solve the related problem of multiple first names such as *Joe Bob* or *Emma Sue*.

As with many features in natural language, there are some anomalies relating to gender in English. It is a custom to refer to ships and large boats as *she*. No attempt is made to identify such instances here as it is a difficult problem and expected to occur relatively infrequently. For completeness we add that sometimes natural features or processes are anthropomorphized and these tend to be identified as *he* (e.g. *Ol' man River,* ***he*** *jus' keep rollin'.* or *When the print manager sees a new job,* ***he*** *queues it up.*). These forms are also not addressed here.

2.5 Syntactic agreement

Empirical evidence suggests that anaphora commonly match their referent in their syntactic roles [Alla]. In addition to the lexical and semantic constraints mentioned so far, AM makes use of one syntactic constraint. It attempts to match the syntactic role of the anaphora (as subject or object only) with that of their possible co-referents. This helps match examples such as

The sun is setting over a lake.

It *is reflected in* ***it****.*

Here, the first *it* (the subject) refers to *sun* which is also the subject of its sentence and the second *it* (the object) refers to *lake* which is correspondingly the object of the first sentence.

Prepositional phrase ambiguity is an interesting problem in relation to syntactic role constraints. Consider the following example and two sucessors:

At this point, EMACS is waiting for a command.

It *is prepared to see if the variable keys are true.*

It *should be entered in lower-case.*

In the first anaphoric sentence, *it* refers to *EMACS* (the subject) while in the second *it* refers to *command* (the object). However, in both cases *it* is the syntactic subject. A constraint match based on this feature would match both *it's* with EMACS. Argument could be made here that what is really needed is the *deep structure* subject (in the transformational grammar sense [Chom]). If we rephrase the second sentence as

Someone *should enter it in lower-case.*

(removing the surface passivization construction) then *it* becomes the object and would correctly match in role with *command*. Unfortunately, to identify this would require the implementation of a transformational grammar on top of the existing anaphora matcher and this is beyond the scope of the current work.

2.6 Animacy agreement

For the pronouns *he* and *she* in English, it is possible to apply a constraint for animacy *vs.* inanimacy. This is distinct from the constraint on gender and is useful in identifying animals whose gender is not otherwise specified, as in the caption pair

A picture of a dog carrying a stick.

He is running in circles.

Here it is possible to distinguish the co-referent of *he* as *dog* instead of *stick* on the basis that *dog* is tagged as animate in WordNet but *stick* is not. This is implemented in AM by searching the WordNet hypernym hierarchy of the noun for the keyword *creature*.

Proper names cause problems with animacy constraints. For example, *George Washington* is animate but *the George Washington Bridge* is not. This assumes that *George Washington Bridge* can even be identified as one object, which is not always the case as mentioned in section 2.4. AM does not handle these forms.

2.7 Pleonastic *it*

2.7.1 Definition

The term *pleonastic* (from the Greek *pleion*, "plus" or as used here, "more") is the adjectival form of *pleonasm*. A pleonasm is a linguistic form where more words are used than needed to convey the intended meaning, i.e. a redundancy. The pronoun *it* is said to be pleonastic when it is used in a context where it has no referent. Lewis Carroll described the phenomenon thusly:

> "I proceed. 'Edwin and Morcar, the earls of Mercia and Northumbria, declared for him; and even Stigand, the patriotic archbishop of Canterbury, found it advisable –'"
>
> "Found *what?*" said the Duck.
>
> "Found *it*," the Mouse replied rather crossly: "of course you know what 'it' means."
>
> "I know what 'it' means well enough, when *I* find a thing," said the Duck: "it's generally a frog or a worm. The question is, what did the archbishop find?" [Carr]

It is interesting to note that despite an extensive treatment of anaphora in the computational linguistics literature (see section 8), only two instances have been found where the problem of pleonastic references is addressed [Kenn][Lapp], and one of them [Kenn] only appears to reference the other. In addition, Ruslan Mitkov, a noted expert on the topic of anaphora resolution, agrees [personal communication] that this problem has been essentially ignored. Although this does not necessarily *prove* that no such work exists, it calls to mind the cartoon in Garey and Johnson's classic book on NP-completenesss [Gare]:

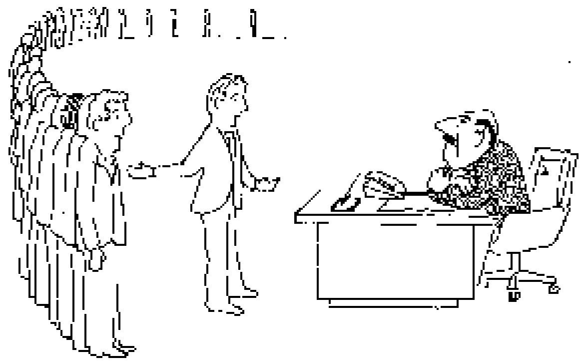

Figure 1 : *I can't find an efficient algorithm, but neither can all these famous people*.

As Garey and Johnson say, "At the very least, this would inform your boss that it would do no good to fire you and hire another expert on algorithms."

In fact, it seems quite surprising that in anaphora resolution work in general, it is considered standard practice to remove pleonasms by hand from the database being used for testing. This is justified by the claim that pleonasms are not truly anaphora since they have no referent. While this is true, it disregards the fact that the computer has no way of knowing *a priori* whether an *it* it encounters is pleonastic or not. Therefore it would appear necessary to give a reasonable accounting of pleonasms in any work on anaphora resolution.

AM has a module for performing pleonastic resolutions which are divided into two main categories, *state references* and *passive references* as described in the following sections.

2.7.2 State references

State references branch into two main forms: *temporal* and *meteorological*. Pleonastic-*it* is commonly involved in descriptions of the weather, for example, *it's sunny*, *it's raining*, etc. and in statements about time as in *It's three o'clock*, *It's time to go,* etc..

2.7.2.1 Meteorological pleonasms

AM tests for meteorological anaphoric references by checking for three different syntactic patterns:

1. ***it*** **<*be*> ADV* PCP1** where the verb *be* may appear in any inflected form, the * indicates "zero or more occurances of" in customary finite state expression form, and

the PCP1 (present progressive) verb appears in a list of 12 common meteorological verbs (*snowing, raining, drizzling,* etc.). This matches forms such as *It is raining.*, and *It is hardly raining*.

2. ***it <be>* ADJ** where the verb *be* may appear in any inflected form and the ADJ appears in a list of 44 common meteorological adjectives (*cloudy, sunny, windy,* etc.). (e.g. *It is cloudy*.)

3. ***it <be>* N** where the verb *be* may appear in any inflected form and the N is one of five season nouns (*spring, summer, autumn, fall, winter*).

It is not unreasonable to believe that such forms might appear in image captions such as:

This was taken just before it started raining.

This was when it was summer.

2.7.2.2 Temporal anaphora

In the literature [Nelk][Part], the term *temporal anaphora* is used to cover words such as *often, before, after,* and *when* in situations such as

Before *taking off on a jump, Katarina Witt* ***always*** *crosses her arms.*

This type of anaphora has not been studied extensively and is not addressed here since it is more important for discourse understanding than pronoun resolution. Instead, we examine pleonastic time-expressions such as

1. *It's three o'clock.*
2. *It's time to go.*
3. *It's past time to go.*
4. *It's about time.*
5. *It's late.*

The first form (containing a definite time) could be handled with a pattern of the form

***it <be>* ADV* NUM**

where NUM matches a time expression (which is parsed as a unit by engcg). Forms 2 through 4 (containing relative time references) could be handled with

it <be>* PREP* *time

Form 5 will match

***It <be>* ADV* (*early* | *late*)**

Interestingly, there do not seem to be any other members of the set in form 5 besides *early* and *late*.

None of these patterns is currently implemented in AM.

2.7.3 Passive construction

The other common form of pleonastic-*it* typically involves passive forms such as *it seems that…, it can be seen that…, it is clear that…*etc., as demonstrated by the Mouse's speech in the previous section. Lappin and Leass [Lappi] describe three syntactic patterns in which these modal adjectives can appear in pleonastic usage. They are incorporated into the design of AM in a slightly revised and generalized form as follows:

it* <be> modadj *that

***it* <be> modadj [*for* N] *to* V**

N Vcog *it* modadj [*for* N] *to* V

In addition, we add a fourth pattern:

***it* <be> modadj PRON**

This matches expressions such as *It seems he left…*

Lappin and Leass also define a set of 15 modal adjectives (including their negations, comparatives, and superlatives) that may appear in these patterns: *necessary, good, economical, possible, useful, easy, certain, advisable, desirable, likely, convenient, difficult, important, sufficient,* and *legal*.

Of course, the problem is that this list is far from exhaustive (one obvious missing adjective is *obvious*). It is here that WordNet can be particularly useful. Adjectives in WordNet can appear with an *attributes* property. It is proposed that an adjective qualifies as modal if it has an *attributes* property and those attributes include one or more of *state, condition, quality,* and *quantity*, but not *color* or *physical*. In addition, any adjective that ends in *–ble* qualifies as modal in this context. Of course, many adjectives that end in *–ble* are not modal (*variable, edible, adjustable,* etc) but none of these may appear in the context of the above patterns in semantically well-formed sentences, for example,

It is **variable that the man left.*

vs.

*It is **understandable** that the man left.*

Lappin and Leass also define seven cognitive verbs (*recommend, think, believe, know, anticipate, assume, expect*) that may be used in the following pattern:

it* <be>* Vcog+past *that

This matches expressions such as *It seems that…, It is thought that,* etc. Again, there are many more cognitive verbs than these (*feel, note, observe*, etc.). Fortunately, engcg tags these verbs with the feature <Vcog> so it is not necessary to maintain an explicit list.

Other linguistic elements may be pleonastic in certain contexts. For example, it can be argued that *else* is plenostic [Culi] in

*She didn't want lasagna, she wanted something **else**.*

However, *it* is by far the most common form of pleonasm in common usage. None of the patterns in this section are included in the current implementation of AM.

3 Results

3.1 Test data

AM was tested on a sample database of 82 two-sentence image captions containing a total of 48 anaphora. No attempt was made to exclude captions which did not contain anaphora in order to more fully test the operation of the program. The captions were collected from various members of the Imaging Science Technology Laboratory who were asked to view random images from the JBJL image database and create captions for them as if they were snapshots they had taken themselves and they wanted to annotate them so that they could remember what they were about in the future. The only restriction was that the captions should be two sentences long, since the program being tested was designed to handle intersentential anaphora. Although the captioners were not specifically requested to use anaphora in their captions, they sometimes did so. This demonstrates that anaphora may actually occur in real captions. The author then reviewed the captions and hand-generated ground-truth data for each anaphor found, explicitly listing its co-referent or "pleonastic" as appropriate. There was one instance where it was deemed impossible to unambiguously determine the antecedent of an anaphor; this instance was labeled "unknown". Table 2 below indicates the breakdown of the 48 instances of anaphora by type according to the taxonomy of section 1.

Type	**pronoun**	**quant.**	**ordinal**	**pleonas.**	**ambig.**	**none**
Number	41	0	0	6	1	51

Table 2 : Test data anaphora distribution

The AM algorithm was run on this test data. Only the pronominal and pleonastic anaphora were included in the scoring since instantiation anaphora were not implemented. There were six demonstrative pronouns (*this*) which were also excluded from the results since these forms are also unimplemented. Also, eight captions containing a total of 13 anaphora had to be omitted because they were not in the proper intersentential form.

Finally, the lone ambiguous anaphor was omitted since there was no reasonable way of deciding if the program's answer was correct or not. An alternative approach would be to include ambiguous references and consider them correct if the program chose one of the reasonable referents. Or it could be argued that in order to be truly "correct", the program should return *all* of the possibilities in the event of an ambiguity. In actual practice, the program will always make a match if at least one possible antecedent exists, unless the referent is found to be pleonastic. In this particular test, the program did choose one of the reasonable alternatives. However, dealing with ambiguous anaphora simply adds complication on top of complexity and was deemed to be beyond the scope of the present work, therefore the ambiguous case was omitted from the results.

Of the remaining 24 anaphora, AM identified 10 correctly, or 42%.

The computational complexity of this algorithm is time O(n * m) where n is the number of nouns in the first input sentence and m is the number of pronouns to be resolved in the second sentence. Typical running time of the algorithm for a two-sentence input with five nouns and two pronouns is approximately 55 seconds in real-time, although this figure is not very useful, since all of the interprocess communication between AM and both WordNet and engcg occurs via networked disk files which incur lengthy delays and the proper name lookup is conducted from within Lisp as a simple linear file search, which itself is exceedingly slow. The actual CPU time spent in performing the resolution itself is well under 1 second on a Sun Sparc 5 workstation.

3.2 Error analysis

Three of the 14 errors AM made, or 21%, were due to faulty information received from engcg. In two cases it reported that the noun *Molly* was being used as an adjective in the construction

Molly, age 8, …

This automatically excluded *Molly* (the correct referent) from further consideration. In the third case, engcg incorrectly identified *Sue* as a verb in the sentence

Sue in a maternity nightgown.

From a purely syntactic point of view the verb reading is legal, however it does bring to mind a rather odd courtroom scenario when viewed in that context. This is one of many examples of sentence fragment problems which are discussed more in section 4.1.1. One solution in this instance might be to have a rule to the effect that when the first word in the sentence is reported by engcg to be a verb, check in the name lists to see if it can also be a name. If so, then prefer the name form. The reasoning is that captions and queries are probably more likely to be descriptive than imperative. Other similar examples include *Bill in a tuxedo.*, *Bob in the pool.*, and *Carol in the snow.*

Two additional proper name related errors occurred when *Grandpa* was not identified as a masculine title by engcg. Although this particular example could be easily corrected by providing an external list of titles similar to the lists of proper names, it points out how any program relying on real-world knowledge can be misled by missing information. The problems associated with proper name recognition were addressed in section 2.4 above.

Four errors occurred because AM contains no logic for processing conjunctions and therefore does not generate the correct number constraints when dealing with input such as

Susie and Molly at the playground.

They are having fun.

They is a plural pronoun, but *Susie* and *Molly* individually are singular and so AM is unable to satisfy the number constraint. Determining the proper scoping of conjunctive (and disjunctive) expressions is more properly a parsing problem than an anaphora resolution issue and was therefore not addressed here.

The remaining four errors occurred because of an animacy constraint mismatch in the context of

Close-up of a puppy chewing on a stick.

It is lying on green grass.

There are no syntactic or lexical cues here to determine that *it* has a referent which is animate (*puppy*). The three nouns in the first sentence, *close-up, puppy* and *stick* are thus left on equal footing with no meaningful way to choose between them. AM then matches by syntactic role (subject with subject) and incorrectly assigns *close-up* to *it*.

This is an extremely difficult problem to solve. It would be possible to eliminate *close-up* as a possible referent by creating a list of exceptions, along with related terms like *a picture of, a shot of,* etc. but then one could argue that this example is in fact ambiguous, since *it* could just as well refer to *stick* as *puppy*. Even performing a semantic analysis would not help in this case, since logically both a puppy and a stick could be lying on grass.

If the multiple errors with identical causes are grouped and treated as single error sources, and the errors due to engcg are excluded, the success rate becomes 10 correct and 4 incorrect, or a success rate of 71% based on type of input.

Comparing this performance to that of other anaphora resolution systems is difficult because there exists no common publicly available standard database comparable to those available for the evaluation of various image processing tasks (such as the FERET database for face detection). In fact, the design of a suitable database for such evaluation is a complex problem in its own right which is currently being addressed [Gris]. The best available programs for anaphora resolution today are claimed to have accuracy rates of 70% to 85% [Kenn], although without knowing how those numbers were obtained, it is rather difficult to make any meaningful comparisons. To the extent that such as comparison can be made, the results obtained here are not out of line. At least some further performance improvement to AM could be made easily, with a number of difficult problems remaining as open questions. Reaching 100% accuracy is probably impossible, given that some anaphoric references will always be ambiguous even to human readers. At least one such example was present even in the limited test data used herre. It should also be remembered that since a typical sentence has more than two possible referents for a given anaphor, that an accuracy of 50% for example is actually better than random choice.

A much more extensive database of 118,794 image captions from the Strong Museum in Rochester, NY (courtesy of Judy Banker) containing many pronominal anaphora is also available. The following table gives the number present of each type:

he	1012
she	943
it	1745
its	726
it's	62
him	263
his	1584
her	1636
hers	9
they	404
them	1330
their	566
they're	1

Table 3: Pronoun distribution in Strong data

Unfortunately, there was no ground truth data available for this dataset at the time of this writing and the data also needs reformatting due to system conversion so it was not used in testing.

4 Discussion

4.1 Parsing problems

AM makes extensive use of two external programs (*engcg* and *WordNet*) to gain information about the words in its input sentences. Unfortunately, AM can be no more accurate than the information it receives. Problems which arise from interacting with both engcg and WordNet are described in the following sections.

4.1.1 Problems with engcg

Some parses contain ambiguities. For example, the input

Joe took this picture of our camp house in Vermont.

returns

```
Joe took this picture of our camp house in Vermont.
"<*joe>"
      "joe" <*> <Proper> N NOM SG  @SUBJ
"<took>"
      "take" <as/SVOC/A> <for/SVOC/A> <SVO> <SVOO> <SV> V PAST VFIN
@+FMAINV
"<this>"
      "this" DET CENTRAL DEM SG @DN>
"<picture>"
      "picture" N NOM SG  @OBJ
"<of>"
      "of" PREP  @<NOM-OF
"<our>"
      "we" PRON PERS GEN PL1 @GN>
"<camp>"
      "camp" N NOM SG  @SUBJ @NN> @<P
"<house>"
      "house" N NOM SG  @<P
      "house" <SVO> <SV> V PRES -SG3 VFIN @+FMAINV
"<in>"
      "in" PREP  @<NOM @ADVL
"<*vermont>"
      "vermont" <*> <Proper> N NOM SG  @<P
"<$.>"
```

Note that it tags *house* as either a noun or a verb. Sometimes engcg is simply wrong. For example, consider the following input similar to the previous sentence:

```
Diana in the wood storage shed of our camp house in Vermont.
"<*diana>"
      "diana" <*> <Proper> N NOM SG  @SUBJ
"<in>"
      "in" PREP  @<NOM
"<the>"
      "the" <Def> DET CENTRAL ART SG/PL @DN>
"<wood>"
      "wood" N NOM SG  @NN> @<P
```

```
"<storage>"
      "storage" <-Indef> N NOM SG  @NN>
"<shed>"
      "shed" N NOM SG  @<P
"<of>"
      "of" PREP  @<NOM-OF
"<our>"
      "we" PRON PERS GEN PL1 @GN>
"<camp>"
      "camp" N NOM SG  @<P
"<house>"
      "house" <SVO> <SV> V PRES -SG3 VFIN @+FMAINV
"<in>"
      "in" PREP  @ADVL
"<*vermont>"
      "vermont" <*> <Proper> N NOM SG  @<P
"<$.>"
```

Note that here it tags *house* exclusively as a verb. Although the word *house* in fact can be used as a verb, that is not possible in the given context due to the number agreement requirement. Adding an *is* to this fragment to make it a complete sentence (*Diana* ***is*** *in the wood storage shed of our camp house in Vermont.*) does yield the noun tag for *house*, but it still has the verb tag too, creating an ambiguous parse as in the previous example.

Engcg also sometimes performs incorrect contraction expansion. For example, in

It's been very cold this spring.

the root form of the verb in *it's* is identified as *be* instead of *have*.

Engcg has particular trouble dealing with sentence fragments. For example, incorrect syntactic tags are assigned in the next example even though this fragment is missing only a leading quantifier to be a grammatically complete sentence:

```
Wood jointed elephant has glass eyes.
"<*wood>"
      "wood" <*> N NOM SG  @SUBJ
"<jointed>"
      "joint" <SVO> V PAST VFIN @+FMAINV
"<elephant>"
      "elephant" N NOM SG  @OBJ
"<has>"
      "have" <SVO> <SVOC/A> V PRES SG3 VFIN  @+FMAINV
"<glass>"
      "glass" N NOM SG  @OBJ @NN>
"<eyes>"
      "eye" N NOM PL  @OBJ
"<$.>"
```

In this case, *wood* has been assigned the subject, whereas it is really only a modifier of the true subject, *elephant*. Given the noun phrase

Friends and relatives enjoying lunch.

lunch is parsed as

```
"<lunch>"
      "lunch" <SV> V PRES -SG3 VFIN @+FMAINV
      "lunch" <SV> V IMP VFIN @+FMAINV
```

Here engcg is unsure and offers two choices. Unfortunately, both interpretations are wrong since *lunch* is actually a noun (the usage of *lunch* as a verb is comparatively uncommon). The IMP (*imperative*) tag is impossible under any interpretation. However, if this example is rephrased as a complete sentence,

Here are my friends and relatives enjoying lunch.

we now get the correct

```
"<lunch>"
      "lunch" N NOM SG  @OBJ
```

4.1.2 Problems with WordNet

AM uses the *hypernym* (part-of) relationships in the WordNet database to provide it with real-world information used to establish constraints on the nouns being considered as possible antecedents during the anaphora resolution process. For example, the second hypernym level for *girl* includes the word *female*. This can be used to establish a gender constraint.

One problem with this occurs in conjunction with nouns which have multiple senses, a situation that is extremely common. Since AM is not a complete discourse-understanding system, it has no way of telling which sense is the correct one. Therefore it examines all senses. This leads to the situation where the sentence

Patty and Sam at the birthday party.

returns *living* as a hypernym of *party*. This happens because one of the senses of *party* is ”a person” (as in “party of the first part”) and one of the attributes of persons *is living being*. Unfortunately, there is no easy way to determine which sense of a word should be used to search for constraints. For example, the first sense of *party* is *political party*, while *party* as a social occasion (which one might expect to encounter more frequently in snapshot captions) is only the second sense listed. However, the first entry for the word *kid* is the expected *child* sense, while the second sense refers to *kidskin*.

Another problem with hypernyms is that some features can be found with unintended meanings. For example, *camp* also has the feature *living*, which initially seems quite odd. In this case it is simply because the second-level hypernym for the first sense of *camp* is *living quarters*. Therefore the word *living* cannot be used to determine a constraint for animacy. However, the word *creature,* which might not be initially thought of, does seem to satisfy that requirement.

4.1.3 Abbreviations

The recognition of abbreviations poses special parsing problems because of the semantic ambiguity in the use of the period character as both an abbreviation indicator and an end-of-sentence (EOS) marker. AM uses the period as a marker to determine where one sentence in its input ends and the next begins. If it encounters an abbreviation in the first sentence, the scan will end prematurely.

One way to deal with this problem would be to maintain a dictionary of abbreviations and check the last word in the sentence being recognized against it. If a match is found, it would be assumed to be an abbreviation and scanning for the true EOS would resume. In fact, engcg does identify abbreviations so one solution would be to let engcg scan the entire input for abbreviations before performing the sentence partitioning. However, this leads to the complementary problem of incorrect abbreviation identification. For example, given a sentence ending in *"…with Ted and Reg."*, engcg incorrectly gives *Reg* the <ABBR> tag rather than the <PROPER> tag and omits the expected <$.> EOS marker entirely. The moral seems to be "you can't win".

In any event, it is unclear to what extent abbreviations may be found in real-world image captions and queries. They occur only twice in the 72 caption set used to test the current program, but they are abundant in a much larger set obtained from the Strong Museum. In any case, this problem is beyond the scope of the problem of anaphora resolution *per se* and cannot be addressed here. The practical effect on AM is that the input will be partitioned into extra "sentences" when abbreviations are encountered. This does not impede the functioning of the constraint matching process itself, although it does present problems for engcg, since that program is considerably less reliable with both part-of-speech and syntactic classification when working on sentence fragments rather than whole sentences as shown in the previous section.

4.2 Internationalization

With the global potential of the market for natural language image query and captioning, consideration should be given to the extension of automatic anaphora resolution to other languages besides English. Anaphora are a linguistic universal, occurring in all natural languages and the semantic problems associated with them are the same. The simplest way of addressing this problem would be to first translate the input text automatically into English and then proceed as usual. This approach is attractive since it requires no modification to the existing code. Unfortunately, its success is directly proportional to the accuracy of the translated text. Given the long-standing difficulties associated with machine translation, it appears that this path is unlikely to be optimal, at least for some time into the future. Constraint-matching depends heavily on having available the proper part-of-speech tags and word senses, and the correct identification of these features is among the most problematic aspects of current machine translation programs.

One alternative is to modify the anaphora resolution program. AM is written in a modular fashion so that the constraint-matching section is independent of the constraint-generation process. Unfortunately, the syntactic and morphological patterns that may be used to generate constraints for anaphora resolution can differ considerably from language to language. Some of the problems that may be encountered include:

- *Gender agreement:* All common nouns in French (as well as many other languages) have grammatical gender and require the appropriate corresponding pronouns although this gender is completely arbitrary and therefore cannot be used reliably to extract semantic information. For example *skirt* is feminine (*la jupe*) but *petticoat* (*le jupon*) is masculine. German and Russian have three grammatical genders; Swahili has at least six [Lyon]. Additional genders help improve the probabilities of arriving at a match since fewer nouns fall into each category. German has an additional complication in that all nouns are capitalized, which complicates the process of proper noun identification, and therefore gender assignment. However, perhaps as some measure of compensation, in some countries such as Germany, first names are assigned by law as being exclusively either male or female.

- *Number agreement:* Some languages have pronominal number ambiguity For example, in German *sie* can be either *she* or *they*. In fact a number agreement problem even exists within English. Some words (such as *family, group, team, corporation*) can be used as plural in British English, however, they are always singular in American English.

Of course one difficulty with this approach is the need to have a parser and lexical database equivalent to engcg and WordNet respectively available for each language for which processing is desired. This appears to be a classic case of the TANSTAAFL Principle (There Ain't No Such Thing As A Free Lunch), however, it is not an insurmountable problem. In fact, the EuroWordNet project [Voss], is currently underway and addresses Dutch, Italian, and Spanish. Parsers are also now available for many languages worldwide including French, German [Weis], Portuguese [Vill], and Chinese [Zhou].

4.3 Factors affecting accuracy

There are a number of factors beyond the control of AM which will adversely affect the accuracy of the results. Among these are the accuracy of the parse returned by engcg. As noted in the previous section, this can be quite variable. For example, it correctly identified *bldg* as an abbreviation and a noun even though the period was missing. However, it misidentified the proper name *Reg* as an abbreviation when it was the final word in a sentence and also sometimes identifies nouns as verbs. If a noun is misclassified as a verb, there is no chance it will be identified as the co-referent of any anaphora.

Spelling and typographical errors present similar problems to both engcg and WordNet. One possible solution is to run the input through a spell-checker before further processing. However, this leads to all of the problems associated with automatic spelling correction, including correction of misspelled words to the wrong word, flagging of unknown words as misspellings, inability to correct typos involving incorrect placement of space characters (e.g. *whic hword*), inability to recognize misspellings that result in valid words, but the wrong word such as *food* vs. *good* (*f* is adjacent to *g* on the keyboard), and inability to correct homophones (many people do not seem to know the difference between *site, sight,* and *cite* or *there, their,* and *they're*.). Spell-checking also cannot address such problems as typos where a sentence is mistakenly ended with a comma rather than a period (the two characters are adjacent on the keyboard) and unconventional capitalization. These problems all occur in practice and need to be anticipated in any application destined for use by a general audience, as opposed to professional captioners trained to operate in a specific style. All of these problems will also occur and even more frequently if voice captioning should be implemented since automatic speech-to-text programs have many of the same problems as machine translation programs.

Another problem with both WordNet and engcg is that of dealing with unknown words. This can arise either because of misspellings as discussed above, or because the word is truly unknown. If one or both of the tagger and lexicon fail to identify the part of speech of a word, it could lead to a matching failure if that word turns out to be a noun that is an anphoric referent. Although none of the words in the test database were unknown, it is not difficult to think of words that neither engcg nor WordNet know. At least engcg will take a guess as to the part of speech of an unknown word based on its syntactic placement. For example, in

The fnord is red.

it thinks *fnord* is a noun and marks it with <?> to indicate that this is only a guess.

However, WordNet has no way of dealing with unknown words. This is a difficult problem that is beyond the scope of AM, but proposals have been made for how to handle it [Mikh] and this should be kept in mind as needing attention to increase the accuracy of results.

5 Summary

Automatic resolution of anaphora by computer is a difficult natural language processing problem that requires considerable knowledge beyond the information which is available in the input text to solve accurately. Despite considerable effort on the part of researchers in computational linguistics, it remains an open problem. The best programs at this time achieve no more than 75% to 85% accuracy. However, anaphora resolution is worth considering because it offers the possibility of increasing the accuracy of matches in a natural language image database query system which could provide a competitive advantage to the operator of such a system by increasing customer satisfaction. As the size of such databases increases in the future, the use of systems which only match keywords or attempt to perform semantic expansion (searching for terms semantically related to those given in the query) will become less acceptable.

The program presented here is capable of performing intersentential pronominal anaphora resolution on ordinary English text and includes a comprehensive treatment of pleonastic pronouns, something which almost all other investigators have ignored, but which I believe is crucial for successful treatment of anaphora.

Many opportunities remain for extending the current work. Different taggers of English could be tried, e.g. TTP [Strz] or TOSCA/LOB.. A more extensive test database with ground truth analysis should be implemented. Finally, the various unresolved issues raised in the discussion could be addressed. At this date, these remain the subject of active research in the natural language processing community. While perfection is probably an unreasonable goal, it would seem that a considerable improvement in resolution accuracy could be obtained for a relatively small additional investment in time simply by adding the unimplemented features described here to the existing code.

Finally, given the recent growing interest in natural language processing and its commercial implications, and the wide applicability of anaphora resolution in natural language processing, it is recommended that consideration be given to obtaining a patent position in this area.

6 Appendix

All file names and URL's included in this section are known to be current at the time of this writing. All programs and data are in the ISL Unix environment.

6.1 Code and data location

AM is implemented entirely in Interlisp as contained in Medley Lisp, the successor to Interlisp-D. The source code is found in the file `/space/cloves1/lisp/lyric/VIMFNS`. The top-level function is called `AM` and it takes one argument: a string which may be either a set of sentences containing the anaphora to be resolved or a file name which contains these sentences. AM internally calls engcg and WordNet.

engcg is found in `/home/bhandari/engcg/engcg-971001/engcg` and can be run from the Unix command line. It takes one argument: a file name containing the input sentences to be parsed. It will only run on the server *natasha* because of the program's licensing arrangement. A wrapper script called `eng.perl` is available in `/space/cloves1/perl/` which allows input to be typed in directly from the command line and can be run on any machine in the ISD computing environment. To use it, alias `eng` to `rsh natasha /space/cloves1/perl/eng.perl`. Then type `eng <CR>` followed by the desired text on the next line. The freeware TOSCA/LOB tagger is available on `/space/cloves1/vim/tlbtag`, however, this only runs in MS-DOS.

WordNet is installed in `/freeware/misc/bin/wordnet/wordnet-1.6/bin/`. It will run on any machine and can either be called from the command line with the command `wn` or via a graphical user interface with the command `wnb`.

The world knowledge proper name data files used by AM are located in `/home/bhandari/nl/mit/nlp/` (`male-names.data`, `female-names.data` and `place-names.data`). This directory also contains a small list of abbreviations, however, these are currently not used by AM. The intersections of the name files are in `/space/raccoon2/vim/data/`.

The caption data files used for development and testing are located in `/space/project3/gray/imagecaptions/`. This directory contains data received from the Strong Museum, the George Eastman House, as well as locally developed captions based on the JBJL image database. The JBJL images are located in `/space/library/jbjl/`.

6.2 WWW resources

Lingsoft, the company that produces engcg has a web site with documentation on their product at http://www.lingsoft.fi. There is no locally available documentation on engcg.

The home page for WordNet is at http://www.cogsci.princeton.edu/~wn/. This site contains documentation and also lets you use WordNet interactively. There is a corresponding site for EuroWordNet at http://www.let.uva.nl/~ewn.

PNI (Picture Network International) operates the Publisher's Depot web site which supports natural language queries for locating stock photography, although without anaphoric resolution. It may be viewed at http://www.publishersdepot.com. Another search engine using natural language input for queries is MetaSEEk at http://www.ctr.columbia.edu/metaseek.

The reader interested in pursuing the references further may be interested in http://gopher.sil.org/reference which is an extensive glossary of technical linguistic jargon. The web site of the Association for Computational Linguistics is http://www.aclweb.org.

7 Patents

Interestingly, a search of the U.S. Patent Database (searching all fields, back to 1971) revealed *zero* patents mentioning the term *anaphora*, and only five that used the term *pronoun*. Of those five, only one could be considered remotely relevant to anaphora resolution [Tana].

This is a natural language understanding patent that implements a reverse question answering scenario (the computer asks the questions, the human user provides answers). At first glance, it appears that they are doing anaphora resolution, based on the following sentence in the abstract:

> "The inputting and editing system analyzes the answer to an interrogative and matches the pronouns and other elements of the answer with their corresponding elements from the interrogative so that the operator does not have to answer the interrogative with the exact language of the interrogative for the system to understand and utilize the answer properly."

However, examination of the actual claim pertaining to this section reveals the following:

> "using said inferences of step (e) [*developing inferences based on the contents of the sentence*] to obtain a case nominal corresponding to a pronoun used in the interrogative;"

So this does not really appear to be anaphora resolution at all. They have the computer generate a query which already contains anaphora, so (presumably) the computer already knows to whom or what the pronouns it is outputting refers to. Therefore they simply have to look for a noun in the user's response that has characteristics similar to the noun it already knows about (and replaced with a pronoun). This is pattern matching, not anaphora resolution. In any event, their claim is strictly limited to question answering.

There is one other patent is worth noting [Kaji]. This is a machine translation system which apparently performs ellipsis identification in the source language and then inserts anaphora into the translation, as stated in their abstract:

> "When a target language translation of the source language sentence is formed, a pronoun having the same gender, person and number as the omitted phrase is used as a target language equivalent for the omitted phrase, and thus a target language translation which is grammatically correct, is obtained."

This of course is also not anaphora resolution.

There actually are many patents on the general topic of systems for retrieving images using natural language. A recent search using the terms *natural language image retrieval library* returned 1000 patents, although only perhaps a dozen are truly relevant to image query by natural language. Many of these patents deal with limited applications, such as question-answering systems for specific domains, and address the natural language component only tangentially providing very little detail as to its actual operation. Perhaps the most relevant patent in this group is one assigned to Matshushita in 1997

[Okam]. It appears to address the major aspects of an image query system including parsing of the input data, semantic analysis using Fillmore's case grammar [Fill], constraint matching, conversion of caption data into an intermediate form, and generating confidence scores for the results. It goes so far as to present a simple grammar of English used to analyze input sentences. However, it specifically does not appear to address anaphora in either the detailed description or the claims, and its rules for noun phrase expansion do not include pronouns.

8 Bibliography

The bibliography is divided into two sections. The first contains all citations in the text not directly related to anaphora resolution including US patents. The second is a general survery of the open literature on anaphora resolution.

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8.2 Literature Survey

Most of the following references are based on a number of online bibliographies including one for a tutorial on anaphora resolution recently given at *COLING-ACL '98*. Although most are not cited in the text they are included here for completeness. They form a reasonably comprehensive view of the treatment of anaphora resolution in the open literature over the last 25 years. For an evaluation of the applicable patent literature, see section 7.

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