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Languages such as English contain a large number of words with multiple meanings. These words are commonly termed "lexical ambiguities", although it is probably more accurate to speak of them as potentially ambiguous. Determining how the contextually appropriate reading of a word is identified presents an important and unavoidable problem for persons developing theories of natural language processing. A large body of psycholinguistic research on ambiguity resolution has failed to yield a consistent set of findings or a general, non-controversial theory. In this paper, we review the results of six experiments which form the basis of a model of ambiguity resolution in context, and at the same account for some of the contradictions in the existing literature.

This work has three foci. The first is that we consider the lexical structure of words with multiple meanings, that is, relations among the meanings which presumably govern their representation in memory, and their access in context. Second, we attempt to characterize the structure and content of the linguistic context in which an ambiguous word occurs. It is clear that the listener/reader uses context to compute the correct reading of a word; however, contexts provide different types of information which may be utilized in different ways. Third, we consider real-time aspects of ambiguity resolution as it occurs in people, using a methodology that permits us to evaluate successive stages in processing.

Relations among the meanings of ambiguous words vary along several dimensions. The component readings may be semantically related (the senses of GRASP in "to grasp a baseball" and "to grasp an idea") or semantically unrelated (e.g., the meanings of TIRE related to "sleeping" and "wheel"). This dimension underlies the traditional distinction between polysemy and homonymy [Lyons, 1978].(1) The number of component readings also varies. The readings of a word can fall into different grammatical classes (e.g., the "sleep" reading of TIRE is a verb, the "wheel" reading a noun) or the same class (the meanings of STRAW related to "sipping" and "hay" are both nouns). The readings may be used approximately equally often in the language (e.g., WATCH) or they may be of unequal frequency (e.g., PEN, COUNT). Our research is concerned with homonymous words with two common readings of approximately equal frequency.

Contexts provide several different types of information which are utilized in resolving ambiguity.(2) In example [1], the context provides syntactic information that

1. John began to tire.

favors the verb reading of the ambiguous word TIRE, and blocks the alternate noun reading. Syntax can function in this way only for ambiguous words with readings that fall into different grammatical classes. In [2], syntax

2. A doctor removed Henry's damaged organ.

is neutral with respect to the alternate readings of ORGAN (because both are nouns), but a word in the context ("doctor") is highly semantically related to one reading, and thus favors it; the alternate reading is not blocked, but merely implausible in the absence of any further information. The appropriate reading of DECK in [3] is

3. John walked on the deck.

indicated by a different means, which might be termed pragmatic. The perceiver knows that a person is much more likely to walk on the surface of a ship than on the surface of a pack of playing cards.

Other types of contextual information can be brought to bear on ambiguity resolution as well. For example, [4] is disambiguated by exploiting mass noun/count noun information; [5] might be disambiguated by applying knowledge of a stereotypic situation (a script or frame; Schank & Abelson, 1977; Minsky, 1975).

4. Henry wanted a straw.
5. John avoided the check.

Extended contexts frequently contain multiple sources of disambiguating information.

Leaving aside vague or misleading cases, it is clear that all of these types of information yield the same outcome, assignment of the contextually-appropriate reading of a word. We sought to determine whether they produced this effect by the same means. Broadly speaking, there are two alternative mechanisms by which the correct reading could be assigned. The perceiver could access all of the common readings of the word in parallel, and use contextual information to perform a subsequent selection. This alternative --traditionally termed "multiple access"--holds that while the perceiver usually is aware of only a single reading, there is transient subconscious activation of others as well. The other possibility--"selective access"--is that contexts restrict lexical access to the single appropriate reading. Both of these alternatives have been supported by experimental evidence.

The time course of processing events is evaluated by using a variable stimulus onset asynchrony (SOA) priming methodology [Warren, 1977]. The subject hears a sentence that is followed by the presentation of a single word on a screen. Latency to read the word aloud is used to diagnose the availability of alternate word senses. For example, sentence [1] above favors the verb reading of TIRE. If subjects access that meaning, they should be faster to read the semantically-related target word SLEEP than when it follows an unambiguous, unrelated control sentence (e.g., "John began to leave"). However, if subjects also access the contextually inappropriate reading of TIRE, faster naming latencies will be observed for a word related to it (e.g. WHEEL) as well. Similar considerations hold for [6], in which the context favors the noun reading of TIRE.

6. John bought the tire.

Changes in the availability of alternate readings over time can be tracked by presenting targets at a variable time interval following the ambiguous word or its control. In our experiments, targets appeared at a delay of either 0 or 200 msec.

The first experiment (Tanenhaus, Leiman and Seidenberg, 1979) examined the resolution of noun-verb (N-V) ambiguities such as TIRE in syntactic frames such as those in [1] and [6]. The results were clear: at 0 msec SOA, targets related to both the appropriate and inappropriate readings showed faster naming latencies than controls. With a 200 msec delay interposed between ambiguous word and target, however, only targets related to the contextually appropriate reading showed facilitation. The results indicated that syntactic information in the context did not restrict lexical

access to a single reading, but instead permitted a rapid selection between alternatives. This occurred despite the fact that the context made it impossible to derive a coherent interpretation of the utterance using the alternate reading.(3)

Seidenberg, Tanenhaus and Leiman [1980] found largely the same pattern of results with noun-noun (N-N) ambiguities such as ORGAN or STRAW and contexts such as [7], which were neutral

7. John removed the organ.

with respect to alternate readings of the ambiguous word. At 0 msec SOA, targets related to both readings showed facilitation, as might be expected since the context did not favor either one. At 200 msec SOA, however, facilitation occurred on approximately half the trials, which would result if listeners had retained only one reading of the ambiguous word on each trial.(4)

The pattern of results was similar to that in the Tanenhaus et al. (1979) study of syntactic contexts: multiple access, followed by availability of only one reading 200 msec later. However, the underlying processes were quite different. In the syntactic frames study, listeners accessed multiple readings and used the context to select the appropriate one. In the Seidenberg et al. (1980) study, listeners accessed multiple readings but the context could not be used to perform a selection. They nonetheless assigned a default value within 200 msec. The results suggest that ambiguity resolution is subject not only to constraints imposed by the nature of the context, but also to limitations of time. Subjects avoid carrying multiple readings longer than 200 msec even when contexts do not unambiguously isolate one. The experiment was designed so that at the moment the ambiguous word occurred, they had no reason to believe that disambiguating information would not be forthcoming. Under this circumstance, they might have been expected to retain multiple meanings. Instead, subjects assigned their best guess, risking the possibility that subsequent re-processing would be necessary. It appears that reprocessing imposes less of a burden on the processing system than that associated with retaining multiple readings over time.

In another experiment, Seidenberg et al. (1980) examined the effects of biasing semantic information on N-N ambiguities in contexts such as [8].

8. The farmer removed the straw.

As in [2], the context contains a word semantically-related to one meaning of the ambiguous word; syntactic information is neutral. These contexts produced selective access: for each item, only the target related to the contextually-appropriate reading of the ambiguous word showed facilitation; the target related to the inappropriate reading showed naming latencies comparable to those in the unrelated control. These outcomes held at both SOAs. Although N-N ambiguities produced multiple access in the previous experiment with neutral contexts, the biasing contextual information in this experiment affected the initial access of meaning. We suggested such contexts prime one reading of the ambiguous word, in the sense of Collins and Loftus (1975), Meyer and Schvaneveldt (1975), Warren (1977) and others. The readings of an ambiguous word are assumed to be coded in memory in terms of relative activation levels which reflect frequency and recency of use. A word or phrase semantically-related to one reading produces a transient increase in its activation level, possibly through a spreading activation process (Collins & Loftus, 1975). The readings are accessed in order of relative activation; the primed reading is accessed first, and assigned on-line.(5)

As noted above, N-N ambiguities can be resolved by using other types of information, e.g. pragmatic, mass noun/count noun, etc. These differ from the priming contexts used in the previous experiment because they do not contain any words or phrases semantically or associatively related to a reading of the ambiguous word. In this way they are comparable to the syntactic contexts of the first experiment. The fourth experiment compared the use of non-priming contextual information in the resolution of N-N and N-V ambiguities. Again the variable SOA methodology was used, with targets appearing at 0 and 200 msec delays. The results in both the N-N and N-V conditions replicated those of our first experiment, showing multiple access at 0 msec, followed by availability of only a single reading 200 msec later.

The experiments to this point can be summarized as follows. There appear to be two classes of contexts that have very different effects on ambiguity resolution. Priming contexts contain words or phrases semantically or associatively related to one reading of an ambiguous word. They increase the activation level of the reading before it is encountered through a non-directed, automatic process. In this way, they can alter the order in which readings are evaluated. These effects are intra-lexical (Forster, 1979), solely due to interconnections among nodes in semantic memory. Non-priming contexts include various types of information—syntactic, pragmatic, and others—which require access of grammatical knowledge and knowledge of the world. The word recognition process yields one or more readings of the ambiguous word to be evaluated against the demands imposed by these contexts. The number of readings accessed and the order in which they are evaluated depends upon their relative activation levels, which may be altered by priming.

In experiment five, we tested an implication of the priming hypothesis. Recall that N-V ambiguities yield multiple access, as do N-N ambiguities, except when the latter occur in priming contexts. Clearly, this suggests that N-V ambiguities might also produce selective access if the context contained a priming word or phrase, as in [9].

9. The nearsighted timekeeper
dropped his watch.

Thus, we compared the processing of N-N and N-V ambiguities in priming contexts. The N-N results replicated those of the Seidenberg et al. (1980) experiment, selective access. The noun-verb conditions, however, continued to show multiple access. Because the result was unexpected, we undertook a replication; it too showed this pattern.

The results of this series of experiments are summarized in Table 1. We found no evidence that listeners could use their knowledge of a language and knowledge of the world to restrict access to a single reading, at least for the class of ambiguous words with two common readings. Although these types of information can facilitate the immediate processing of a word (as demonstrated by Marslen-Wilson and Tyler, 1980), they do not influence the activation of word senses. It was suggested that the latter could be affected only by priming; however, the status of this hypothesis is in doubt. Twice we observed selective access for N-N ambiguities in priming contexts; twice we failed to obtain selective access with N-V ambiguities in similar contexts. This forces us to conclude that priming affects nouns differently than verbs, and strongly suggests that theories of lexical memory and recognition must begin to take into account the syntactic functions of words.

Table 1

Type of Context	Type of Ambiguous Word	Outcome
1,3. syntactic	N-V	multiple--->selection
2. neutral	N-N	multiple--->selection
3,5. priming	N-N	selective access
4. non-priming bias	N-N	multiple--->selection
5,6. priming	N-V	multiple--->selection

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Footnotes

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1. Of course, a word can have semantically-distinct readings that are themselves polysemous.
2. These distinctions among types of context are not intended to prejudge any theoretical issues, only to facilitate exploratory research.

3. It should be noted that a large number of sentences were utilized, and that precautions were taken to ensure that the experimental procedure itself would not induce subjects to access meanings they would otherwise ignore.

4. For details, see the cited reference. Essentially, the experiment included control conditions which provided estimates of the amount of facilitation that would occur if either both readings or no readings were accessed on every trial. At 200 msec SOA, the amount of facilitation was almost exactly halfway between these two figures, suggesting that only one reading was available.

5. The data are unclear as to whether activation of the alternate reading is entirely suppressed, or merely delayed.

