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# Ambiguity Resolution: Behavioral Evidence for a Delay

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## Abstract

This paper presents experimental evidence for a model of human language processing in which ambiguity resolution is delayed when there is a conflict between semantic contextual bias and the syntactically preferred interpretation. If there is no conflict, an immediate decision is made. Decision is not delayed indefinitely; the length of the delay is limited by available processing resources.

## Introduction

Are ambiguous sequences initially treated as if they were unambiguous? Alternatively are both or all of the possibilities considered until it is possible to make a choice? These questions continue to interest researchers concerned with language comprehension. In this paper I will propose that neither of these alternatives is correct. I will summarize recent evidence that ambiguities are recognized and decision may be temporarily delayed, waiting for evidence that can decide the issue. However, it appears (not surprisingly) that there are limits on the extent of delay that is possible. If no disambiguating evidence becomes available within the limits on delay, an arbitrary decision must be made. This model appears to extend to both syntactic ambiguity resolution, which will be the major focus of this paper, and lexical ambiguity resolution.

## Immediate Resolution Models

Many researchers have proposed that one analysis is initially pursued; the alternative initially pursued may be based on syntactic (e.g. Frazier & Rayner 1982) or on semantic criteria (e.g. Crain & Steedman 1985). The major type of evidence that has been adduced for initial treatment of syntactically ambiguous structures as if they were unambiguous is the "garden path" effect. In garden path sentences, a hearer or reader is "led up the garden path," that is the sentence appears initially to have one structure and

then it turns out, to the surprise of the hearer, that the sentence in fact meant something else entirely. This effect suggests that at least under some circumstances people do **not** wait until they receive disambiguating evidence before selecting one of the alternatives. If they do so immediately, the initial unambiguous model is supported.

An example of a characteristic garden path structure is the reduced relative clause, shown in (1).

- (1) a. The officers hidden in the bushes observed the practice attack.  
b. The officers taught at the military academy were very demanding.

An easily interpreted example of such a structure appears in (1a). However, if the reduced relative contains a passive participle which is not formally differentiated from the past tense form, as in (1b), ambiguity results. It has long been recognized that reduced relatives containing such verbs are typically misanalyzed as main verb phrases, producing a garden path effect when the actual main verb phrase is read. This effect implies that the wrong structure has been calculated.

## Syntactic Resolution Procedures

An important question for any model of ambiguity resolution is what determines which structure is selected. For reduced relative clauses, the fact that people are surprised when they encounter the main verb phrase shows that they had assumed the reduced relative clause to be a main verb phrase. A specific proposal made by Frazier (1978) is that the main verb phrase analysis is initially pursued because it is the simplest, in terms of the number of nodes necessary to build a phrase structure representation: the Minimal Attachment Hypothesis.

Two other sentence types cited in support of the Minimal Attachment Hypothesis (Frazier & Rayner 1982; Rayner, Carlson & Frazier, 1983) are sentential complement sentences, as in (2) and prepositional phrase attachment ambiguities, as in (3).

Table 1: Mean Reading Times for Reduced Relative Clauses: Accumulating Presentation

	RelVerb	Next	Next	MainVerb	Next
Animate Subject					
Ambiguous	364	366	367	488	599
Unambiguous	371	377	385	475	495
Inanimate Subject					
Ambiguous	343	382	374	506	476
Unambiguous	358	378	394	493	511

(2) The reporter saw the woman who came in was not happy.

In (2), due to the absence of the grammatical marker *that*, it is not initially clear that the phrase following the verb *see* is the subject of a sentential complement rather than a direct object. Constructing the direct object structure does not require accessing as many phrase structure rules as the sentential complement structure, and therefore is simpler. Some people may feel that the verb phrase *was not happy* is unexpected (i.e., a garden path). Frazier and Rayner (1982) found that eye-tracking patterns suggested that people had to go back to and reprocess the ambiguous sequence only if it turned out that a sentential complement structure had to be assigned.

(3) The spy saw the cop with the binoculars.  
As can be seen in (3), a prepositional phrase may frequently attach either to a verb phrase (e.g., *saw using the binoculars*) or to a direct object noun phrase (e.g., *the cop who had the binoculars*). Rayner, Carlson and Frazier (1983) argued that the lower (noun phrase modifier) attachment is not minimal, thus predicting that people tend to prefer the verb phrase attachment interpretation. When the meaning of the prepositional phrase forces the lower attachment, as *saw the cop with a revolver* (i.e., you can't see using a revolver), they found evidence for longer reading times and more regressions, apparently to "fix up" the initial error. Thus difficulties involving both of these types of structures can be predicted and explained under the Minimal Attachment Hypothesis.

### Semantic Resolution Procedures

However, before accepting that the Minimal Attachment Hypothesis is the correct account of the data, it is appropriate to consider if other types of information affect the structure initially assigned to the phrase, and if so how. The Minimal Attachment Hypothesis does not predict that semantic information has any initial effect on the structure that is built.

Nevertheless, it is clear that the comparative interpretability of the two structures can have an impact on which is eventually constructed, as illustrated in (4).

- (4) a. The officers taught at the military academy were very demanding.  
b. The courses taught at the military academy were very demanding.

Moreover, Crain and Steedman (1985), Cupples and Stowe (1991), and Taraban and McClelland (1989), have argued that semantic information can have an early impact on how ambiguous reduced relative clauses and prepositional phrase attachment ambiguities are handled.

Cupples and Stowe (ms.) used the accumulating self-paced reading task to compare how subjects read sentences like those in (4). Subjects had to press a button to get each new word of the sentence, until the entire sentence was present on the screen. The time from the appearance of the word on the screen until the button was pressed is a measure of the time necessary to read the word in the sentential context. In (4a), the animate subject noun is equally plausible as either subject or object of the following verb; in (4b) the inanimate subject noun is anomalous as subject of the following verb, but plausible as its object. This semantic information, if available to the parser, can potentially decide between the active main clause reading and the passive reduced relative clause reading at the ambiguous verb itself, as soon as the ambiguity is encountered. We may call this the Immediate Semantic Decision Hypothesis. Certainly readers have the intuitive judgment that the semantic information makes the ambiguity easier to deal with.

Results for this experiment are summarized in Table 1. When the reading times for these sentences are compared with syntactically unambiguous controls (containing the phrase *that were* in the relative clause), a very large and significant increase in difficulty was found at the main verb phrase for (4a), as predicted by the Minimal Attachment Hypothesis. However, no significant difference was found at any point in the

sentence for (4b). Here, of course, semantic information is available to decide which structure is assigned to the relative clause. This evidence clearly indicates that semantic information can be used to assign the correct structure to the ambiguous sequence before reaching the syntactically disambiguating region.

A model in which semantic information is used immediately to decide immediately between the two possible structures, such as the Immediate Semantic Decision Hypothesis, is compatible with this data.

It might be suggested that this result is consistent with a version of the Minimal Attachment Hypothesis in which an unacceptable interpretation provides feedback to the parser and revision is started during the relative clause itself. However, this account suggests that the revision should cause increased reading times in the relative clause instead. No such difference was found, and to that extent the Immediate Semantic Decision Hypothesis is more compatible with the experimental results.

Taraban and McClelland (1989) examined the effect of sentential context preceding a prepositional phrase. They found that people consistently rated a nominal modifier completion as less expected than a main verb phrase completion for Frazier and Rayner's materials, like the sentence in (3). They constructed a set of materials for which the nominal attachment was rated more favorably instead, as in (5).

- (5) a. The reporter exposed corruption in government.  
b. The reporter exposed corruption in the article.

In (5a), the expected low attachment reading is compatible with the ending (e.g. *corruption which is found in the government*), while in (5b), the final word is more compatible with verb phrase attachment (e.g., *exposed in the article*). According to the Minimal Attachment Hypothesis, the syntactic bias should take priority over contextual effects. Under the Immediate Semantic Decision Hypothesis, however, the context is used to make a decision between the alternatives as soon as the ambiguity is recognized; here, that point is the preposition.

Taraban and McClelland tested both sets of sentences using the self-paced reading paradigm. They found that there was no main effect of high vs. low attachment, providing no support for the hypothesis that Minimal Attachment is preferred. However, there was a significant interaction with sentential context; when the context predicted high attachment, verb phrase attachment was easier, but when the context predicted nominal attachment, attachment to the noun phrase was easier instead. These results support the

Immediate Semantic Decision Hypothesis then, rather than Minimal Attachment.

## Delayed Resolution Procedures

The experiments that I have reviewed here suggest that the Minimal Attachment Hypothesis is in need of replacement or revision. At the very least, the model must be extended to include an early and almost cost-free revision procedure based on semantic information. When semantically biasing information is available, recovery from the incorrect analysis is not problematic

Do these experiments provide unequivocal evidence for the Immediate Semantic Decision Hypothesis? It would be difficult to argue that. As just pointed out, the Minimal Attachment Hypothesis with the above modifications can also account for the data. The Taraban and McClelland results provide the clearest evidence for the Immediate Semantic Decision model, since they show evidence of garden pathing in **both directions**, based on differences in context. However, in the Cupples and Stowe materials, animate subjects were explicitly selected that were rated as equally plausible when taken as the subject or object of the following verb. Thus, there is no basis for an Immediate Semantic Decision between the two alternatives and no garden path is predicted. This is clearly not an insuperable objection to the Immediate Semantic Decision Hypothesis. Crain and Steedman (1985) propose that discourse conditions can explain the clear preference for the main verb phrase interpretation. However, there is additional evidence that is worth considering before accepting this model.

Holmes, Stowe and Cupples (1989) looked at sentences like those in (6) using the self-paced reading task described above, with the exception that in this experiment only one word at a time appeared on the screen, although their positions were the same as if the entire sentence had been present. As discussed above, according to the Minimal Attachment Hypothesis, the direct object reading is preferred for ambiguities of this sort. This predicts that reading times during the verb phrase of the embedded clause should be longer than for versions of these sentences containing the disambiguating grammatical marker *that*.

- (6) a. The reporter saw the woman was not very happy.  
b. The student realized the answer was not clear.

The Immediate Semantic Decision Hypothesis, on the other hand, predicts that sentential context can be used to choose among the alternatives. In (6a), the verb *saw*

has a primary meaning of physical perception, compatible with the direct object. In (6b), the verb *realize* has a primary meaning of comprehension of a concept, which is most compatible with a clausal complement. This information should be used to choose between the alternatives, according to the Immediate Semantic Decision Hypothesis. This in fact was the pattern that was found for the sentences in (6). However, in the Holmes, Stowe and Cupples experiment, the length of the ambiguous phrase was also varied (e.g. *the woman* vs. *the woman who cam in*). The differences in reading times between the ambiguous and control sentences for the complement verb phrase, which provides disambiguating information for the ambiguous sentences, are summarized in Table 2.

Table 2: Mean Difference between Ambiguous and Non-Ambiguous Sentences for Holmes, Stowe and Cupples Experiment 3

	Verb	Next	Next
Object Preference			
Short NP	97	49	8
Long NP	71	36	16
Complement Preference			
Short NP	1	25	-17
Long NP	68	36	-3

A positive difference means that the verb phrase causes increased parsing difficulties in the ambiguous sentences, in other words that people have garden pathed. For the short versions, the Immediate Semantic Decision Hypothesis appears to be correct. People only have difficulty in those cases where the semantic bias of the sentence should cause the choice of the wrong structure. However, for the long versions, it appears that the Minimal Attachment Hypothesis is correct. People have trouble with the more complex syntactic structure despite the semantic bias. Frazier and Rayner (1982) found a trend in the same direction. Clearly, the predictions of neither hypothesis are completely met.

How then are these results to be accounted for? The way that the results were described in the last paragraph perhaps provides a clue. Both the hypotheses appear to tell part of the story. That is, early in processing, semantic information has an impact that mimics an immediate decision in the correct direction. However, if the ambiguous region is long, it appears that semantic information loses its effect and the syntactic structure determines what happens. It hardly seems credible that semantic information is used to make an early decision and then a structurally based

criterion causes a revision. However, the lack of a garden path effect at the verb phrase for the sentences containing a bias toward a complement completion may not be because the complement structure has been chosen but because no decision has been made. That is, semantic information appears to **delay the decision**, rather than causing a decision to be made, for this ambiguity.

Clearly the Delayed Decision Model requires elaboration. First, if ambiguity is typically recognized and decision is delayed until disambiguating information is available, there is no reason to expect garden pathing for any of these sentences. The results do not support that prediction. In the case of the long ambiguous region, people typically do garden path. The most obvious explanation for that is that they cannot delay the decision any longer. That is, the hypothesis is that there is a **Limited Delayed Decision**.

There are two other points to notice about these results. First, it is clear that when the decision cannot be delayed any longer, the basis for the decision is syntactic structure rather than contextual bias, since Minimal Attachment effects are found for both context types. A second point is that the decision is delayed only for those sentences where the semantic bias is in opposition to the minimal attachment structure. Even short ambiguous regions for those sentences with a contextual bias toward the direct object structure show garden path effects.

Additional support for this model comes from further experiments reported by Cupples and Stowe (ms.). Sentences like those in the experiment discussed earlier were used, but the memory or processing load was altered in various ways. In one version, an introductory phrase was added to the beginning of the sentence, as illustrated in (7).

- (7) a. According to the major, the officers taught at the military academy were very demanding.  
 b. According to the major, the courses taught at the military academy were very demanding.

This phrase must be integrated with the rest of the sentence and thus must be held in memory and accessed during comprehension of the rest of the clause. Another change in method was that the words did not accumulate on the screen; only one word was visible at a time, although each word appeared in the position that it would have if the entire sentence were visible. Presumably both of these alterations change the processing load associated with reading the sentence.

In another version, the sentences did not

Table 3: Mean Reading Times for Reduced Relative Clauses: Central Presentation

	RelVerb	Next	Next	MainVerb	Next
Animate Subject					
Ambiguous	416	401	396	497	492
Unambiguous	419	415	410	439	435
Inanimate Subject					
Ambiguous	428	421	402	485	459
Unambiguous	414	407	402	448	422

accumulate on the screen, but appeared only one word at a time. This means that subjects must rely on their memory of the preceding material to accomplish sentence comprehension. Table 3 contains data from this version of the experiment. It is obvious that people required additional reading time during the main verb phrase for both the animate and inanimate versions. This pattern of results suggests that people select the main verb phrase analysis despite the presence of semantic information that could guide the choice. This result was found for the version with an introductory phrase described above as well.

Thus, we again see a pattern where in the easier case, semantic information is used in a way that mimics a correct decision, but that structure appears to guide the decision under more difficult conditions. As with the direct object/complement clause ambiguity, these results can be accounted for by a model in which a decision about an ambiguity is delayed in just that case where there is semantic information in opposition to the structural bias. Again there are limits past which a decision cannot be delayed, although the limits are set by other processing load considerations rather than by simple length.

One last question concerns the contrast between the pattern of results seen in the reduced relative clause and complement clause cases and those reported by Taraban and McClelland (1989). There semantic information appeared to be used to actually make a decision, producing garden paths in both directions, as predicted by the Immediate Semantic Decision model. I would like to suggest that this case is different than those that I have just discussed and an immediate decision is indeed made. The cases differ in that for both of the sets of experiments that supported the Limited Delayed Decision model, additional information is always eventually available to disambiguate between the two alternatives: that is, there is something to delay for. With the prepositional attachment case, no syntactically disambiguating information can be expected and therefore, in terms of the syntactic

structure, there is nothing to delay for.

One implication of this argument is that Minimal Attachment, as such, is not the reason for the syntactic preference found in reduced relative clauses and complement sentences. There is no overall preference to build the simplest structure. If there were, Taraban and McClelland ought to have found evidence of a conflict of syntactic and semantic bias and a delayed decision, just as for the reduced relatives and complement clauses. In stead of an across the board preference, a syntactic preference seems to be found only where at least one of the alternatives cannot be completed without the presence of additional material, but the other can. Consider *The courses taught at the university*. If that is the entire sentence, then in fact the ambiguous sequence is the main verb phrase, no matter how anomalous the interpretation. It is only locating an alternative main verb phrase that allows the reduced relative interpretation. If it is not found by the end of the sentence (or within a reasonable period of time), then the main verb phrase analysis is chosen. In other words, it is not the simplicity of one structure as opposed to the other that determines the choice, but instead whether additional structure is necessary to validate one of the structures. I have called the alternative that does not require additional material the **syntactic default**.

## Conclusion

To summarize then, I have discussed evidence that when a sentence contains a syntactic ambiguity:

- (1) An **immediate choice** is made if possible.
- (2) Both syntactic preference and semantic information are taken into account in making the choice.
- (3) The basis of syntactic preference is not simplicity of structure, but whether the structure requires additional material to be completed. If it does

not, it can serve as the preferred **syntactic default**.

(4) If the syntactic default and semantic bias are in opposition, the **decision is delayed**.

(5) The decision can only be delayed as long as there are processing resources available to do so: **Limited Delay**.. If resources run out, an immediate decision is made, and the basis of the decision is the syntactic default, not semantic bias.

Clearly additional evidence is necessary to fully support this model. However, it seems to be compatible with a large amount of data for which the Minimal Attachment and Immediate Semantic Decision models fail.

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