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THE CONTROL OF INFERENCE IN
NATURAL LANGUAGE UNDERSTANDING

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Abstract

The understanding of a natural language text requires that a reader (human or computer program) be able to resolve ambiguities at the syntactic and lexical levels; it also requires that a reader be able to recover that part of the meaning of a text which is over and above the collection of meanings of its individual sentences taken in isolation.

The satisfaction of this requirement involves complex inferencing from a large database of world-knowledge. While human readers seem able to perform this task easily, the designer of computer programs for natural language understanding faces the serious difficulty of algorithmically defining precisely the items of world-knowledge required at any point in the processing, i.e., the problem of controlling inferencing. This paper discusses the problems involved in such control of inferencing; an approach to their solution is presented, based on the notion of determining where each successive sentence "fits" into the text as a whole.
1. Introduction

The topic of this paper is one aspect of the algorithmic "understanding" of natural language texts. In operational terms we will define "understanding" as the ability to answer those questions concerning the contents of a text which a typical human reader would be able to answer after having read the text. While this is clearly not a precise formal criterion - different human readers might "understand" a text somewhat differently from one another - it will suffice for the purposes of this discussion.

In what follows we will not be concerned with the process whereby questions relating to a text might be answered, but rather with that part of the understanding process which immediately precedes question answering: the sub-process whereby a text is reduced to a (logic-like) formal representation from which the attempt to answer specific questions would proceed. The language in which such a formal representation is expressed is typically referred to as a semantic representation language (SRL).

Suppose, then, that we have a text T consisting of sentences \( S_1, S_2, \ldots, S_n \) in that order. The long-recognized existence of levels of regularity in language (Chomsky 1957, Chomsky 1965, Katz and Fodor 1963) suggests the following fairly traditional model for the computation of the formal representation of T. Each sentence \( S_i \) in turn, goes through the following three steps: 

1. \( S_i \) is processed by a parser to expose the hierarchy (tree-structure) of syntactic categories which constitutes its syntactic structure.

2. The "meaning" of each lexical item in \( S_i \), i.e. the item's representation in the SRL, is substituted for that item in the parse tree.

3. The resulting parse tree is processed in bottom-up fashion by an interpreter to produce the "meaning" of each phrase (non-terminal node in the parse tree) from those of its constituents, terminating, ultimately, with that of the entire sentence; we shall term this product (an SRL expression) the semantic interpretation of \( S_i \), abbreviated \( SI(S_i) \).

The set \( \{SI(S_1), SI(S_2), \ldots, SI(S_n)\} \) is then taken to constitute the "meaning" of text T. Example 1-1 illustrates this process for a single simple sentence.

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1. This division of the understanding process into steps does not imply that these steps must occur in the indicated order or that there is no communication between them.
Example 1-1: Parsing and Interpretation in the Traditional Model

The insufficiency of this traditional model for achieving understanding has been evident since the very earliest attempts at implementing computational natural language understanding. In the first place, a sentence taken in isolation can be ambiguous on both the grammatical and lexical levels, as is illustrated by examples 1-2 and 1-3.
Today they are flying planes.

**parse a**

```
S
   |   |
   ADVERB NP   VP
   |       |
Today   they   VERB
         |       NP
         AUX V planes
         are flying
```

**parse b**

```
S
   |   |
   ADVERB NP   VP
   |       |
Today   they   VERB
         |       NP
         V ADJ. N
         are flying planes
```

**Example 1-2: Syntactic ambiguity**
(slightly modified from Chomsky 1957)

Yesterday he shot two bucks.

**interpretation a**: Yesterday he shot two male deer with a gun.

**interpretation b**: Yesterday he squandered two dollars.

**Example 1-3: Lexical ambiguity**
(from Riesbeck 1974)

Thus the output of step 3 of the traditional model is not the semantic interpretation of $S_1$, but is rather, in the general case, a number of possible semantic interpretations of $S_1$.

In the second place, the set $\{S_{K_1}, S_{K_2}, \ldots, S_{K_n}\}$, even if all of its elements have been disambiguated, rarely constitutes the full interpretation which a reader would place on the text. In 1-4, for example, we see (indicated in square brackets) instances of additional information which a reader would extract upon reading each of the two-sentence texts.
pronominal reference: I got together with Mike yesterday. He told me what he had been doing for the past four years. [He "is identical to" Mike]

pro-adverbial reference: I was in Chicago last week; Bill was there also. [there "is identical to" Chicago]

verb-phrase to verb-phrase reference: John got a real workout yesterday. He swam four miles. [swam four miles "is the manner in which" got a real workout]

noun-phrase to noun-phrase reference: All great men have problems. War heroes have to live with their emotional wounds for the rest of their lives. [The set of war heroes "is a subset of" the set of great men]

sentence to sentence reference: I missed the meeting yesterday. I broke my leg just as I was about to leave home. [The event of/fact that the second sentence "is the cause of" the event of/fact that the first sentence]

Example 1-4: Some types of contextual reference

In what follows we will use the term "contextual reference" to refer to the phenomenon (illustrated in example 1-4) whereby the author of a text, for the sake of brevity, omits explicit mention of certain relations (e.g. "is identical to," "is the manner in which," etc.) intended to hold between items occurring in the text. We shall use the term full interpretation of a sentence $S_i$, abbreviated $FI(S_i)$, to denote the result of resolving all ambiguities in $SI(S_i)$ and augmenting the resulting $SI(S_i)$ with all instances of contextual reference which a human reader would recover when reading $S_i$ in the context of the preceding sentences of $T$. It is this full interpretation of all of the sentences of a text that is the goal of natural language understanding. How, then, might one compute $FI(S_i) - SI(S_i)$?

It has long been realized that the solution to the problems of disambiguation and

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2 We include in this phenomenon the phenomena of anaphora and definite noun phrase reference, as well as notions such as "implicature" (Clark, 1978); see Lockman and Klippelho 1980 for a more complete discussion of the notion of contextual reference.
contextual reference recovery lies in:

- codifying a large amount of world-knowledge (pragmatic information) into a database;

- using an inferencing mechanism which operates on S(S), on the full interpretations of S, S_1, S_2, ..., and on the database of world-knowledge to perform complex chains of reasoning which end in the disambiguation of S(S) and in the determination of that part of Fr(S) which is over and above the interpretation of S_1 taken in isolation.

Consider, for instance, the last example of 1-4:

I missed the meeting yesterday.
I broke my leg just as I was about to leave home.

The recovery of the intended "cause" reference from the second sentence to the first might involve a chain of inferencing from the following type of world-knowledge:

a) A meeting is a type of activity which has a precise setting in time and in location.

b) Participating in an activity which has a precise setting in time and in location requires being at the indicated location during the indicated time period.

c) Being in a particular physical location during a particular time period requires moving oneself from one's previous location to the indicated location by the beginning of the indicated time period.

d) When one intends to arrive at a particular location by a particular time one begins the process of moving oneself to the indicated location sufficiently in advance so that one will arrive by the indicated time.

e) Breaking a leg is (typically) an unexpected (accidental) occurrence.

f) When one experiences an unexpected occurrence one must often divert one's efforts from one's previous plans and spend time dealing with it.

Example 1-5: The type of world-knowledge required for the recovery of an instance of contextual reference

Continuing in this vein, example 1-6 below gives two different preceding texts

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4For a natural language understander with full human-equivalent capabilities over a wide range of texts, the contents of this database would seem to have to approach all of a human's knowledge concerning the world.
for each of the syntactically/lexically ambiguous sentences of 1–2 and 1–3; when combined with world-knowledge, the full interpretation of each preceding text would allow the disambiguation of the second sentences, which would otherwise (in isolation) be ambiguous. Details of the required types of world-knowledge are omitted for the sake of brevity.

- **syntactic ambiguity**
  1. Before the salvage crews got to work, those aircraft which you see were just parts in junkyards. Today they are flying planes.
  2. John and Betty are addicted to fast transportation. Yesterday they were driving sports cars. Today they are flying planes.

- **lexical ambiguity**
  1. John is always gambling but never risks very much money. Yesterday he shot two bucks.
  2. John has been out in the woods hunting for the past three weeks. Yesterday he shot two bucks.

*Example 1–6: Contexts within which inferencing can resolve ambiguity*

Now the type of inferencing required may be thought of as akin to deriving (in some logic) a set of conclusions from a set of axioms. The set of axioms in this case would be:

a) the disjunction of the set of possible interpretations of $S_i$ which is provided by the interpreter;

b) $P(S_{i1}), P(S_{i2}), ..., P(S_{iM})$;

c) the set of propositions constituting the world-knowledge database.

The rules of inference would be some set allowing us to combine propositions from (a), (b) and (c) to produce new propositions.

In its simplest form we may think of an inferencing algorithm as recursively "applying" (i.e. combining as allowed by the rules of inference) propositions from (c) to
those in (a) and (b), as well as to those already inferred, until $S_j(S_j)$ has been produced. The resolution of instances of ambiguity would result from contradictions derived from unintended interpretations of $S_j$; instances of contextual reference would be newly inferred propositions linking items in $S_j(S_j)$ with items in the full interpretation of the preceding part of the text.

The above is, however, a simplification. We agree with many researchers that the inferencing process should not be viewed as deduction in a two-valued logic: but rather as something closer to probability-like reasoning about the relative “plausibilities” of various propositions. This requires the following modifications:

- a “plausibility” value is attached to each axiom in the world-knowledge database;
- the rules of inference are augmented by a “calculus of plausibility,” so that each derived proposition has a plausibility which is a function of those of the propositions used in its derivation;
- the notions of “validity” and “contradiction” are replaced by suitable notions of high and low plausibility.

In the next section we will discuss some of the difficulties inherent in the construction of an inferencing mechanism, and point out problems with certain of the proposed approaches to this task. In section 3 we will discuss what we believe to be the proper approach, namely the use of text structure to control inferencing. In sections 4 and 5 we will sketch the natures of (respectively) the data structure and algorithm that the proposed approach would require.

2. The Control of Inferencing

The major problem which immediately arises when we consider doing world-knowledge based inferencing is that, if we simply recursively “apply” every piece of world-knowledge to every part of each $S_j(S_j)$ ($j<i$) to which it can be applied, then we will be faced with a combinatorial explosion of derived conclusions. The “understanding” of 2-1a, for example, requires a very different chain of reasoning from that required for 2-1b.
a) John has been out in the woods hunting for the past three weeks. His
girlfriend won’t go near him until after he has taken a shower.

b) John has been out in the woods hunting for the past three weeks.
Yesterday he shot two bucks.

Example 2-1: Sentences requiring different reasoning from the same context

Moreover, there is a vast number of sentences \( S^j \) for which the two-sentence
text

\[
T^j: \text{John has been out in the woods hunting for the past}
\text{three weeks.} \quad S^j
\]

is a coherent text. Each such \( T^j \) would require a different chain of reasoning for its
understanding. But if the first sentence, “John has been out in the woods hunting for
the past three weeks,” caused the inferencer to pursue all of these (potentially
necessary) chains then it would very likely be swamped before it was at all close to
understanding a particular text.

A second major problem is that of how the inferencing mechanism decides that
it has completed the processing of \( SI(S^j) \), i.e. how it concludes that all instances of
ambiguity have been resolved and all contextual references have been recovered. That
this is in fact a problem may not be obvious. Given the definition of \( FI(S^j) \), one might
propose the following termination condition: halt when a) the most plausible parse has
been chosen for \( S^j \); b) the most plausible word sense has been chosen for every
word in \( S^j \); and c) the most plausible referent has been found for each referring item in
(the now disambiguated) \( SI(S^j) \).

The problem with termination condition (b) is that in the general case it is not
possible to include a complete set of word senses for every word in the lexicon.
Rather, even in very prosaic texts, words are used in highly metaphoric senses (as in
"The towns were scattered across the peninsula." senses which must be determined through the use of world-knowledge based inferencing. There is, therefore, no fixed set of senses to choose from: as a result the inferencer cannot conclude that it has determined the correct sense when only one of the original lexical entries remains uncontradicted.

The problem with termination condition (c) is that, in general, by examining only $S(i,S_j)$, one cannot detect all items in $S_i$ which refer to (i.e. are intended by the author to be interpreted as bearing some relation to) items in the full interpretation of the preceding part of the text; in fact, almost any item in any sentence can be a referring item for some suitable previous text. Thus the only way to reformulate termination condition (c) would be: "every item in $S(i,S_j)$ has been checked against every item in the full interpretation of the preceding sentences and for each such pair either an intended relation has been found or none exists." Attempting to satisfy such a condition would only aggravate the combinatorial explosion.

What is clearly needed then, is some method of controlling the inferencer, i.e. some method for deciding:

- which portions of the world-knowledge database are relevant to the processing of $S_i$;
- which of the derived propositions are, at any point in the inferencing process, relevant to that part of the processing of $S_i$ which still remains to be done, and which others should simply be discarded;
- when the inferencer has derived $P(S_j)$ and may halt.

One proposal for the control of inferencing is that the world-knowledge database be pre-organized in such a way as to expose those of its parts which are inherently most likely to be useful in the inferencing process and should therefore be applied before other, less-relevant, parts of world knowledge; typical of such proposals are the notions of "natural salience" in Hobbs 1980 and the "items to be foregrounded" in Chafe 1972. A more refined version of this type of approach

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5 We refer the reader to Lockman and Klaproth 1980 for evidence on this point.
proposes that world-knowledge be pre-organized into clusters of commonly associated ideas and/or events (e.g. Cullingford 1978, Riesbeck 1974, and Schank and Abelson 1975). The motivation for such clustering is the hypothesis that those clusters associated with items occurring in $S_i$ or in the interpretations of the previous sentences of the text contain exactly the world knowledge that need be "applied" in the processing of $S_i$.

The problem with considering pre-organization of knowledge to be the solution to the control of inferencing is that this approach presumes the possibility of effectively anticipating (when pre-organizing the database) all associations which will be required in the full interpretation of any text. What it frequently leads to is the design of a recognizer of a relatively small set of text involving a relatively small set of ideas and/or events which were anticipated by the builder of the database. The problem is that there is as yet no workable general notion of how to do such pre-organization, i.e., of how to decide how large such clusters should be and exactly what they should contain. Some researchers attempt to attack this problem by proposing a very large set of fairly small clusters which may be "triggered" (i.e. brought in as applicable) by other clusters, as well as by items in the semantic interpretation of the text (e.g. Bullwinkle 1977, Deutsh 1975, Rieger 1975, and Schank 1980). This simply reintroduces the combinatorial explosion and termination problems of the original naive inferencer, although the larger units of world-knowledge used might mitigate the problem somewhat.

3. Inferencing and Text Structure

A major problem with the approaches to inferencing sketched thus far is that they make little use of a very important aspect of what there is to work with, namely the structure of the text; by this we mean the manner in which the text itself introduces and expands upon the items (ideas) with which it deals. The simplest text-structural feature is just the order in which the sentences of a text appear. To see its effect on the recovery of contextual references consider, for example, 3-1
below. As its sentences are currently ordered, the phrase "to that effect" in sentence (f) is clearly a reference to the "fact that"/"event of" sentence (e). Yet in any reordering one might choose to make of sentences (a) through (e), "to that effect" in sentence (f) would always refer to the "fact that"/"event of" the last sentence in that reordering.

a) It was a dark moonless night.
b) We were camped on the banks of the Walapaloosa.
c) The fire had just gone out.
d) I remember that the crickets were making an incredible racket.
e) We were all tired from the day's exertions.
f) Jack said something to that effect.

Example 3-1: The effect of sentence order on full interpretation: contextual reference resolution

Similarly, example 3-2 illustrates the effect of text order on the resolution of lexical ambiguity.

a) John drove across the country this summer.
b) His first stop was in Chicago where he visited some friends.
c) He then drove to Montana to go hunting.
d) After a week there he went to Las Vegas to gamble.
e) Surprisingly, he shot only two bucks.

vs.

a) John drove across the country this summer.
b) His first stop was in Chicago where he visited some friends.
c) After a week there he went to Las Vegas to gamble.
d) He then drove to Montana to go hunting.
e) Surprisingly, he shot only two bucks.

Example 3-2: The effect of sentence order on full interpretation: lexical ambiguity
Clearly, then, an inferencer should attempt to detect and make use of the clues which the text itself provides in determining: a) which parts of the world-knowledge database might be relevant to the processing of the sentence at hand; b) which parts of the full interpretation of the previous text are of importance.

The linguistic notion of "focus" attempts to capture the latter. A focus is maintained dynamically as part of the processing of sentences $S_1$ through $S_{i-1}$, and consists of a small subset of the set of items occurring in their full interpretation. In the processing of $S_i$, the inferencer "applies" the world-knowledge database only to items in this focus or in $S_i$.\(^8\) Attempts to define such a "focus" have typically made use of syntactic structure, order of appearance in the text, and "newness" of the items in each sentence's interpretation; the problem is, however, that such techniques attempt to extract the focus of $S_1$ through $S_{i-1}$ independently of $S_i$, i.e. before $S_i$ has been seen by the algorithm. While any such small focus may suffice for the full interpretation of many possible next sentences $S_i$, there will always be many other possible $S_i$'s whose full interpretation requires the use of (i.e. inferencing from) items from outside the small extracted focus.\(^7\) This approach to text structure is, therefore, inadequate.

Recognizing that text structure should play a significant role in resolving instances of ambiguity and recovering contextual references still leaves open the problem of exactly how it might be used to effectively control inferencing to this end. What we propose as a solution requires that we first consider exactly what it is that makes texts understandable, i.e. that enables a human reader to successfully recover the missing portion of each FI(S).

We first recall the very basic fact that the process of writing a text consists of introducing ideas/events and elaborating upon ideas/events which have already been

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\(^7\) See Lockman 1978 for substantiation of this claim.
introduced. In adding each new sentence to a text the author must follow certain structural conventions - not as yet very well understood - if the reader is to be able to determine either:

- that the new sentence is meant to introduce something new;

or

- how the new sentence is meant to elaborate on some idea(s)/event(s) previously introduced.

If such conventions were not observed, then the human reader would not be able to recover the full interpretation of the text; in fact, he/she would probably not even consider the text coherent.

We propose, therefore, that the inferencer be driven by the goal of determining the most plausible way in which each new $S_i$ can be interpreted as "fitting in" to $F(S_j)$. $F(S_{j-1})$, i.e. which portion(s) of the (already interpreted) preceding text $S_i$ elaborates on and the nature of the elaboration. The claim is that the recovery of $F(S_j) = SI(S_j)$ emerges from this process in the following way. The highest level task of the inferencer is the generation and evaluation of hypotheses concerning where and how $SI(S_j) "fits in" to the full interpretation of the preceding part of the text. The evaluation of each such hypothesis devolves into the generation and evaluation of a set of sub-hypotheses concerning particular resolutions of ambiguity and the recovery of particular contextual references, a set which, if assumed to be true, would support the "fit" of $S_j$ into a particular part of the preceding text. The most plausible such set of sub-hypotheses which does not contradict (in the system of plausibility reasoning) anything in the world-knowledge database (or in the full interpretation of the preceding part of the text) is assumed to have been intended by the author to be inferred by the reader, and constitutes the missing part of $F(S_j)$. If such an inferencer could be constructed, it would offer a solution to the termination problem: the mechanism would terminate, and would have produced $F(S_j)$, exactly when it has found a coherent "fit" to the previous text for $S_j$. 

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In the next two sections we consider:

- the nature of the text-structural clues which should be maintained in processing a text in the manner just proposed, and the type of data structure which they naturally fit into;

- the nature of an algorithm for hypothesizing and testing possible "fits."

4. A Data Structure for Context

In discussing just what sort of text-structural clues should be maintained during the processing of a text (for use in processing later parts) we shall concentrate on the requirements induced by the need to recover intended contextual references. Let us assume, then, that \( F(S_1), F(S_2), \ldots, F(S_{i-1}) \) have already been determined, and that we are about to start the inferencing process on \( S(S_i) \). The question is, exactly what data structure must we have on hand in order to process \( S(S_i) \)? Since an item in \( S(S_i) \) may, in general, refer to almost any item in the full interpretation of the text,\(^8\) a minimal requirement for the data structure is that it contain \( F(S_1), F(S_2), \ldots, F(S_{i-1}) \). What else, though, is necessary to enable the inferencer to find the point(s) at which \( S_i \) "fits in" to the preceding text?

As we have noted above, the order of appearance of the sentences of a text can have an effect on the recovery of contextual references. Simply keeping track of sentence order, however, is by no means sufficient. In text A of example 4-1 below, most readers would interpret "these particles" of sentence 5 as referring to "Zilchons" of sentence 2; in text B (which is identical to text A save for sentence order) the same phrase seems to refer to "The Bilpons" of sentence 4. Yet in both of these texts Bilpons are mentioned after Zilchons in linear text order. Clearly the implicit (via "high seriousness") reference to Zilchons in sentence 4 of text A affects a reader's picture of the structure of this text, which in turn affects the different resolution (from that made for text B) of the reference in sentence 5.

\(^8\) We refer the reader to Lockman and Klappholz 1980 for arguments in support of this claim.
text A

1. Consider the common pseudo-atomic particles.
2. Zilchons exhibit high seriosity.
3. The Blipons, however, have a low seriosity level.
4. Harkimer attributed the high seriosity to extreme multifluicicy.
5. This explains why these particles are so hard to detect.

text B

1. Consider the common pseudo-atomic particles.
2. Zilchons exhibit high seriosity.
3. Harkimer attributed the high seriosity to extreme multifluicicy.
4. The Blipons, however, have a low seriosity level.
5. This explains why these particles are so hard to detect.

Example 4-1: Non-linear text-structural effects on reference resolution

Since linear order does not completely capture those clues to preferred “fit position” which an author has built into a text, the data structure must also include the pattern of sentence-to-sentence connections (e.g. via “high seriosity” above) which the text establishes, i.e. the pattern in which the author has introduced new concepts and expanded on already introduced concepts. Some clues to this pattern are explicitly marked in texts: paragraph breaks and introductory words such as “Now,” “As for,” or “Anyway” indicate a “pop” from the latest topic discussed to either some earlier, more general topic, or to something quite new; parenthetical phrases indicate a more detailed exploration of some component of a more general topic before returning to the more general topic. Most of this pattern, however, is extracted as part of the inferencing on the previous text, i.e. as part of the process whereby each of the previous sentences has itself been fitted into its preceding text.

We propose representing this pattern by organizing the full interpretation of the text into a “context graph” whose nodes are the $(S_i)$ for $j < i$ (where $S_i$ is the current sentence). The nodes are connected by two types of link. The first type connects each (established) referring item to its referent; such links, however, capture
only part of what is necessary. The second type of link, termed an inter-sentence relation, connects each \( \text{RIS}_i \) to the nodes representing the (those) sentence(s) to which \( S_j \) was fitted when it was itself processed; we will elaborate further on this type of link in section 5. Informally, each node of the context graph may be thought of as representing a "topic" which its descendants in the graph have "expanded upon." Example 4-2 below depicts such a context graph for text A of example 4-1. The single arrows (labelled on the left) indicate the first reference to referent type of link, while double arrows indicate inter-sentence relations. Again, no attempt is made here to suggest a suitable semantic representation language; the \( \text{RIS}_i \) are represented here by abbreviations of the original sentences.

\begin{itemize}
  \item 1: Consider [the common pseudo atomic particles]
  \item 2: [Zilchons] exhibit [high seriousness]
  \item 3: [Blimps] have low seriousness
  \item 4: Herkimer attributed [high seriousness] of [A] to [extreme multifluicency]
  \item 5: [This] explains why [these particles] are so hard to detect.
\end{itemize}

*Example 4-2: A context graph for text A of 4-1*
From the point of view of contextual reference recovery the utility of these links is clear in the following sense. While it is certainly not the case that a reference from some item in $S_i$ must have its referent in $\text{FI}(S_{i-1})$, it is the case that $\text{FI}(S_{i-1})$ should be the starting point for the search for any such reference, and that the ancestors of $\text{FI}(S_{i-1})$ in the context graph are logical continuation points for pursuing the search. The links in the context graph thus provide a notion of "discursive proximity" which may be used in fitting $S_i$ to the "closest point(s)" to $S_{i-1}$ to which it may reasonably be interpreted as belonging.

5. The Nature of the Fit Algorithm

In this section we sketch an algorithm for fitting $\text{SI}(S_i)$ into the context graph just described. Now the goal of "fitting" the current sentence $S_i$ into its context amounts to deciding which (if any) node(s) of the context graph $S_i$ can best be interpreted as an "expansion of" or "further elaboration on." We shall use the notation $\text{EXPANDS}(S_i, S_j)$ to denote that $S_j$ expands on or elaborates on $S_i$. Our contention is that the attempt to find the "most suitable" sentence $S_j$ ($j < i$) in the context graph such that $\text{EXPANDS}(S_i, S_j)$ is plausible should be the overall controlling goal of world-knowledge based inferencing. We contend, further, that the determination of $\text{FI}(S_i) - \text{SI}(S_i)$ will result from the achievement of this goal.\(^9\)

The algorithm which we propose for finding the "most suitable" $S_i$ makes use of the context graph in the following manner: we first attempt to fit $\text{SI}(S_i)$ to the node representing $\text{FI}(S_{i-1})$, i.e. to show that $\text{EXPANDS}(S_i, S_{i-1})$ is sufficiently plausible to be accepted; if we fail, i.e. if we cannot generate a set of assumptions which would (in the light of our world-knowledge database and the full interpretation of the preceding text) make $\text{EXPANDS}(S_i, S_j)$ sufficiently plausible, then we move up the context graph to the immediate ancestor(s) of $S_{i-1}$; for each immediate ancestor $S'_i$.

\(^9\) An earlier version of this approach may be found in Klaptholz and Lockman 1977 and in Lockman 1978. Also, in Hobbs 1979 and 1980 it is suggested that some of the what we define as $\text{FI}(S_i) - \text{SI}(S_i)$ may be resolved as a by-product of determining the type of fit between a sentence $S$ and the (previously occurring) sentence $S'$ to which it fits.
we attempt to show that EXPANDS(S_i, S'_j) is sufficiently plausible. The process of moving up the context graph continues until either we find an appropriate node (or nodes) or we reach the top of the context graph without a successful fit. In the former case we add the necessary supporting assumptions to SI(S_i) to form FI(S_i); in the latter we conclude that S_i is incoherent in its context.

In order to complete the picture we will sketch:

- how EXPANS(S_i, S_j) can be algorithmically defined, i.e. how to generate a set of assumptions which will make it sufficiently plausible (or decide that there is no such set);

- how the determination of FI(S_i) - SI(S_i) results from finding, in the manner sketched above, an S_j such that EXPANDS(S_i, S_j) meets the plausibility criterion; i.e. why FI(S_i) - SI(S_i) is exactly the set of assumptions which enables EXPANDS(S_i, S_j) to meet the plausibility criterion.

The intuitive notion of "expansion" or "elaboration" denoted by the predicate EXPANDS can be viewed as the disjunction of a number of inter-sentence relations. A number of researchers concerned with the question of text coherence have proposed such relations. (In particular, we refer the reader to Altenman 1981, Crothers 1978, Halliday and Hasan 1976, Hirst 1981, Hobbs 1976, Hobbs 1979, and Lockman 1978.) Typical of the type of relation proposed are:

1. **EXAMPLE(S_i, S_j)**
   - **definition:** The event/state described by S_i is a particular instance of or subclass of the events/states described by S_j.
   
   - **example:** All great men seem to have special emotional problems. War heroes have to live with their emotional wounds for the rest of their lives.

2. **RESULT(S_i, S_j)**
   - **definition:** The event/state described by S_i is (in at least a contributory way) a cause of the event/state described by S_j.
   
   - **example:** John was late to work yesterday. He missed the meeting.

3. **CAUSE(S_i, S_j)**
   - **definition:** The event/state described by S_i is (in at least a contributory way) a cause of the event/state described in S_j.
• example: John invited Bill to the conference. He thought that he might have something to contribute.

4. **DETAIL(S_j, S_i)**
   - **definition**: S_j gives further elaboration of some aspect of the event/state described in S_i (e.g. manner adverbial).
   - **example**: John mowed the lawn. He did an excellent job.

5. **SEQUENCE(S_j, S_i)**
   - **definition**: The event described by S_j takes place in the same general spatial context as S_i and follows it in time-sequence.
   - **example**: He decided to call the Police. The sergeant took down all the details.

Assuming that one can define a set of relations whose disjunction defines the predicate EXPANDS, our goal of generating the set of propositions which will support EXPANDS(S_j, S_i) (or demonstrating that there is none) becomes one of finding a set of propositions which will support at least one of the sentence relations between S_i and S_j. The “fit” algorithm thus amounts to utilizing the structure of the text to generate a specific goal for the inferencing mechanism. Once the goal has been generated the inferencer must attempt to generate a set of assumptions which will achieve the goal, i.e., from which one of the inter-sentence relations can be demonstrated to be plausible.

Essentially this process is analogous to a top-down inference proof-procedure (as discussed in Kowalski 1979, Loveland 1968, and Loveland 1969) in that we start from a goal proposition and work backwards via rules of inference to axioms. The essential difference is that here the axiom-equivalents terminating the “proof” process are generally not in the world-knowledge database; rather they are any set of propositions whose inclusion in the database would not cause a (plausibility-logic) contradiction. When such a set is found, it is assumed to be true (actually intended by the author of the text), and added to the database. These set is, then, F(S_j) - S(S_j).

To illustrate the point that the propositions so derived constitute the missing portion of F(S_j), we sketch their derivation for the following two sentences text:
1. All of the common pseudo-atomic particles exhibit unusual behavior.

2. Blipons spontaneously change their turgidity from positive to negative.

Assume that $S_2$ is the sentence currently being processed, and that we are examining the possibility of establishing $\text{EXPANDS}(S_2,S_1)$. In particular, we will investigate the possibility of establishing the inter-sentence relation $\text{EXAMPLE}(S_2,S_1)$. In order to do so we must first elaborate on the sketchy definition of $\text{EXAMPLE}$ which was given earlier. We shall use the following schema as an approximation to such a definition:\(^{10}\)

If sentences $S_i$, $S_j$ have the forms

$$S_i: \ (\exists x)[P(x) \rightarrow Q(x)]$$

$$S_j: \ (\exists y)[P'(y) \rightarrow Q'(y)]$$

where $\exists$ is the SRL equivalent of any of the English quantifiers "all," "most," "many," etc.

Then $\text{EXAMPLE}(S_i,S_j)$ (i.e. the event/state described by $S_i$ is a particular instance of or subclass of the events/states described by $S_j$) holds if and only if it is plausible that:

$$\ (\exists v)[P(v) \rightarrow P'(v)]$$

and

$$\ (\exists w)[Q(w) \rightarrow Q'(w)]$$

The application of this definition to the sentences under consideration is as follows:

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\(^{10}\) Note that in this definition $P$, $Q$, $P'$, and $Q'$ are arbitrarily complex well-formed formulas.
• \( P(x) = x \) is a Blipon.
• \( Q(x) = x \) spontaneously changes its turgidity from positive to negative.
• \( P'(x) = x \) is a common pseudo-atomic particle.
• \( Q'(x) = x \) exhibits unusual behavior.

In order to support EXAMPLE(S,S'), our inferencing mechanism would have to find support for the propositions:

• Blipons are common pseudo-atomic particles.
• Spontaneously changing turgidity from positive to negative is unusual behavior.

Now in general, \((\forall v) [P(v) \rightarrow P'(v)] \) and \((\forall w) [Q(w) \rightarrow Q'(w)]\) may or may not be inferable from the basic world knowledge of a particular reader; in this particular example they cannot possibly be, since we have deliberately chosen fictitious terms. However in order to give this text a coherent interpretation, a reader must assume that the author intended to communicate that "Blipons are common pseudo-atomic particles" and that "Spontaneously changing turgidity from positive to negative is unusual behavior," and must add these propositions to his \( \Phi(S_{2})\) unless they contradict some other aspects of his world-knowledge. In this example, as is usual when reading about some hitherto unfamiliar topic, a reader possesses no relevant world-knowledge and takes the author on faith.

6. Conclusions

The approach presented above is, clearly, just the beginning of a theory of inference control. A number of serious problems remain to be solved. The first is the compilation of a far more complete catalog of formally defined inter-sentence relations. If, in fact, the theoretical framework proposed here is a workable approach, one can reasonably expect that the details of these specifications will delimit exactly what the power of the inferencer must be, and therefore provide clues concerning the
rules of inference which it should use and the appropriate organization for the world-knowledge database which it must utilize.

In addition, the procedure for traversing the context graph must be refined, since we are already aware of text-structural effects which are not taken into account by the procedure proposed in section 5. Consider, for example, the short text of 6-1:

I walked into the room.
The chandelier was the largest I had ever seen.

**Example 6-1: Coherent text: DETAIL**

There is no question that this text is coherent, and that the second sentence is a DETAIL of the first, i.e. an elaboration of a particular aspect ("the room") of the first sentence. Consider, however, 6-2 below, which is created by simply inserting an intervening sentence between the sentences of 6-1.

I walked into the room.
John approached me and began to complain about his salary.
The chandelier was the largest I had ever seen.

**Example 6-2: Incoherent text**

6-2 is clearly incoherent; in particular, the third sentence does not seem to "fit." The algorithmic sketch of section 5, however, would have no problem fitting this third sentence to the preceding text as follows. We first attempt to fit it to the immediately preceding, second, sentence; it is hard to devise any plausible assumptions which would relate the two, so we reject this and move up the context graph to the first. And as 6-1 demonstrated, the third sentence is easily interpreted as a DETAIL of
the first, under the not unreasonable assumption that "the chandelier" of the former hangs in "the room" of the latter.

Clearly what is occurring is some sort of "blocking" effect, in that certain types of intervening material may prevent the interpretation of following sentences as "expanding upon" preceding (to the blocking material) sentences. The particular explanation for what occurs in 6-2 is something like: after a sentence which describes a change of state it is acceptable to further elaborate upon details of the new state; however after such elaboration has stopped, it may not be resumed without explicit reminders of the change of state or of the new state. The codification of such rules (which are really structural text conventions) is a prerequisite to further elaboration of a fit algorithm.

Finally, of course, there is the problem of how the inferencer will generate and test supporting assumptions for a particular hypothesis of fit. Both the definition of EXPAND(S, S') as a disjunction of inter-sentence relations and the different possible instantiations of each inter-sentence relation create a complex disjunction as the goal to be supported. This, of course, creates the immediate problem of how to decide when to "cut off" the inferencing process down any one of these disjunctive paths; i.e. how to decide that any possible set of supporting assumptions for it is unlikely to meet the minimal (for coherence) plausibility requirement.

We hope, however, that we have convinced the reader that the most likely source of control for the inferencing required in understanding natural language text is information embedded in the structure of the text itself.
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