

Thematic Roles in Language Processing¹

Michael K. Tanenhaus
Curt Burgess
Susan Hudson D'Zmura
University of Rochester
Greg Carlson
University of Iowa

1 Abstract

We present some ideas about how thematic roles (case roles) associated with verbs are used during on-line language comprehension along with some supporting experimental evidence. The basic idea, following Cottrell (1985), is that all of the thematic roles associated with a verb are activated in parallel when the verb is encountered. In addition, we propose that thematic roles are provisionally assigned to arguments of the verbs as soon as possible, with any thematic roles incompatible with such an assignment becoming inactive. Active thematic roles that are not assigned arguments within the sentence are entered into the discourse model as unspecified entities or addresses. In our first experiment we show that temporary garden-paths arise when subjects initially assign the wrong sense to a verb as in *Bill passed the test to his friend*, but not when subjects initially assign the wrong role to the noun phrase, as in *Bill loaded the car onto the platform*. This prediction follows directly from our assumptions. In our second experiment we show that definite noun phrases without explicit antecedents in the preceding discourse can be more readily integrated into a preceding discourse when they can be indexed to an address created by an open thematic role.

2 Introduction

Although case roles have played an important part in linguistic theory since the seminal work of Fillmore (1968), and they are frequently incorporated into AI models of natural language understanding, there has been little experimental work that examines their role in human language processing. In this paper we present experimental evidence suggesting that thematic roles (case roles) associated with verbs, play an important role in language comprehension. The idea that we will be exploring is that thematic roles can provide a mechanism whereby the parser can make early semantic commitments, yet quickly recover from the inevitable missassignments that occur as a consequence of the local indeterminacy that is characteristic of natural language. We further suggest that thematic roles provide a mechanism for interaction among the parser, the discourse model, and real-world knowledge.

¹This research was supported in part by NSF grant BNS-8217378.

3 Motivation

Our motivation for exploring these ideas comes from a confluence of findings from the language comprehension and word recognition literature. First, research on language processing suggests that the language processor makes extremely early commitments, with each word being fully interpreted and integrated with preceding context as it is processed (Marslen-Wilson, 1975). Secondly, the processor appears to compute structures serially (Frazier, 1978; Ford et al, 1983; Frazier & Rayner, 1982). Evidence comes from studies demonstrating local increases in processing complexity when the parser pursues an analysis that turns out to be inconsistent with the remainder of the sentence or resolves an ambiguity in a manner that is contextually inappropriate. Yet feedback from context clearly enables the parser to rapidly recover from and perhaps occasionally avoid these local garden-paths. This picture suggests that the parser computes structures serially but also has rapid access to alternative structures.

4 Multiple Codes

Our central assumption is that thematic roles associated with a verb are activated in parallel. Placing the parallelism in the lexicon is attractive because there is a large body of research on lexical processing demonstrating that multiple codes associated with a word become activated regardless of processing context. For example, multiple senses of ambiguous words are initially accessed even in the presence of contextual bias (Seidenberg et al, 1982; Swinney, 1979; Tanenhaus et al, 1979). Moreover, a number of lexical and sublexical effects such as the word superiority effect, effects of spelling-sound regularity, and of orthographic regularity in visual word recognition can be explained elegantly by the assumption that there is a great deal of bottom-up parallel activation, with incompatible representations inhibiting one another (McClelland & Rumelhart, 1981; Seidenberg, 1985). When representations are compatible, however, multiple codes remain active (Seidenberg & Tanenhaus, 1979; Tanenhaus, Flanigan & Seidenberg, 1980).

Frazier and colleagues (Frazier, 1986; Rayner, Carlson & Frazier, 1984) have argued that the vocabulary of thematic relations is shared by the parser, discourse model, and world knowledge. They have proposed a thematic processor which provides a channel of communication among these domains. In light of the growing evidence for multiple code activation in lexical processing, for strong lexical effects in parsing, and for on-line serial commitment and rapid local garden-path recovery, it seems reasonable to seek a mechanism whereby lexical structures can help to organize a parse, guide local garden-path recovery, and communicate with the discourse model. Thematic roles provide a promising candidate for such structures.

5 Representational and Processing Assumptions

In order to motivate our experiments it will be necessary to briefly outline some representational and processing assumptions. These assumptions are presented in more detail in Carlson and Tanenhaus (1987).

5.1 Representational Assumptions

We assume that a verb meaning is represented in terms of a *core meaning* (sense) and an associated set of thematic roles. Following Carlson (1984) we assume that the main function of thematic roles is to relate the arguments of a verb to the core meaning in semantic interpretation. We also assume that an integral part of the interpretation of a discourse is a mental model, or discourse model, which represents an ongoing record of the discourse (Heim, 1982; Johnson-Laird, 1983; Kamp, 1979). We also make the following standard assumptions about the mapping between thematic roles and arguments.²

1. Every argument of a given verb is assigned a thematic role.
2. No argument is assigned more than one thematic role.
3. Every argument of a verb is assigned a unique thematic role.

We finally assume that the set of arguments that are assigned thematic roles by a verb are the subject of the sentence and the subcategorized phrases in the verb phrase.³

5.2 Processing Assumptions

In addition, we make the following processing assumptions:

1. Lexical access makes available the core meaning (sense) of a verb and the thematic roles associated with the sense. For an ambiguous verb, all the senses will be activated in parallel, along with the set of thematic roles associated with each sense (see Cottrell, 1985, for a similar proposal).
2. Only the sense of the verb that is contextually appropriate (or, in the absence of biasing context, the most frequent sense) remains active, along with its thematic roles.
3. Thematic roles are provisionally assigned to arguments of the verb as soon as possible; any active thematic roles incompatible with such an assignment becomes progressively less active.
4. Any active thematic roles not assigned to an argument remain as open thematic roles in the discourse model, appearing as free variables or unspecified *addresses* in the model. Thus, we do not assume that every active thematic role assigned by a verb ends up assigned to the meaning of some syntactic constituent.

6 Experiment 1: Sense and Thematic Role Ambiguities

The model we have sketched above predicts a processing difference for sentences exhibiting temporary ambiguities such as those illustrated in (1) and (2).

²See Carlson and Tanenhaus (1987) for some qualifications.

³The phrasing here is a matter of convenience. It is actually the meanings themselves that are assigned thematic roles. See Carlson (1984) and Carlson and Tanenhaus (1987) for discussion.

1. Bill *passed* the test to his friend.
2. Bill *loaded* the car onto the platform.

In sentence (1), *passed* is ambiguous between two senses, roughly, earning a *passing grade*, and *hand over*. In sentence (1), the phrase which follows the verb, *the test*, biases the *grade* sense. Readers should experience a small garden-path when this sense later turns out to be incorrect. This follows from the assumption that lexical access will make available multiple senses of such a word as *pass*, but only the contextually most appropriate (or, in absence of context, most frequent (Simpson & Burgess, 1985)) sense will remain active and the others become unavailable (see Simpson, 1984, for a review of relevant literature). When a reader or hearer initially selects the wrong sense of an ambiguous verb, reinterpretation would require retrieving the alternative sense. This should take time and processing resources. In sentence (2), the noun phrase *the truck* could either be the location of the loading, or what is being loaded. When the wrong thematic assignment is initially made, thematic reassignment should be relatively cost-free because: (a) the core meaning of the verb remains constant, and hence the verb's lexical entry need not be re-opened; (b) the alternative thematic roles are generally active and available; and, (c) the syntactic-thematic mappings provide explicit information about how roles are to be assigned so only a limited domain of information needs to be reexamined. Thus, thematic roles allow the processor to make early commitments without undue cost. The null hypothesis is that both ambiguities are really just sense ambiguities, and hence are not fundamentally distinct.

6.1 Experimental Methodology

6.1.1 Stimuli

The experimental materials are illustrated in (3) and (4), for sense and thematic role ambiguities, respectively.

3. a. Bill *passed* the test to his complete surprise.
3. b. Bill *failed* the test to his complete surprise.
3. c. Bill *passed* the test to the person behind him.
3. d. Bill *handed* the test to the person behind him.
4. a. Bill *loaded* the truck with bricks.
4. b. Bill *filled* the truck with bricks.
4. c. Bill *loaded* the truck onto the ship.
4. d. Bill *drove* the truck onto the ship.

In examples (3a) and (3c), different senses of *pass* are selected by the final disambiguating phrase; disambiguation does not take place until after presentation of the direct object noun phrase. Examples (3b) and (3d) are control sentences using unambiguous verbs that have core meanings related to the appropriate sense in the ambiguous version of the sentence. The sentences of (4) repeat that same pattern for the thematic ambiguities; (4a) and (4c) involve temporary ambiguity of thematic assignment to the direct object, to be disambiguated by the final constituent; (4b) and (4d) serve as unambiguous controls. Sets of sentences similar to those in (3) and (4) were constructed for 16 verbs with different senses and 16 verbs for which the

thematic assignment of the following noun phrase is ambiguous. The four sentences for each verb were counterbalanced across four lists, with each subject seeing only one list.

6.1.2 Procedure

The sentences were displayed on a CRT and the subjects' task was to decide as quickly as possible whether or not the sentence *made sense*. We assumed that subjects would initially select the incorrect verb sense or thematic assignment on approximately half the trials where temporary ambiguity is possible. If incorrect sense selection results in a garden-path once disambiguating information to the contrary arrives, this should be reflected either in fewer sentences with sense ambiguities being judged to make sense or in longer reaction times to comprehend these sentences, all relative to control sentences. In contrast, thematic role ambiguities should result in much weaker garden paths. Filler trials included some sentences that were incongruous, such as: *Several people borrowed ideas under the bed*.

6.2 Results and Discussion

Data from 28 subjects are presented in Table 1, which displays reaction time (in msec) to the sentences judged to make sense, and the percentage of sentences judged to make sense. Separate ANOVAs were conducted on the judgment data and on the reaction time data. The ANOVA on the judgment data revealed a significant interaction between Verb Type (Sense versus Thematic) and Ambiguity (Ambiguous or Control conditions) with subjects as a random factor, ($F(1, 24) = 6.17, p = .02$). The interaction obtained because sentences with sense ambiguities were less likely to be judged to make sense than their controls ($F(1, 13) = 6.07, p = .029$), whereas sentences with thematic role ambiguities were not ($F(1, 15) = .02, p = .88$).

The reaction time results were less clear cut. Both sense and thematic role ambi-

Ambiguity Type	Verb Type	Control
SENSE	2445 (77)	2290 (94)
THEMATIC	2239 (92)	2168 (93)

Table 1: Latencies (in msec) for sentences judged to make sense. Percent judged to make sense in parentheses.

guities took longer to comprehend when they were judged to make sense than their controls ($F(1, 24) = 14.69, p = .0008$), and although the effect was numerically larger for the sense ambiguities, the interaction between type of verb and ambiguity was not significant. However, the effect of ambiguity was significant only for the sense ambiguities in the item analysis ($F(1, 13) = 6.73, p = .02$). The reaction time results were more consistent with the judgment results, when using our intuitions,

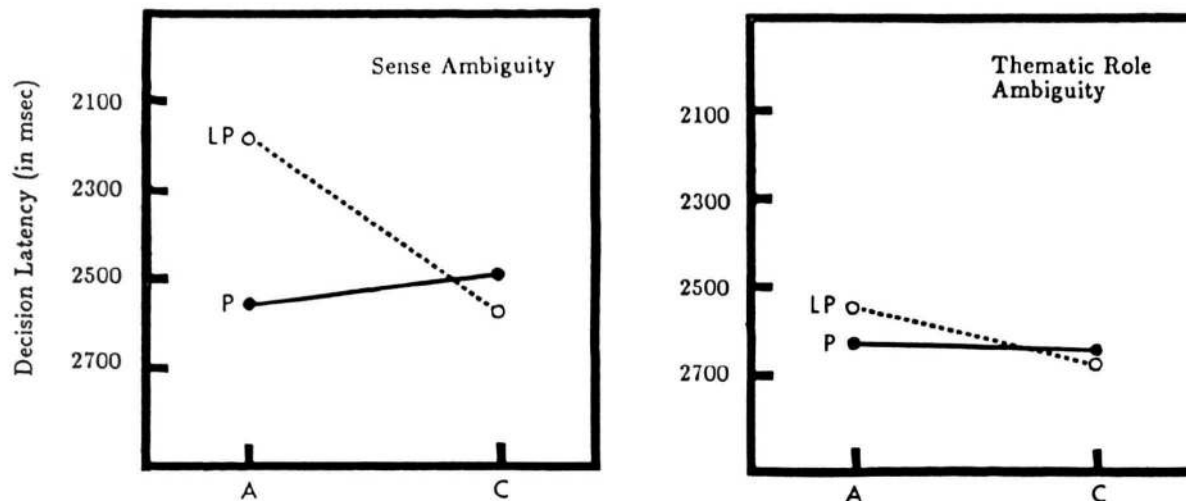


Figure 1: Latencies for sentences judged to make sense when preferred (P) or less preferred (LP) sense or thematic assignment turned out to be correct (A = ambiguous verb; C = unambiguous control verb).

we divided the ambiguous sentences into those in which the preferred and less preferred initial sense or thematic assignment is correct and incorrect (see Figure 1). We see that the sense ambiguities are more difficult than their controls only when the less preferred sense turns out to be correct. This is reflected in the interaction between Sense (preferred and less preferred) and Ambiguity ($F(1, 13) = 6.79, p = .02$). This interaction is not present with the thematic role ambiguities ($F(1, 15) = 1.19, p = .29$).

7 Experiment 2: Open Thematic Roles

The results of Experiment 1 demonstrate a processing difference between thematic role ambiguities and sense ambiguities, thus lending support to our assumption that thematic roles can be distinguished from core meanings. Experiment 2 tested the idea that open thematic roles are entered into the discourse model as unspecified discourse entities. Open thematic roles obtain when an active thematic role is not filled by an argument. For example, the verb *load* has three thematic roles associated with it: Agent, Theme and Location. In a sentence such as (5)

5. Bill *loaded* the car.

one of the thematic roles, most likely the Theme, would be left open. If this idea is correct, then listeners should not have difficulty interpreting a subsequent sentence that begins with a definite noun phrase as long as the noun phrase could plausibly fill the open role. Thus sentence (6)

6. *The suitcases* were heavy.

should be relatively natural when it follows (5) in a discourse because *the suitcases* can fill the open Theme role. In contrast the same sentence should be more difficult to understand when there is not an open thematic role, because the reader will have to make an inference to build a bridge from the noun phrase to the context (Haviland & Clark, 1974).

7.1 Experimental Methodology

7.1.1 Stimuli

We constructed sixteen sets of two sentence discourses in which a target sentence beginning with a definite noun phrase (8) was preceded by either a context sentence that introduced an open thematic role that the NP could fill as in (7b) or a sentence that created a plausible context for the target sentence but that did not leave an open role, as in (7a).

7. a. John had difficulty running fast to catch his plane
7. b. John had difficulty loading his car.
8. *The suitcases* were very heavy.

The two context sentences for each set were counterbalanced across two presentation lists.

7.1.2 Procedure

Subjects were presented with the context sentence on a CRT. When they pressed a button indicating that they had read and understood the context sentence, they were presented with the target sentence. Their task was to decide whether or not the target sentence made sense given the context.

7.2 Results

Target sentences were judged to make sense more often when the context sentence introduced an open thematic role than when it did not, (97% vs 84%; $F(1, 22) = 5.76, p = .025$). Latencies to target sentences judged to make sense were faster when the context introduced an open thematic role than when it did not, (1628 msec vs 1847 msec; $F(1, 22) = 6.32, p = .019$). Thus the results strongly supported the hypothesis.

8 Discussion

The studies that we have presented provide initial encouragement for the framework that we have been developing. Two interesting, and to our knowledge, previously unobserved phenomena were predicted and confirmed experimentally. It is important to acknowledge, however, that thematic roles are not the only possible explanation for our results. It is difficult, for example, to rule out the hypothesis that thematic roles are not distinct grammatical entities, but rather just aspects of

verb meanings as Ladusaw and Dowty (1987) have argued. A great deal of future research will be necessary before it becomes clear which of these frameworks will provide the more interesting insights about comprehension processes.

References

- Carlson, G. (1984). Thematic roles and their role in semantic interpretation. *Linguistics*, 22, 259-279.
- Carlson, G., & Tanenhaus, M. K. (1987). Thematic roles and language comprehension. To appear in W. Wilkens (Ed.), *Thematic relations*. New York: Academic Press.
- Cottrell, G.W. (1985). *A connectionist approach to word sense disambiguation*. (Tech. Rep. No. TR154). Rochester, NY: University of Rochester, Department of Computer Science.
- Fillmore, C. J. (1968). The case for case. In E. Bach & R. T. Harms (Eds.), *Universals in Linguistic Theory*. New York: Holt, Rinehart & Winston.
- Ford, M., Bresnan, J., & Kaplan, R. (1983). A competence-based theory of syntactic closure. In J. Bresnan (Ed.), *The mental representation of grammatical relations* (pp. 727-796). Cambridge, MA: MIT Press.
- Frazier, L. (1978). *On comprehending sentences: Syntactic parsing strategies*. University of Connecticut doctoral dissertation.
- Frazier, L. (1986). Theories of sentence processing. To appear in J. Garfield (Ed.), *Modularity in knowledge representation and natural language*. Cambridge, MA: MIT Press.
- Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, 14, 178-210.
- Haviland, S. E., & Clark, H. H. (1974). What's new? Acquiring new information as a process in comprehension. *Journal of Verbal Learning and Verbal Behavior*, 13, 512-521.
- Heim, I. (1982). *The semantics of definite and indefinite noun phrases*. University of Massachusetts doctoral dissertation.
- Johnson-Laird, P. (1983). *Mental models*. Cambridge, MA: Harvard University Press.
- Kamp, H. (1979). Events, instants, and temporal reference. In R. Bauerle, U. Egli & A. von Stechow (Eds.), *Semantics from different points of view* (pp. 376-417). Berlin: Springer-Verlag.
- Ladusaw, W., & Dowty, D. (1987). *Toward a non-grammatical account of thematic roles*. To appear in W. Wilkens (Ed.), *Thematic relations*. New York: Academic Press.
- McClelland, J., & Rumalhart, D. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88, 375-405.
- Rayner, K., Carlson, M., & Frazier, L. (1984). The interaction of syntax and semantics in sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior*, 22, 358-374.
- Seidenberg, M. S. (1985). Constraining models of word recognition. *Cognition*, 14, 169-190.
- Seidenberg, M. S., & Tanenhaus, M. K. (1979). Orthographic effects in rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, 5, 546-554.

- Seidenberg, M. S., Tanenhaus, M. K., Leiman, J. M., & Bienkowski, M. (1982). Automatic access of the meanings of ambiguous words in context: Some limitations of knowledge-based processing. *Cognitive Psychology, 14*, 489-537.
- Simpson, G. B. (1984). Lexical ambiguity and its role in models of word recognition. *Psychological Bulletin, 96*, 316-340.
- Simpson, G. B., & Burgess, C. (1985). Activation and selection processes in the recognition of ambiguous words. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 28-39.
- Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)Consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18*, 645-659.
- Tanenhaus, M. K., Flanigan, H., & Seidenberg, M.S. (1980). Orthographic and phonological code activation in auditory and visual word recognition. *Memory & Cognition, 8*, 513-520.
- Tanenhaus, M. K., Leiman, J. M., & Seidenberg, M. S. (1979). Evidence for multiple stages in the processing of ambiguous words in syntactic contexts. *Journal of Verbal Learning and Verbal Behavior, 18*, 427-440.