A Logic for Semantic Interpretation

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Abstract

We propose that logic (enhanced to encode probability information) is a good way of characterizing semantic interpretation. In support of this we give a fragment of an axiomatization for word-sense disambiguation, noun-phrase (and verb) reference, and case disambiguation. We describe an inference engine (Frail3) which actually takes this axiomatization and uses it to drive the semantic interpretation process. We claim three benefits from this scheme. First, the interface between semantic interpretation and pragmatics has always been problematic, since all of the above tasks in general require pragmatic inference. Now the interface is trivial, since both semantic interpretation and pragmatics use the same vocabulary and inference engine. The second benefit, related to the first, is that semantic guidance of syntax is a side effect of the interpretation. The third benefit is the elegance of the semantic interpretation theory. A few simple rules capture a remarkable diversity of semantic phenomena.

I. Introduction

The use of logic to codify natural language syntax is well known, and many current systems can parse directly off their axiomatizations (e.g.,)[1]. Many of these systems simultaneously construct an intermediate "logical form" using the same machinery. At the other end of language processing, logic is a well-known tool for expressing the pragmatic information needed for plan recognition and speech act recognition [2-4]. In between these extremes logic appears much less. There has been some movement in the direction of placing semantic interpretation on a more logical footing [5,6], but it is nothing like what has happened at the extremes of the language understanding process.

To some degree this is understandable. These "middle" parts, such as word-sense disambiguation, noun phrase reference, case disambiguation, etc. are notoriously difficult, and poorly understood, at least compared to things like syntax, and the construction of intermediate logical form. Much of the reason these areas are so dark is that they are intimately bound up with pragmatic reasoning. The correct sense of a word depends on context, as does pronoun resolution, etc.

Here we rectify this situation by presenting an axiomatization of fragment of semantic interpretation, notably including many aspects previously excluded: word-sense disambiguation, noun-phrase reference determination, case determination, and syntactic disambiguation. Furthermore we describe an inference engine, Frail3, which can use the logical formulation to carry out semantic interpretation. The description of Frail3 is brief, since the present paper is primarily concerned with semantic interpretation. For a more detailed description, see [7].

The work closest to what we present is that by Hobbs [5]; however, he handles only noun-phrase reference from the above list, and he does not consider intersentential influences at all.

Our system, Wimp2 (which uses Frail3), is quite pretty in two respects. First, it integrates semantic and pragmatic processing into a uniform whole, all done in the logic. Secondly, it provides an elegant and concise way to specify exactly what has to be done by a semantic interpreter. As we shall see, a system that is roughly comparable to other state-of-the-art semantic interpretation systems [6,8] can be written down in a page or so of logical rules.

Wimp2 has been implemented and works on all of the examples in this paper.

II. Vocabularies

Let us start by giving an informal semantics for the special predicates and terms used by the system. Since we are doing semantic interpretation, we are translating between a syntactic tree on one hand and the logical, or internal, representation on the other. Thus we distinguish three vocabularies: one for trees, one for the internal representation, and one to aid in the translation between the two.

The vocabulary for syntactic trees assumes that each word in the sentence is represented as a word instance which is represented as a word with a numerical post-fix (e.g., boy22). A word instance is associated with the actual lexical entry by the predicate word-inst:
The correspondence between trees and formulas is as follows: the outputs are asserted into the database. The correspondence is not perfect: if there is more than one parse and the parser disagrees on the propositional output, a disjunction is used. Propositions denoting syntactic relations are generated in a breadth-first search and outputs propositions on a word-by-word basis. If there is more than one parse and the parser disagrees on the propositional output, a disjunction of the outputs is asserted into the database. The correspondence between trees and formulas is as follows:

| Trees     | Formulas                                      |
|-----------|-----------------------------------------------|
| s — np    | (syn-pos subject head-v np) head-v symbol is s symbol |
| vp — head-v np ... | (syn-pos object head-v np)                  |
| vp — head-v np | (syn-pos indirect-object head-v np)         |
| vp — head-v ... (pp prep ...) | (syn-pp head-prep head-v prep)              |
| pp — prep np | (-syn-pp prep-np prep np)                         |
| pp — prep np | (-syn-pp prep-np prep np)                         |
| np — head-n ... | head-n symbol is np symbol                   |
| np — pronoun | pronoun symbol is np symbol                    |
| np — propnoun | propnoun symbol is np symbol                   |
| np — adj head-n ... | (syn-pos adj adj head-n)                     |
| np — head-n ... (pp prep ...) | (syn-pp head-prep head-n prep)              |
| np — that s | s symbol is np symbol                          |
| s — np (vp ... copula) (pp prep ...) | (syn-pp head-prep np prep)                     |
| s — np (vp ... copula) adj          | (syn-pos adj adj np)                          |

This is enough to express a wide variety of simple declarative sentences. Furthermore, since our current parser implements a transformational account of imperatives, questions (both yes-no and wh), complement constructions, and subordinate clauses, these are automatically handled by the above as well. For example, given an account of “Jack wants to borrow the book,” as derived from “Jack wants (np that (s Jack borrow the book)).” or something similar, then the above rules would produce the following for both (we also indicate after what word the formula is produced):

| Words | Formulas                                      |
|-------|-----------------------------------------------|
| Jack  | (word-inst jack1 pronoun jack)               |
| wants | (word-inst want1 verb want) (syn-pos subject want1 jack1) |
| to    | (syn-pos object want1 borrow1)               |
| borrow| (syn-pos subject borrow1 jack1)              |
| the   | (word-inst book1 noun book)                  |
| book  | (syn-pos object borrow1 book1)               |

This is, of course, a fragment, and most things are not handled by this analysis: negation, noun-noun combinations, particles, auxiliary verbs, etc.

Now let us consider the internal representation used for inference about the world. Here we use a simple predicate-calculus version of frames and slots. We assume only two predicates for this: == and inst. inst.

(inst instance frame).

This is a restricted use of equality. The second argument is a “better name” for the first, and thus may be freely substituted for it (but not the reverse). Since slots are represented as functions, == is used to fill slots in frames. To fill the agent slot of a particular action, say borrow1, with a particular person, say jack1, we say

(== (agent borrow1) jack1).

At an implementation level, == causes everything known about its first argument (the worse name) to be asserted about the second (the better name). This has the effect of concentrating all knowledge about all of an object’s names as facts about the best name.

Frail will take as input a simple frame representation and translate it into predicate-calculus form. Figure 1 shows a frame for shopping along with the predicate-calculus translation.

Naturally, a realistic world model requires more than these two predicates plus slot functions, but the relative success of fairly simple frame models of reasoning indicates that they are a good starting set. The last set of predicates (word-sense, case, and role-inst) are used in the translation itself. They will be defined later.
(deframe shop-
   isa action
   ;(inst ?s.shop- action)
   slots (agent (person-))
   ;(inst (agent ?s.shop-) person-)
   (store-of (store-))
   ;(inst (store-of ?s.shop-) store-)
   acts (go-step
      (go- (agent (agent ?shop-))
      (destination (store-of ?shop-)))
      ;(== (agent (go-step ?shop-)) (agent ?shop-))
      ;(== (destination (go-step ?s.shop-))
      (store-of ?s.shop-))
   )

Figure 1: A frame for shopping

III. Word-Sense Disambiguation

We can now write down some semantic interpretation
rules. Let us assume that all words in English have one or
more word senses as their meaning, that these word senses
correspond to frames, and that any particular word in-
stance has as its meaning exactly one of these senses. We
can express this fact for the instances of any particular
lexical entry as follows:

(\text{word-inst } \text{inst part-of-speech word}) \Rightarrow
\text{(inst rest sense1)} \lor \ldots \lor \text{(inst inst sense,=)}

where sense1 through sense,= are senses of word when it
is used as a part-of-speech (i.e., as a noun, verb, etc.)

Not all words in English have meanings in this sense.
"The" is an obvious example. Rather than complicate
the above rules, we assign such words a "null" mean-
ing, which we represent by the term garbage*. Nothing
is known about garbage* so this has no consequences.
A better axiomatization would also include words which
seem to correspond to functions (e.g., age), but we ignore
such complications.

A minor problem with the above rule is that it re-
quires us to be able to say at the outset (i.e., when we
load the program) what all the word senses are, and new
senses cannot be added in a modular fashion. To fix this
we introduce a new predicate, word-sense:

(\text{word-sense lex-item part-of-speech frame})
(\text{word-sense straw noun drink-straw})
(\text{word-sense straw noun animal-straw}).

This states that lex-item when used as a part-of-speech
can mean frame.

We also introduce a pragmatically different form of
disjunction. \(\neg\)OR:

(\text{\neg OR } \text{formula1 \ldots formula_n}).

In terms of implementation, think of this as inferring
\text{formula1 in all possible ways and then asserting the dis-
junction of the \text{formula2 with each set of bindings. So if
there are two sets of bindings, the result will be to assert

(OR \text{formula2/bindings1 } \text{formula2/bindings2}).

Logically, the meaning of \(\neg\)OR is that if \(x_1 \ldots x_n\) are
unbound variables in \text{formula1}, then there must exist \(x_1 \ldots x_n\) that make \text{formula1 and formula2} true.

We can now express our rule of word-sense ambiguity as:

(\text{word-inst ?instance ?part-of-speech ?lex-item}) \Rightarrow
(\text{\neg OR (word-sense ?lex-item ?part-of-speech ?frame)})
\text{(inst ?instance ?frame})

IV. The Inference Engine

While it seems clear that the above rule expresses a rather
simple-minded idea of how words relate to their mean-
ings, its computational import may not be so clear. Thus
we now discuss Wimp2, our language comprehension pro-
gram, and its inference engine, Frail3.

Like most rule-based systems, Frail distinguishes for-
ward and backward-chaining use of modus-ponens. All
of our semantic interpretation rules are forward-chaining
rules:

(\text{\neg (word-inst ?instance ?part-of-speech ?lex-item)})
(\text{\neg OR (word-sense ?lex-item ?part-of-speech ?frame)})
\text{(inst ?instance ?frame})

Thus, whenever a new word instance is asserted, we
forward-chain to a statement that the word denotes an
instance of one of a set of frames.

Next, Frail uses an ATMS [9,10] to keep track of
disjunctions. That is, when we assert (OR \text{formula1}
\ldots \text{formula_n}) we create n assumptions (following DeK-
leer, these are simply integers) and assert each formula
into the data-base, each with a label indicating that the
formula is not true but only true given some assumptions.
Here is an example of how some simple disjunctions come
out.

\begin{tabular}{|c|c|}
\hline
\text{Formulas} & \text{Assumptions} \\
\hline
A & (()) \\
B & (1) \\
C & (2) \\
D & (1 3) \\
E & (1 4) \\
\hline
\end{tabular}

Figure 2 represents this pictorially. Here D, for example,
haves the label (1 3), which means that it is true if we grant
assumptions 1 and 3. If an assumption (or more gener-
ally, a set of assumptions) leads to a contradiction, the
assumption is declared a “nogood” and formulas which
depend on it are no longer believed. Thus if we learn (not
D) then (1 3) is a nogood. This also has the consequence
that E now has the label (1). It is as if different sets
of assumptions correspond to different worlds. Seman-
tic interpretation then is finding the “best” of the worlds
defined by the linguistic possibilities.
We said "best" in the last sentence deliberately. When alternatives can be ruled out on logical grounds the corresponding assumptions become nogoods, and conclusions from them go away. But it is rare that all of the candidate interpretations (of words, of referents, etc.) reduce to only one that is logically possible. Rather, there are usually several which are logically consistent, but some are more "probable" than others. For this reason, Frail associates probabilities with sets of assumptions ("alternative worlds") and Wimp eventually "garbage collects" statements which remain low-probability alternatives because their assumptions are unlikely. Probabilities also guide which interpretation to explore. Exactly how this works is described in [7]. Here we will simply note that the probabilities are designed to capture the following intuitions:

1. Uncommon vs. common word-senses (marked vs. unmarked) are indicated by probabilities input by the system designer and stored in the lexicon.
2. Wimp prefers to find referents for entities (rather than not finding referents).
3. Possible reasons for actions and entities are preferred the more specific they are to the action or entity. (E.g., "shopping" is given a higher probability than "meeting someone" as an explanation for going to the supermarket.)
4. Formulas derived in two different ways are more probable than they would have been if derived in either way alone.
5. Disjunctions which lead to already considered "worlds" are preferred over those which do not hook up in this way. (We will illustrate this later.)

V. Case Disambiguation

Cases are indicated by positional relations (e.g., subject) and prepositional phrases. We make the simplifying assumption that prepositional phrases only indicate case relations. As we did for word-sense disambiguation, we introduce a new predicate that allows us to incrementally specify how a particular head (a noun or verb) relates to its syntactic roles. The new predicate,

\[(\text{case head syntactic-relation slot})\]

states that \textit{head} can have its \textit{slot} filled by things which stand in \textit{syntactic-relation} to it. For example

\[(\text{inst ?g go-}) \Rightarrow (\text{case ?g subject agent}).\]

This can also be expressed in Frail using the typed variables

\[(\text{case ?g go- subject agent}).\]

This says that any instance of a go- can use the subject position to indicate the agent of the go-event. These facts can be inherited in the typical way via the isa hierarchy, so this fact would more generally be expressed as

\[(\text{case ?a.action subject agent}).\]

Using case and the previously introduced \textit{--OR} connective, we can express the rule of case relations. Formally, it says that for all syntactic positional relations and all meanings of the head, there must exist a case relation which is the significance of that syntactic position:

\[(\text{syn-pos ?rel ?head ?val}) \wedge (\text{inst ?head ?frame}) \Rightarrow (\text{--OR (case ?head ?rel ?slot)})
\]

\[\Rightarrow (\text{(== (?slot ?head) ?val)})).\]

So, we might have

\[(\text{syn-pos subject gol jack1}) \wedge (\text{inst gol go-})
\]

\[\wedge (\text{case gol subject agent}) \Rightarrow (\text{(== (agent gol) jack1)}).
\]

A similar rule holds for case relations indicated by prepositional phrases.

\[(\text{syn-pp head-prep ?head ?pinst}) \wedge (\text{inst ?head ?frame}) \wedge (\text{word-inst ?pinst prep ?prep}) \wedge (\text{inst ?head ?frame}) \Rightarrow (\text{--OR (case ?head ?prep ?slot)})
\]

\[\Rightarrow (\text{(== (?slot ?head) ?np))}).\]

For example, "Jack went to the supermarket." would give us

\[(\text{syn-pp head-prep gol tol}) \wedge (\text{case gol to destination})
\]

\[\wedge (\text{syn-pp prep-np tol supermarket1}) \wedge (\text{word-inst tol prep to}) \wedge (\text{inst gol go-})
\]

\[\Rightarrow (\text{(== (destination gol) supermarket1)}).
\]

We now have enough machinery to describe two ways in which word senses and case relations can help disambiguate each other. First consider the sentence

Jack went to the supermarket.

Wimp currently knows two meanings of "go," to travel and to die. After "Jack went" Wimp prefers travel (based upon probability rule 1 and the probabilities assigned to these two readings in the lexicon) but both are possible. After "Jack went to" the die reading goes away. This is because the only formulas satisfying

\[(\text{case gol to ?slot})
\]

all require gol to be a travel rather than a die. Thus "die" cannot be a reading since it makes

\[\Rightarrow (\text{(== (?slot ?head) ?val)})
\]

states that \textit{head} can have its \textit{slot} filled by things which stand in \textit{syntactic-relation} to it. For example

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\]

\[\Rightarrow (\text{(== (?slot ?head) ?np))}).\]

For example, "Jack went to the supermarket." would give us

\[(\text{syn-pp head-prep gol tol}) \wedge (\text{case gol to destination})
\]

\[\wedge (\text{syn-pp prep-np tol supermarket1}) \wedge (\text{word-inst tol prep to}) \wedge (\text{inst gol go-})
\]

\[\Rightarrow (\text{(== (destination gol) supermarket1)}).
\]

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\[(\text{case gol to ?slot})
\]

all require gol to be a travel rather than a die. Thus "die" cannot be a reading since it makes

\[\Rightarrow (\text{(== (?slot ?head) ?val)})
\]
false (a disjunction of zero disjuncts is false).

We also have enough machinery to see how “selectional restrictions” work in Wimp2. Consider the sentence

Jack fell at the store.

and suppose that Wimp knows two case relations for “at,” loc and time. This will initially lead to the following disjunction:

$$\begin{align*}
(1) & \quad (** \text{loc fell}1 \text{store}1) \\
(2) & \quad (** \text{time fell}1 \text{store}1).
\end{align*}$$

However, Wimp will know that

$$\text{(inst time} \ ?a \text{.action) time-)}.$$ 

As we mentioned earlier, == statements cause everything known about the first argument to be asserted about the second. Thus Wimp will try to believe that store1 is a time, so (2) becomes a nogood and (1) becomes just true.

It is important to note that both of these disambiguation methods fall out from the basics of the system. Nothing had to be added.

VI. Reference and Explanation

Definite noun phrases (np’s) typically refer to something already mentioned. Occasionally they do not, however, and some, like proper names may or may not refer to an already mentioned entity. Let us simplify by saying that all np’s may or may not refer to something already mentioned. (We will return to indefinite np’s later.) We represent np’s by always creating a new instance which represents the entity denoted by the np. Should there be a referent we assert equality between the newly minted object and the previously mentioned one. Thus, in “Jack went to the supermarket.” We generalize this as for representing the basic rule of reference, the == statements cause everything known about the first argument to be asserted about the second. Thus Wimp will try to believe that store1 is a time, so (2) becomes a nogood and (1) becomes just true.

As for representing the basic rule of reference, the idea is to see the call for a referent as a statement that something exists. Thus we might try to say

$$(\text{inst} \ ?x \ ?a \text{.frame}) \Rightarrow (\text{Exists} \ (y \ ?\text{frame}) (** \ ?x \ ?y)).$$

This is intended to say, if we are told of an object of type ?frame then there must exist an earlier one \(y\) of this same type to which the new one can be set equal.

The trouble with this formula is that it does not say “earlier one.” Exists simply says that there has to be one, whether or not it was mentioned. Furthermore, since we intend to represent an np like “the taxi” by $$(\text{inst taxi}27 \text{taxi-})$$ and then look for an earlier taxi, the Exists would be trivially satisfied by taxi27 itself.

Our solution is to introduce a new quantifier called “previously exists” or P Exists. (In [5] a similar end is achieved by putting weights on formula and looking for a minimum-weight proof.) Using this new quantifier, we have

$$\text{(inst} \ ?x \ ?a \text{.frame) \Rightarrow (P Exists} \ (y \ ?\text{frame}) (** \ ?x \ ?y)).$$

If there is more than one a disjunction of equality statements is created. For example, consider the story

Jack went to the supermarket. He found the milk on the shelf. He paid for it.

The “it” in the last sentence could refer to any of the three inanimate objects mentioned, so initially the following disjunction is created:

$$\begin{align*}
&\quad (** \text{it}8 \text{shelf}6) \\
&\quad (** \text{it}8 \text{milk}5) \\
&\quad (** \text{it}8 \text{supermarket}2).
\end{align*}$$

This still does not allow for the case when there is no referent for the np. To understand our solution to this problem it is necessary to note that we originally set out to create a plan-recognition system. That is to say, we wanted a program which given a sentence like “Jack got a rope. He wanted to kill himself.” would recognize that Jack plans to hang himself. We discuss this aspect of Wimp2 in greater detail in [7]. Here we simply note that plans in Wimp2 are represented as frames (as shown in Figure 1.) and that sub tasks of plans are actions which fill certain slots of the frame. So the shop-plan has a go-step in Figure 1. and recognizing the import of “Jack went to the supermarket.” would be to infer that $$**(\text{go-step shop-74} \text{go61})$$ where go61 represented the verb in “Jack went to the supermarket.” We generalize this slightly and say that all inputs must be “explained”; by this we mean that we must find (or postulate) a frame in which the input fills a slot. Thus the go-step statement explains go61. The presence of a supermarket in the story would be explained by $$**(\text{store- of shop-74} \text{supermarket}64)$$. The rule that everything mentioned must be explained looks like this:

$$(\text{inst} ?x \ ?a \text{.frame}) \Rightarrow
\begin{align*}
&\quad (-\text{OR (role-inst} \ ?x \ ?\text{slot} \ ?\text{superfrm})
\end{align*}

(\text{Exists} \ (y \ ?\text{superfrm}) (** \ ?slot \ ?y)).$$

(Some things cannot be explained, so this rule is not strict.) Here the role-inst predicate says that \(x\) can fill the ?slot role of the frame ?superfrm. E.g., (role-inst \ ?x \ ?store- of shop- ?) says that stores can fill the store- of slot in the shop- frame. Here we use Exists, not P Exists since, as in the rope example, we explained the existence of the rope by postulating a new hanging event. The semantics of Exists is therefore quite standard, simply saying that one must exist, and making no commitment to whether it was mentioned earlier or not. As a matter of implementation, we note that it works simply by always
creating a new instance. The impact of this will be seen in a moment.

We said that all inputs must be explained, and that we explain by seeing that the entity fills a slot in a postulated frame. There is one exception to this. If a newly mentioned entity refers to an already extant one, then there is no need to explain it, since it was presumably explained the first time it was seen. Thus we combine our rule of reference with our rule of explanation. Or, to put it slightly differently, we handle the exceptions to the rule of reference (some things do not refer to entities already present) by saying that those which do not so refer must be explained instead. This gives the following rule:

\[
\begin{align*}
\text{(inst } x & \text{ frame) } \land \neg (\text{frame is garbage}) \implies \\
(\text{OR (PExists (y } & \text{ frame) (== } x \text{ y)}) \cdot .9 \\
\quad & \text{ (OR (role-inst } x & \text{ superfrm } \text{ slot)} \\
\quad & \exists (y \text{ superfrm}) \\
\quad & (== \text{ (slot } y \text{ ?x)))} \cdot .1
\end{align*}
\]

Here we added the restriction that the frame in question cannot be the garbage* frame, which has no properties by definition. We have also added probabilities to the disjunctions that are intended to capture the preference for previously existing objects (probability rule 2). The rule of reference has several nice properties. First, it might seem odd that our rule for explaining things is expressed in terms of the Exists quantifier, which we said always creates a new instance. What about a case like “Jack went to the supermarket. He found the milk on the shelf.” where we want to explain the second line in terms of the shopping plan created in the first? As we have things set up, it simply creates a new shopping plan. But note what then occurs. First the system asserts (inst new-shopping5 shopping4). This activates the above rule, which must either find a referent for it, or try to explain it in terms of a frame for which it fills a role. In this case there is a referent, namely the shopping created in the course of the first line. Thus we get (== new-shopping5 shopping4) and we have the desired outcome. This example also shows that the reference rule works on event reference, not just on reference.

This rule handles reference to “related objects” rather well. Consider “Jack wanted to play the stereo. He pushed the on-off button.” Here the “on-off button” is to be understood as the button “related” to the stereo mentioned in the first line. In Wimp this falls out from the rules already described. Upon seeing “the on-off button” Wimp creates a new entity which must then either have a referent or an explanation. It does not have the first, but one good explanation for the presence of an on-off button is that it fills the on-off-switch slot for some power-machine. Thus Wimp creates a machine and the machine then has to be explained. In this case a referent is found, the stereo from the first sentence.

VII. Pragmatic Influence

We finish with three examples illustrating how our semantic interpretation process easily integrates pragmatic influences: one example of pronoun reference, one of word-sense disambiguation, and one of syntactic ambiguity. First pronoun reference:

Jack went to the supermarket. He found the milk on the shelf. He paid for it.

In this example the “milk” of sentence two is seen as the purchased of shop-1 and the “pay” of sentence three is postulated to be the pay-step of a shopping event, and then further postulated to be the same shopping event as that created earlier. (In each case other possibilities will be considered, but their probabilities will be much lower.) Thus when “it” is seen Wimp is in the situation shown in Figure 3. The important thing here is that the statement (== it7 milk5) can be derived in two different ways, and thus its probability is much higher than the other possible referents for “it” (probability rule 4). (One derivation has it that since one pays for what one is shopping for, and Jack is shopping for milk, he must be paying for the milk. The other derivation is that “it” must refer to something, and the milk is one alternative.)

The second example is one of word-sense disambiguation:

Jack ordered a soda. He picked up the straw.

Here sentence one is seen as the order-step of a newly postulated eat-out1. The soda suggests a drinking event, which in turn can be explained as the eat-step of eat-out1. The straw in line two can be one of two kinds of straw, but the drink-straw interpretation suggests (via a role-inst statement) a drink-drinking event. This is postulated, and Wimp looks for a previous such event (using the normal reference rule) and finds the one suggested by the soda. Wimp prefers to assume that the drinking event suggested by “soda” and that from “straw” are the same event (probability rule 2) and this preference is passed back to become a preference for the drink-straw meaning of “straw” (by probability rule 5). The result is shown in Figure 4.

Our third and last example shows how semantic guidance of syntax works:

Janet wanted to kill the boy with some poison.

Starting with the “with” there are two parses which disagree on the attachment of the prepositional phrase (pp). There are also two case relations the “with” can indicate if it modifies “kill,” instrument and accompaniment. When Wimp sees “poison” it looks for an explanation of its presence, postulates a poisoning and which is found to be potentially coreferential with the “kill.” The result looks like Figure 5. In this interpretation the poison can be inferred to be the instrument of the poisoning, so this option has higher probability (probability rule 4). This
Figure 3: A pronoun example

Other alternatives

(inst pay7 pay-)

(== (pay-step shop-1) pay7)

(== it8 milk5)

(inst it8 inanimate-)

(== it8 shelf6)

(== it8 supermarket2)

Figure 4: A word-sense example

Other alternatives

(inst order2 order-)

(== (order-step eat-out1) order2)

(== (eat-step eat-out1) drink3)

(== (patient drink3) soda4)

Other alternatives

(inst straw3 drink-straw)

(== (straw-of drink3) straw3)

(word-inst straw3 noun straw)

(inst straw3 animal-straw)

Figure 5: A syntactic disambiguation example

the boy with

(syn-pp head-prep

boy1 with1)

Accompany

(syn-pp head-prep

kill1 with1)

Instrument

(== (instr kill1) poison4)

(inst poison4 poison-)

Other alternatives
higher probability is passed back to the disjuncts representing a) the choice of instrument over accompaniment, and b) the choice of attaching to "kill" over "boy" (probability rule 5). This last has the effect of telling the parser where to attach the pp.

VIII. Future Research

This work can be extended in many ways: increased syntactic coverage, more realistic semantic rules, improved search techniques for possible explanations, etc. Here we will simply look at some fairly straightforward extensions to the model.

Our rule preferring finding a referent to not finding a referent is not reasonable for indefinite np's. Thus Wimp currently misinterprets

Jack bought a gun. Mary bought a gun.
since it wants to interpret the second gun as coreferential with the first. A simple change would be to have two rules of reference/explanation. The rule for indefinite np's would look like this:

$$(\text{inst } ?x ?\text{frame}) \land (\text{not } (= ?\text{frame garbage*}))$$

$$\land (\text{syn-pos indef-det } ?x ?\text{det})$$

$$\Rightarrow (\text{OR (PExists (y \ ?\text{frame}) (== ?x ?y)) .1})$$

$$(-\text{OR (role-inst ?x ?superfrm ?slot)}$$

$$\text{(Exists (s \ ?superfrm)}$$

$$\text{(== (?slot ?s) ?x))) .9})$$

This looks just like our earlier rule, except a check for an indefinite determiner is added, and the probabilities are reversed so as to prefer a new object over an already existing one. The earlier reference rule would then be modified to make sure that the object did not have an indefinite determiner.

Another aspect of language which fits rather nicely into this framework is metonymy. We have already noted that the work closest to ours is [5], and in fact we can adopt the analysis presented there without a wrinkle. This analysis assumes that every np corresponds to two objects in the story, the one mentioned and the one intended. For example:

I read Proust over summer vacation.

The two objects are the entity literally described by the np (here the person "Proust") and that intended by the speaker (here a set of books by Proust). The syntactic analysis would be modified to produce the two objects, here proustl and read-objl respectively.

$$(\text{syn-pos direct-object read1 read-obj1)}$$

$$(\text{word-inst proustl propernoun proust})$$

$$(\text{syn-pos metonymy read-obj1 proustl)}$$

It is then assumed that there are a finite number of relations that may hold between these two entities, most notably equality, but others as well. The rule relating the two entities would look like this:

$$(\text{(- (syn-pos metonymy } ?\text{intended } ?\text{given})}$$

$$(\text{OR (== ?\text{intended } ?\text{given}) .9})$$

$$(== (\text{creator-of } ?\text{intended}) ?\text{given}) .02)$$

...)).

This rule would prefer assuming that the two individuals are the same, but would allow other possibilities.

IX. Conclusion

We have presented logical rules for a fragment of the semantic interpretation (and plan recognition) process. The four simple rules we gave already capture a wide variety of semantic and pragmatic phenomena. We are currently working on diverse aspects of semantics, such as definite vs. indefinite np's, noun-noun combinations, adjectives, non-case uses of prepositions, metonymy and relative clauses.

References

[1] F. Pereira & D. Warren, "Definite clause grammar for language analysis – a survey of the formalism and a comparison with augmented transition networks," Artificial Intelligence 13 (1980), 231-278.

[2] Philip R. Cohen & C. Raymond Perrault, "Elements of a plan-based theory of speech acts," Cognitive Science 3 (1979), 177-212.

[3] Eugene Charniak, "A neat theory of marker passing," AAAI-86 (1986).

[4] Henry Kautz & James Allen, "Generalized plan recognition," AAAI-86 (1986).

[5] Jerry R. Hobbs & Paul Martin, "Local pragmatics," Ijcai-87 (1987).

[6] Graeme Hirst, Semantic Interpretation and the Resolution of Ambiguity, Cambridge University Press, Cambridge, 1987.

[7] Robert Goldman & Eugene Charniak, "A probabilistic ATMS for plan recognition," forthcoming.

[8] Barbara J. Grosz, Douglas E. Appelt, Paul A. Martin & Fernando C.N. Pereira, "Team: an experiment in the design of transportable natural-language interfaces," Artificial Intelligence 32 (1987), 173-243.

[9] Drew V. McDermott, "Contexts and data dependencies: a synthesis," IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-5 (1983).

[10] Johan deKleer, "An assumption-based TMS," Artificial Intelligence 28 (1986), 127-162.