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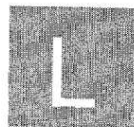
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The Role of Thematic Structures in Interpretation and Parsing

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This paper explores how thematic role information associated with verbs is used in language processing. We suggest that thematic roles are useful for co-ordinating different types of information in language processing because they represent aspects of conceptual/semantic representation that map directly on to syntactic form. We review some recent studies investigating the use of thematic information in syntactic ambiguity resolution and present some new evidence that thematic information can be used to eliminate completely the garden path typically associated with reduced-relative clauses. We then review some of our recent work investigating lexical structure in the processing of sentences with long-distance dependencies, and conclude that thematic structure guides the initial interpretation of these sentences. We conclude with a discussion about how thematic information might enable the processing system to make early semantic commitments that take into account relevant aspects of discourse context.

INTRODUCTION

Language comprehension is clearly an integrative process in which different types of linguistic and non-linguistic knowledge are rapidly combined to develop a mental representation of the input (Swinney, 1982). Many of the most basic questions about language processing focus on how different aspects of representation are co-ordinated during comprehension. In recent work that builds upon earlier proposals by Frazier and colleagues (e.g. Frazier, 1987; Rayner, Carlson, & Frazier, 1983), we have argued that, given certain assumptions, lexical representations can provide much

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of the machinery necessary to integrate rapidly different types of knowledge during comprehension (Carlson & Tanenhaus, 1988; Tanenhaus & Carlson, 1989; Tanenhaus, Garnsey, & Boland, in press). In particular, we have suggested that verb-based *thematic roles* help guide parsing decisions and mediate between discourse information, general knowledge, and parsing. In addition, we have suggested that the use of thematic structures allows the comprehension system to make early commitments in the face of indeterminate structure, yet recover rapidly from mistakes. This is particularly important given the persuasive evidence that listeners and readers make immediate commitments to a single interpretation of locally ambiguous segments, rather than maintaining parallel interpretations or delaying commitment until subsequent structural information disambiguates the input (Frazier, 1978; Marslen-Wilson & Tyler, 1987).

The general phenomenon of thematic roles goes under a number of different terms in the linguistics literature, including "case roles", "thematic relations", "semantic case", and others. Thematic roles are the possible semantic roles that may be played by the subcategorised complements (or arguments) of a verb.¹ So, for example, the verb "put" subcategorises for three syntactic complements, a subject nounphrase, an object nounphrase, and a locative prepositional phrase, e.g. *The man* (subject) put *the car* (object) *in the garage* (PP). In standard accounts of thematic roles, each of these complements is assigned a different thematic role by the verb, where the role characterises the semantic role or "mode of participation" for (the denotation of) that argument in the event denoted by the verb. In this case, the subject of "put" is an *agent*, the object is the *theme* (the thing in motion), and the prepositional phrase designates the *location* or *goal*. It is important to keep in mind that the theoretical status of thematic roles within the linguistics literature remains unresolved. Not only is there considerable question about whether thematic roles are syntactic, semantic, or conceptual in nature, but also whether they should be regarded as grammatically significant entities at all (see Dowty, 1988; Ladusaw & Dowty, 1988). In this paper, we assume that thematic roles are part of the semantic or conceptual phenomena that are closely associated with the syntactic/lexical structure of a sentence. We need not claim that these roles are primitives: All that is important for our claim, is that there are certain types of semantic/conceptual information that play a distinguished role in defining verb-argument relations implicit in the labels "agent", "instrument", "theme", etc. We are also assuming, for the sake of simplicity, that

¹We will speak of a verb assigning a thematic role to an argument (or a complement), but we intend throughout that the thematic role actually constitutes a relation between denotations of the expressions and are only derivatively a syntactic relation holding between linguistic expressions themselves (see, e.g. Carlson, 1984; Parsons, 1980).

a verb has associated with it a set of thematic roles, or a thematic grid, with each argument of the verb being assigned a single thematic role that differs from the roles assigned to the other arguments of that verb.

Thematic roles are of particular interest in the study of sentence processing because they cut across aspects of representation that are typically considered distinct from one another. On the one hand, thematic roles are aspects of conceptual representation. Events and modes of participating in events are arguably conceptual notions. It is also commonplace to assume that events and their participants are elements of a discourse structure. More locally, thematic roles are closely tied to the syntactic structure of a sentence, as only those modes of participation that are realised as syntactic complements of a verb are associated with thematic roles. Thematic roles, then, provide a form of representation with access to concepts and meaning and elements of discourse structure that map directly on to syntactic form. This property of thematic roles suggests that they should be useful to the comprehension system in co-ordinating different types of information. In addition, the way that the comprehension system exploits the information supplied by thematic roles may provide interesting insights into its architecture.

In order for thematic information to be used in sentence processing, we assume that the recognition of a verb makes available the following information:

1. The semantic representation or "sense" of the verb.
2. The thematic roles associated with the verb.
3. The types of constituents that can serve as complements of the verb.
4. How roles and syntactic constituents are connected to one another.

Let us take the verb "donate" as an example. Its sense, we assume, is a certain type of event with typical causes, effects, time-courses, etc. It is also an event in which one finds an entity participating as an agent, another as a theme, and another as a recipient; thus, there are three roles associated with the event. The verb itself always requires a subject, as do all English verbs, and most typically takes an object NP and a dative PP afterwards (i.e. "John donated *fifty dollars to his favourite charity*"). The verb may also appear less often without an object NP ("John donated to few charities"), or without the PP ("John donated fifty dollars"). In each case, the subject NP plays the role of the agent, the object NP is the theme, and the PP is the recipient. Even in cases where one of these last two constituents is missing, the existence of an entity playing that role is implied by the lexical entry (e.g. "John donated \$50" still requires that the money be donated to *somebody* or *something* that remains unspecified).

Now, suppose that the comprehension system makes use of all this information whenever the verb "donate" is encountered in an ongoing discourse. Not only can it project an expectation about what kinds of linguistic elements occur after the verb, but it can also assign a provisional meaning for the whole sentence by leaving the particular identities of the elements playing the theme and recipient roles temporarily unspecified, awaiting the denotation of the post-verbal phrases. Or, as we will suggest later, if a likely entity has already been introduced in the discourse or even the same sentence, it may be provisionally assumed to be playing one of those roles until further evidence shows otherwise.

This paper will explore ways in which thematic roles contribute to language comprehension. Our focus will be on when thematic roles associated with verbs are accessed, when thematic assignments are made, and the role that thematic representations play as an interface between discourse-level and sentence-level processing. We will address these questions by examining the recent literature in two domains. The first domain is attachment ambiguity, where a number of recent studies have explored the question of whether or not thematic information can influence syntactic decisions. The second domain is long-distance dependencies. We have been using long-distance dependency constructions to explore both the use of lexical representations in language processing, and the hypothesis that the interpretation of certain empty categories makes direct use of thematic representations.

EXPERIMENTAL EVIDENCE

In this section we briefly review some recent studies examining the interaction between thematic assignment and syntactic ambiguity resolution. A central assumption that is common to all recent proposals about how thematic information is used in sentence processing (with the possible exception of Pritchett, 1988), is that the process of thematic role assignment provides information that is used in resolving syntactic ambiguity. It seems likely that thematic assignments in processing are made on the basis of the meaning of an argument, the core meaning of the verb, and also general world knowledge. Therefore, "pack the suitcases" prefers "suitcases" as the location, whereas "pack the clothes" prefers "clothes" as the theme, because of the nature of suitcases and clothes but not because of the grammatical properties of words used to refer to them. It also seems likely that thematic assignments can be guided by discourse context, as suggested by Frazier (1987). Therefore, "his sister" would be assigned the theme role in the context "John didn't know who he could trust with the errand. He finally decided to send *his sister* . . .", whereas it would be assigned the recipient or goal role in the context, "John didn't know which

present to mail to his sister for her birthday. He finally decided to send *his sister . . .*". Two questions then arise about thematic assignments and how they influence parsing. First, when are thematic assignments made and, secondly, what is the timing of thematic assignments *vis-à-vis* parsing decisions? To the extent that thematic assignments can mediate initial parsing decisions, they provide a mechanism whereby grammatically relevant world knowledge and discourse context enter into one of the most basic parsing processes—the determination of grammatical relations.

There is now a small but rapidly growing experimental literature on the interaction of thematic and syntactic processing. Recent studies have focused on three locally ambiguous syntactic structures where thematic information can provide disambiguating information: (1) prepositional phrase attachment ambiguity; (2) clause boundary ambiguity with optionally transitive verbs; (3) past-tense–past-participle ambiguity with reduced relative clauses.

Prepositional Phrase Attachment Ambiguity

The ambiguity in sentences containing prepositional phrase attachments lies in the attachment of the prepositional phrase to either the verb or the object nounphrase (as in sentences 1a and 1b). According to Frazier and colleagues, attachment to the object NP requires the building of a more complex syntactic structure than the attachment to the verb, and therefore would be the unpreferred structure.

In one study, Rayner et al. (1983) monitored eye movements while subjects read sentences containing prepositional phrase attachment ambiguities like the ones in (1):

- 1a. The spy saw the cop with the binoculars, but the cop didn't see him.
- 1b. The spy saw the cop with the revolver, but the cop didn't see him.

Sentence (1a) contains a prepositional phrase that is semantically biased towards verb attachment, because the noun "binoculars" contains semantic information supporting its use as an instrument of the verb "see". Sentence (1b) is semantically biased towards object attachment because the noun "revolver" is a poor instrument for the verb "see". Rayner et al. (1983) found that people frequently re-read the prepositional phrase in (1b) but not in (1a), suggesting that the prepositional phrase was initially attached to the verb and then the anomaly was detected afterwards. Rayner et al. (1983) proposed the existence of two separate processors in the sentence comprehension system: the syntactic processor and the thematic processor. The thematic processor receives and analyses the output of the syntactic processor through the use of semantic and pragmatic knowledge concerning the constituents. If the output of the syntactic

processor does not match the output of the thematic processor, then the conflict is resolved in favour of the thematic processor.

Taraban and McClelland (1988) argued against Rayner et al.'s (1983) interpretation on the grounds that Rayner et al.'s results were due to the semantic content biasing the verbphrase attachment in their materials. They developed a set of sentences that have a semantic bias towards the nounphrase attachment. Using these materials and Rayner et al.'s materials, Taraban and McClelland demonstrated in a self-paced reading study that reading times were equally fast for both semantically biased attachments. They further suggested that the attachment preferences were due to an expectation about the thematic role of the phrase following the verb that was based upon the preceding semantic context.

Clause Boundary Ambiguity

Stowe (1988) used causative/ergative verbs such as "stopped". When used transitively (e.g. "The police stopped the car"), the subject is the agent and the object is the theme; when used intransitively (e.g. "The car stopped"), the subject is the theme. These verbs were placed in sentences where a subordinate clause preceded the main clause, as in "Even before the police stopped the driver was getting nervous." Frazier (1978) and Frazier and Rayner (1982) have shown that in the absence of punctuation, readers have difficulty beginning at "was", indicating that the NP following the verb "stopped" is taken to be its object, rather than the subject of the next clause.

Stowe (1988) manipulated the animacy of the first noun in the subordinate clause, and whether there was a prepositional phrase following the verb, comparing sentences like those in (2):

- 2a. Even before the police stopped the driver was getting nervous.
- b. Even before the truck stopped the driver was getting nervous.
- c. Even before the police stopped at the light the driver was getting nervous.
- d. Even before the truck stopped at the light the driver was getting nervous.

In general, animate nouns will be readily interpreted as likely agents, whereas inanimate nouns will not be. (However, as Taraban and McClelland (1988) point out, one can create contexts in which an inanimate noun has agent-like properties.) Stowe hypothesised that if thematic assignment takes place at the verb and provides immediate feedback to the parser, then readers should not experience a garden path at the verb in sentences like (2b). The reason is that an inanimate subject will force the intransitive "ergative" analysis in which there is no argument position for an NP

following the verb. As a result, processing the NP ("the driver") should signal the beginning of a new clause.

Subjects read sentences one word at a time, pressing a button if and when the sentence became ungrammatical. Reading times and judgements of ungrammaticality were recorded. As expected, reading times were longer at the verbphrase in the main clause for the sentences with animate subjects (2a) than in the control condition (2c), where the NP ("the driver") unambiguously signals the beginning of the main clause, indicating that subjects had initially pursued the transitive analysis of the verb "stopped". However, there was no evidence of a reading time difference between the two inanimate conditions (2b and 2d).

These results would seem to show that the thematic assignment of the subject NP in the subordinate clause (e.g. "police" or "truck") determined the structural analysis pursued by the parser for the subsequent verb. When the NP was animate and thus a good agent, the verb was processed as a causative, whereas when the NP was inanimate and thus a poor agent but a good theme, then the verb was processed as an ergative.

Stowe's (1988) study suggests that thematic assignments are made rapidly and that they have immediate parsing consequences. The study, though, is far from definitive. For one thing, it does not show that only a restricted range of semantic dimensions come into play, as predicted by the thematic analysis. Also, the reading times are quite long—more than 700 msec per word. A likely explanation for the long reading times has to do with the task. Stowe provided subjects with feedback following the grammaticality judgements. A subject who judged a sentence to be ungrammatical when garden-pathed (e.g. at "was" in the sentence, "Even before the police stopped the driver was getting nervous"), would be told that he or she had made a mistake. This kind of feedback may well have made subjects think carefully before responding. More recently, however, Stowe has replicated her results using a self-paced, word-by-word reading task without requiring subjects to make grammaticality judgements (Stowe & Cupples, 1989). Stowe's results, then, provide at least preliminary evidence that thematic assignment can influence syntactic closure.

Reduced Relative Clauses

The ambiguity associated with reduced relative clauses such as sentence (3), a variation on Bever's (1970) famous "The horse raced past the barn fell" example, provides another testing ground for thematic feedback:

3. The lawyer sent the memo arrived late.

The ambiguity arises because the past-tense and the past-participle *forms* of the verb "sent" are identical. If "sent" is taken to be a past tense, it is

the matrix verb of a main clause with the preceding nounphrase as its subject. If it is taken to be a past-participle, then "sent" is part of a reduced relative clause which itself is part of a nounphrase that is the subject of a later verb. In the main clause analysis, the nounphrase preceding the verb plays the role of agent, whereas in a relative clause analysis the nounphrase plays the role of theme. There is, of course, a strong main clause bias when the subject is animate, accounting for the typical garden path associated with the reduced relative form.

Ferreira and Clifton (1986, experiment 1) manipulated the animacy of the first nounphrase within the relative clause in order to determine whether thematic information could be used by the processing system to eliminate the usual garden path for reduced relative clauses, compared to controls with unreduced relatives. Their reasoning was that inanimate nounphrases cannot be plausible agents (or are unlikely to be agents) and thus could, in principle, provide thematic feedback to the parser that would block a past-tense/main clause analysis. Sample materials from their study are presented in (4):

- 4a. The defendant examined by the lawyer turned out to be unreliable.
- b. The defendant that was examined by the lawyer turned out to be unreliable.
- c. The evidence examined by the lawyer turned out to be unreliable.
- d. The evidence that was examined by the lawyer turned out to be unreliable.

Using an eye-tracker to monitor fixation durations, Ferreira and Clifton (1986) found striking evidence against the immediate use of thematic information. In the animate conditions, the usual garden-path effects for reduced relatives obtained—namely, longer fixation durations at the disambiguating prepositional phrase for the reduced relative clauses compared to the unreduced controls, and also more regressive ("second-pass") eye movements. In the inanimate conditions, reading times were still longer at the prepositional phrase ("by the lawyer") in the reduced condition compared to the unreduced condition. However, fixation durations at the ambiguous verb ("examined") were also longer in the reduced condition, indicating that readers had found the inanimate nounphrase to be implausible as the agent of the verb. Thus Ferreira and Clifton (1986) concluded that readers pursued the main clause analysis despite the availability of biasing thematic information.

However, there are two problems with Ferreira and Clifton's materials that weaken their conclusions. First, and most seriously, at least half of the materials used by Ferreira and Clifton used inanimate nounphrases that could be completed sensibly using the past-tense form of the verb, e.g. "The car towed . . ." could be plausibly continued as "The car towed the

trailer." The problem arises because inanimate nounphrases can occur in the subject position as instruments of many verbs. Thus Ferreira and Clifton did not provide the most stringent test of the thematic feedback hypothesis. Secondly, unreduced relative clauses may not provide the most appropriate baseline control for reduced relatives. Crain and Steedman (1985) have argued that relative clauses require special discourse conditions to be felicitous. Basically, relative clauses are used to pick out a unique antecedent; therefore, one would not say "The car towed yesterday was badly damaged" unless there was at least one other car and the reduced relative allowed the listener to identify which car was being referred to (see also Altmann & Steedman, 1988). If Crain and Steedman (1985) are correct, then more processing would be required for readers to construct an appropriate discourse representation for a relative clause in isolation than for a main clause. For reduced relatives, this processing would be distributed over fewer words than for unreduced relatives. Fortunately, the discourse effects can be controlled for by using reduced relatives with morphologically unambiguous verbs (e.g. "The evidence *stolen*").

Trueswell, Tanenhaus, and Garnsey (submitted) conducted an eye-tracking experiment using the same methodology as Ferreira and Clifton (1986), but with slightly different materials. First, care was taken to make sure that the inanimate nounphrases did not allow plausible past-tense completions. Secondly, reduced and unreduced relative clauses with inanimate nounphrases were included for a set of morphologically unambiguous verbs. A sample of the materials is presented in (5):

Ambiguous verb

- 5a. The man recognized by the spy took off down the street.
- b. The man that was recognized by the spy took off down the street.
- c. The van recognized by the spy took off down the street.
- d. The van that was recognized by the spy took off down the street.

Unambiguous verb

- 5e. The money taken by the student was finally returned.
- f. The money that was taken by the student was finally returned.

The results for first- and second-pass fixation durations are presented in Table 1.

For reduced relative clauses with animate nounphrases, the usual garden-path effects occurred, similar to those obtained by Ferreira and Clifton (1986). Reading times were significantly longer at the "by-phrase" for the reduced relatives compared to the unreduced relatives in the first-pass reading times (i.e. 5a was more difficult to read than 5b). In addition, the

TABLE 1
Mean First-pass and Second-pass Reading Times (msec per character)

Condition ^a	First Pass (sentence region)		Second Pass (sentence region)	
	V1	by-phrase	V2	V1
AR: <i>The man . . .</i>	37.1	39.4	43.9	29.2
AU: <i>The man that was . . .</i>	36.8	34.6	39.6	12.1
IR: <i>The van . . .</i>	37.7	36.8	41.5	19.9
IU: <i>The van that was . . .</i>	38.1	36.9	43.6	10.9
UR: <i>The money . . .</i>	52.8	33.1	46.4	13.2
UU: <i>The money that was . . .</i>	49.7	33.3	46.9	7.3
	<i>recognised</i>	<i>by the spy</i>	<i>took off</i>	<i>recognised</i>
				<i>by the spy</i>
				14.9
				9.6
				5.8
				8.0
	<i>taken</i>	<i>by the student</i>	<i>was finally</i>	<i>taken</i>
				13.2
				4.9
				6.1
				10.3
				6.6

^aAR, animate reduced; AU, animate unreduced; IR, inanimate reduced; IU, inanimate unreduced; UR, unambiguous reduced; UU, unambiguous unreduced.

second-pass reading times showed longer fixation durations at the by-phrase and at the ambiguous verb.

The results were markedly different for the sentences with inanimate nounphrases. Neither the first-pass reading times nor the second-pass reading times showed any reliable differences between the reduced and the unreduced relatives at the by-phrase (the by-phrase of 5c was as easy as the by-phrase in 5d; the crucial interactions between reduction and animacy were significant in both the first- and second-pass reading times). Second-pass reading times at the ambiguous verb were longer for the reduced relatives; however, a similar effect obtained for the reduced relatives with *unambiguous* verbs (5e and 5f), suggesting that the effect is not due to garden-pathing, but is likely to be an inferencing effect. The pattern of results obtained in the experiment, then, provide strong support for the hypothesis that thematic information can determine parsing decisions.

Note that this does not mean that thematic information actually supersedes syntactic analysis. In fact, the model argued for in Trueswell et al. (submitted) is one in which thematic information selects among two competing analyses. The basic idea is that ambiguous morphological forms are accessed in the same manner as other lexical ambiguities with parallel access of competing morphological forms (Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). In addition, each verb-form makes available its associated thematic structures (Cottrell, 1988; McClelland & Kawamoto, 1986), as well as information about how the thematic roles are to be assigned to syntactic complements. Thematic role assignment then can provide disambiguating information. Thus the thematic information helps to select from among potential morphological possibilities.² Note that a similar model will account for Stowe's ergative-causative results. However, it is debatable whether one should treat the causative-ergative ambiguity as a lexical ambiguity or as a case of the same core meaning of a verb having associated with it two incompatible thematic grids (see Carlson & Tanenhaus, 1988 and Tanenhaus & Carlson, 1989, for a discussion). The parallelism in a model like this comes not from pursuing several complete parses in parallel, but rather from the parallel access of morpho-

²It is important to note, though, that thematic role assignment is not the only factor relevant to selecting between the past-tense and past-participle forms of a verb. The relative frequency of the past-tense and past-participle forms is likely to be important (Burgess & Hollbach, 1988). Clearly, there is also a strong general bias in favour of the past-tense form when the subject nounphrase could be either an agent or theme. Described by Bever (1970) as the NVN strategy, this bias is likely to be determined by a range of factors (see Trueswell et al., submitted). It seems unlikely, though, that a syntactically based simplicity metric such as Minimal Attachment underlies the past-tense/main clause bias.

logical forms and more generally from the immediate access and use of lexical information.

The studies cited above lead to the conclusion that thematic roles provide a mechanism for general knowledge and context to interact with syntactic processing in syntactic ambiguity resolution. In the final section of this article, we will briefly review some of our recent work on verb argument structure, which suggests that thematic structure provides a mechanism for early semantic interpretation and interaction with discourse. The evidence comes from studies investigating sentences with filler-gap dependencies. We will be suggesting that at least the initial association of fillers with empty category or gap positions takes place using thematic rather than syntactic categories, a hypothesis first explored—and rejected—by Fodor (1979).

Long-distance Dependencies

In a recent series of studies, we have been developing the hypothesis that thematic representations are used in interpreting sentences with long-distance dependencies (Boland, Tanenhaus, Carlson, & Garnsey, in press; Carlson & Tanenhaus, 1988; Tanenhaus & Carlson, 1989; Tanenhaus et al., in press). In a sentence with a long-distance dependency, a questioned or relativised phrase (or “filler”) must be associated with an empty category (or “gap”) that occurs later in the sentence. For example, in the sentence illustrated in (6) (a wh-question), the questioned phrase “which customer” must be semantically interpreted as the direct object of “call”:

6. *Which customer*_i did the secretary call _i about the article?

In the Government and Binding grammatical framework (Chomsky, 1981), an empty category or trace follows the verb “call”. The trace is assigned the thematic role normally associated with the object of “call”. “Which customer” then inherits the thematic role from the trace through the process of co-indexing.

We have been studying the processing of wh-questions in order to explore the time-course with which information about verb-argument structure is accessed and used in sentence processing. Wh-questions provide a useful domain for exploring these questions because the wh-phrase (e.g. “which customer”) is a nounphrase filler that needs to be assigned a role, and the argument positions associated with verbs define possible roles for the filler. The paradigm that we have been using is a variant of an oddity detection task that we have referred to as the *embedded anomaly* approach. We contrast fillers that are either semantically plausible or implausible with respect to a particular gap position using an on-line judgement task combined with self-paced, word-by-word (or, in some

cases, phrase-by-phrase) presentation. The place in the sentence where plausibility effects are “noticed” by the subject, reflected in overt “does not make sense” judgements or in slowed reading times, indicates when the filler has been associated with the gap. Contrast the sentences in (7):

- 7a. *Which book_i* did the boy read ____i in class?
 b. *Which food_i* did the boy read ____i in class?

Which book is a plausible direct object of *read*, because one typically reads books, whereas *which food* is not, because one cannot plausibly read food (setting aside metaphoric interpretations). Thus sentence (7b) becomes implausible when the reader or listener interprets *which food* as the direct object of *read*.

The position of the gap in a filler-gap construction is often locally ambiguous. To see this, consider the sentences in (8) in which the filler phrase is now the object of a preposition that comes after the verb. Sentence (8b) is now plausible:

- 8a. *Which book_i* did the boy read about ____i?
 b. *Which food_i* did the boy read about ____i?

On a syntactic account of gap filling, a thematic role is assigned to a filler once it has been indexed with an empty category that has been identified by the parser (see Clifton & Frazier, 1989, Frazier & Clifton, 1989, and Fodor, this volume, for a discussion of the distinction between gap-driven and filler-driven syntactic accounts of gap-filling). In contrast, a thematically based account assumes that a filler can be associated directly with a thematic role that is made available when a verb is recognised, which can be before an empty category has been encountered.

In studies in collaboration with Susan Garnsey and Julie Boland using the embedded anomaly logic, we have obtained a constellation of results that, taken together, make what we feel is a persuasive case that fillers are initially associated with thematic rather than syntactic representations (see Boland et al., in press; Garnsey, Tanenhaus, & Chapman, 1989; Tanenhaus et al., in press; Tanenhaus, Boland, Garnsey, & Carlson, forthcoming). We will discuss a few of these results here.

For verbs that are typically used transitively, such as *read*, we find an anomaly effect at the verb (and before the empty category has been encountered) for fillers that would be implausible as the object of the verb, using both behavioural response measures and event-related brain potentials (ERPs). In the studies using ERPs, an implausibility effect is indexed by an N400—a brain potential sensitive to the plausibility of a word in context (Garnsey, Tanenhaus, & Chapman, 1989). In the behavioural studies, subjects read sentences one word at a time and respond “no” if the sentence stops making sense. “No” responses to sentences with implausi-

ble fillers begin at the verb (Tanenhaus, Boland, Garnsey, & Carlson, 1989).

In subsequent research, we have shown that the place in the sentence where anomaly effects occur depends upon the argument structure of the verb. In particular, we do not find anomaly effects at the verb when the filler would be implausible as the object of the verb, but the argument structure of the verb makes available another argument position in which the filler could be plausible. Thus far, we have looked at two types of verbs in addition to simple transitive verbs. The first type is dative verbs like "grant". We have examined these verbs in sentences in which the filler would be implausible as the direct object, but plausible as the indirect object, such as (9):

9. *Which secretary_i did the boss grant the maternity leave to —_i?*

The second type is verbs like "remind", verbs that are typically used transitively and with an infinitive complement, such as (10):

10. The man reminded *the woman to call home*.

We have examined these verbs in sentences in which the filler would be implausible as the direct object of the verb but plausible somewhere within the infinitive complement, such as (11):

11. *Which movie_i did your brother remind us to watch —_i?*

In order to illustrate the differences that we observe among verb types, we will briefly present the results from a recent study conducted in collaboration with Julie Boland and Susan Garnsey (Boland et al., in press; Tanenhaus et al., forthcoming). This experiment used three types of verbs, all of which are typically used transitively: simple transitive verbs such as "watch", transitive verbs that frequently occur with infinitive complements, such as "remind", and "dative" verbs that can be used with a direct and an indirect object, such as "read". Note that we included some dative verbs like "read" in earlier studies, but always with fillers that would have been implausible as either the direct or indirect object. In this experiment, the plausible fillers were plausible direct objects of the verb and the implausible fillers were implausible direct objects. Sample materials are presented in (12) and in Table 2:

- 12a. Which star / stone did the assistant watch all through the night.
 b. Which poem / baby did the babysitter read in a funny voice.
 c. Which girl / movie did the woman remind to watch the show.

For all three verb types, the word immediately after the matrix verb provides unambiguous syntactic evidence that the filler was in fact the direct object of the verb, therefore making the sentence implausible when

TABLE 2

Condition ^b	Critical Word Positions ^a						
	N	V	V + 1	V + 2	V + 3	V + 4	
Tran-plaus } Tran-implaus }		assistant	watch	all	through	the	night
		<i>Which star did the</i> <i>Which stone did the</i>					
Dat-plaus } Dat-implaus }		babysitter	read	in	a	funny	voice
		<i>Which poem did the</i> <i>Which baby did the</i>					
Icomp-plaus } Icomp-implaus }		woman	remind	to	watch	the	show
		<i>Which girl did the</i> <i>Which movie did the</i>					

^aThe final four words in a sentence formed either an adverbial phrase (for the first two verb types) or an infinitive complement (for the Icomp verb type).

^bTran, transitive; Dat, dative; Icomp, infinitive complement; plaus, plausible; implaus, implausible.

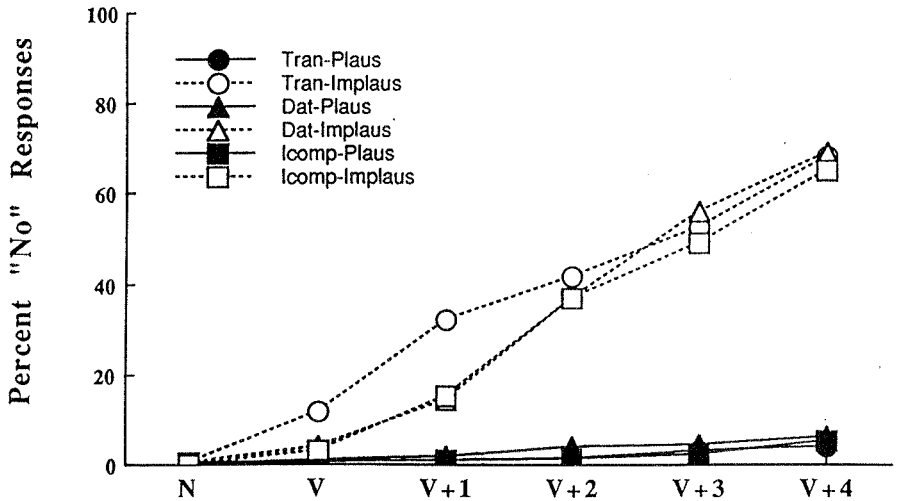


FIG. 1 Cumulative percentages of sentences judged to make sense up through each word for wh-sentences with plausible and implausible fillers. Data for three verb types are shown: transitive, dative, and infinitive complement verbs.

the filler is an implausible direct object. The results that we typically obtain are illustrated in Fig. 1 (from Boland et al., in press).

The cumulative percentage of trials on which subjects judged sentences to stop making sense at the word positions indicated on the graph, are plotted for the simple transitive, dative, and infinitive complement-taking verbs. Note that the implausibility is first detected at the verb itself for the simple transitive verbs, but not until the next word for the dative and infinitive complement verbs. Note also that at the end of the sentence, the cumulative percentage of sentences judged to make sense are nearly identical for the plausible and implausible conditions across verb types. This is important given Mitchell's suggestion (this volume) that verb differences might be due to baseline plausibility differences.³

The interpretation that we have offered for these results is that recognition of the verb makes available the set of thematic roles associated with the verb, which define the possible gap sites. Thus for a dative verb, both

³Mitchell has also suggested that plausibility detection is a weak response measure because many implausible sentences are judged to be plausible. Subjects are instructed that most of the sentences in the experiment will be plausible; therefore, subjects have a relatively high threshold for making a "no" judgement. This also accounts for the relatively low "false alarm" rate to plausible sentences. More importantly for Mitchell's argument, we find plausibility effects when we analyse reading times for only those trials on which subjects respond that the sentence made sense.

the direct object and indirect object roles are available immediately at the verb. A filler which is an implausible direct object, but plausible indirect object, is immediately assigned the indirect object role. For an infinitive complement verb, the direct object role and the role associated with the infinitive complement would be available immediately. A filler that is implausible in the direct object role is assigned to the role associated with the infinitive complement.

Several additional studies provide results that support the hypothesis that the thematic structure of the verb is being used to associate fillers with roles (see Boland et al., in press; Tanenhaus et al., forthcoming). In a recent study we examined "dative-like" verbs such as "donate" that take a direct and an indirect object and in addition allow only the direct object to follow the verb. Thus sentence (13a) is acceptable, but (13b) is not:

- 13a. John donated some cheap liquor to the campus party.
 b. *John donated the campus party some cheap liquor.

We used two types of fillers that were plausible indirect objects of the verb, such as "public library" and "campus party", with a direct object that was only plausible with one of the fillers, as in (14):

14. Which campus party/public library did John donate some cheap liquor to?

Thus an implausibility effect at "liquor" when "which public library" was the filler, would indicate that the filler had been interpreted as the indirect object. Plausibility effects obtained at the direct object. This result clearly demonstrates that the filler is being interpreted as the indirect object prior to the syntactic location of the gap.

We have also ruled out the possibility that readers are simply delaying filler-gap assignment for infinitive complement verbs. Tanenhaus et al. (forthcoming) found that readers do interpret a filler as belonging to a direct object gap at the verb, when it would be a plausible direct object, as in (15):

15. *Which friend_i* did your brother remind us to visit $_{-i}$?

The result supporting this interpretation is that reading times at "us" are longer in wh-questions like (15) than in control sentences where there is no possible gap following the verb (e.g. "Your brother reminded us to visit his friend"). This "filled gap effect", first observed by Crain and Fodor (1985) and Stowe (1986), indicates that the filler has been incorrectly assigned to the direct object role, so that when the true direct object "us" is encountered, readers are confused. Crucially, no filled gap effect occurs when the filler would be implausible as the direct object of the verb. Recall that the results with the simple transitive verbs suggested that the absence of a gap

position associated with the verb *where the filler could be plausible* results in an implausibility effect. That result in combination with the result that there is no implausibility effect at the verb for infinitive complement-taking verbs, converge on the interpretation that subjects "know" that there will be an infinitive complement which could contain the real gap. Clearly, one cannot know that an optional complement will be there in the linguistic input before it is actually encountered. But the thematic structure of the verb, coupled with the meaning of the verb, does provide the processing system with sufficient information to construct a semantic representation that would allow the filler to be interpreted. To see this, consider the verb "invite", which typically is used transitively and with an infinitive complement (e.g. *Mary invited Bill to go along to the party*). In an "invite" event, somebody is inviting someone to do something. Thus at the verb in a sentence beginning "Which movie did Bill invite . . .", the listener or reader could interpret "movie" as a constituent of the embedded event. Note that even when a verb like "invite" is used without an infinitive complement, then the embedded event is strongly implied, as is illustrated by the sentence "Bill invited Tom." In the example, Tom is clearly being invited to go or come somewhere.

The claim advanced by Frazier, Clifton, and Randall (1983), that access to verb-based "control" information is delayed, would seem to argue against the hypothesis that this type of event structure information can be used rapidly in sentence processing. However, we have recently demonstrated that people can, in fact, use control information rapidly. Boland, Tanenhaus, and Garnsey (1989) examined sentences like those in (16) in an anomaly detection task:

- 16a. Which horse/outlaw did the cowboy refuse to surrender to the sheriff?
 b. Which horse/outlaw did the cowboy force to surrender to the sheriff?

"Refuse" is a "subject" control verb, meaning that the subject of the verb "the cowboy" is understood as, or controls, the subject of the following infinitive complement. In contrast, "force" is an object control verb. In sentence (16b), the *wh*-phrase is the object of force and this phrase is the understood subject of the infinitive. Implausibility effects obtained at "surrender", when the filler was "which horse" (horses cannot surrender) for the object control verbs but not for the subject control verbs, indicating that readers used the control information correctly.

What our filler-gap studies demonstrate, then, is that the meaning and thematic structure of the verb allow the reader or listener to construct rapidly a schematic representation that includes the central components of the "situation" described by the verb. Thus this type of representation may

well play an important role in allowing the comprehension system to develop interpretations as rapidly as it does.

DISCOURSE, SYNTAX, AND THEMATIC ROLES

One interesting observation that supports our conjectures about the use of thematic structure in parsing and that complements our results with dative verbs and infinitive complement verbs, is that argument roles made available at the verb seem to function as anaphors when not associated with an actual constituent in the sentence. Consider the short discourses in (17):

- 17a. Bill almost forgot to go to the bank.
 Fortunately, Tom reminded him.
- b. The library had its budget slashed.
 So, Bill donated some books.

Note that "remind" in (17a) has an infinitive phrase following it, and that "donate" has no "to"-phrase designating a recipient. Still, each is somehow implied in the sentences. The example in (17a) illustrates null complement anaphora (Hankamer & Sag, 1976). In (17a), the empty infinitive complement, or alternatively its thematic representation, functions as an anaphor, taking as its antecedent "to go to the bank" from the context sentence before it. Likewise, in (17b), the otherwise unspecified recipient role seems to function as an anaphor leading to the inference that it was the library that Bill donated books to. Note that in isolation the sentences with the missing complements seem less complete than versions that include the complements, whereas in a context that supplies an antecedent for the complement, the truncated versions are more natural and the "full" versions (18a and 18b) seem somewhat awkward because they feel redundant:

- 18.a. Bill almost forgot to go to the bank.
 Fortunately, Tom reminded him to go to the bank.
- b. The library had its budget slashed.
 So, Bill donated some books to the library.

We should note that our claims that thematic structures allow early interpretation do not in any way mean that syntactic analysis is bypassed. On the contrary, the success of early interpretation requires the successful linkage of thematic structures and syntactic forms. If a thematically based interpretation is incorrect, then the syntactic analysis will provide clear evidence to that effect, as well as clear information about how it is to be revised.

Of course, early interpretation will sometimes be incorrect. However, in

many cases, mistaken interpretations preserve the basic thematic or situational structure of the correct analysis. For example, listeners will initially assume that John is reading the book in “Which book did John read about?” However, when it turns out that he is reading *about* the book, the situation remains basically the same. He is still reading something. But an early interpretation presents problems when the thematic structure assumed by the comprehender is incompatible with the actual input. This presents an alternative interpretation for Pritchett’s (1988) interesting claim that garden paths can be defined thematically.

Pritchett (1988) proposes that the difficulties associated with various garden-path sentences can be accounted for with a sentence processing system that makes immediate thematic assignments. Pritchett assumes that upon encountering a verb, the maximal thematic grid for that verb, which is the grid containing the largest number of thematic roles, is initially accessed. For example, for the verb “warned”, a maximal grid of (agent, goal, proposition) is first accessed. Pritchett proposes two principles that describe the comprehension process:

1. *Theta-attachment*: The parser attempts to assign a theta role to a potential argument at every point in processing.
2. The *theta-reanalysis constraint*: if a syntactic reanalysis involves a syntactic constituent that has already been assigned a thematic role, then the new syntactic constituent (which syntactically dominates the structure of the old constituent) should be assigned the same thematic role that was assigned the constituent it now dominates, or else the reanalysis will be “costly”.

Pritchett’s second principle, theta-reanalysis, makes the prediction that once a structure has been assigned a thematic role, any reanalysis that results in a change in thematic assignment to that structure or any structure that syntactically dominates it, will result in a garden path. Pritchett’s lead example is the garden-path sentence “Mary warned her mother hated her.” On his account, “her” is initially assigned the goal role. Then, when “mother” is encountered, a reanalysis must be done, in which “her mother” is assigned the goal role. This does not violate the theta-reanalysis principle because “her” is still part of the goal, and thus the reanalysis is not costly. However, when the verb “hated” is encountered, “her” becomes the goal again, and “mother hated . . .” becomes an incomplete proposition. This reanalysis violates the theta-reanalysis constraint because the noun “mother”, which was previously in a structure assigned the goal role, is now in a structure assigned the proposition role, and thus processing becomes difficult.

However, difficulties arise with Pritchett’s thematic account of garden-path sentences. Pritchett’s proposal cannot account for the results found in

Taraban and McClelland (1988) and Trueswell et al. (submitted), because he requires that only one grid—"the maximal grid"—is initially accessed, and, more crucially, because his thematic assignments are based only on *syntactic* information associated with the grid. In other words, Pritchett proposes early assignment of thematic roles, but not early semantic interpretation. Semantically inappropriate thematic assignments can thus be made without the immediate detection of an anomaly. As a result, Pritchett's proposal predicts that both sentences (19a) and (19b) would be equally difficult to process:

- 19a. The doctor warned the patient would be contagious.
- b. The doctor warned the virus would be contagious.

In both sentences, "the patient" and "the virus" would initially be assigned a goal role. The verb "would" causes a reanalysis that violates the theta-reanalysis principle, because the new role of proposition dominates a noun that was initially assigned the goal. However, intuition suggests that the garden path associated with (19a) is substantially reduced or perhaps even avoided in (19b), where semantic information indicates that "virus" is an unlikely goal for "warned". Intuition also suggests that the garden path associated with (19a) can be avoided in a context that supplies a likely *goal*, as is illustrated in (20):

- 20. The nurses started to come into the room but they stopped when the doctor warned the patient was contagious.

Clearly, experimental data investigating these issues is required. However, the data based on intuitions that we have presented suggests that thematic assignment makes use of both semantic and discourse-model information.

CONCLUSION

The evidence that we have reviewed, especially the studies of sentences with long-distance dependencies, provide clear evidence that thematic information is rapidly accessed once a verb is recognised, and that it is used to structure the interpretation of a sentence. In addition, we have reviewed evidence which indicates that thematic information can eliminate garden paths that are frequently attributed to syntactic attachment strategies. This evidence demonstrates that thematic information is rapidly accessed and used in parsing. On the assumption that thematic and syntactic information are distinct types of information, it is natural to ask how they are coordinated. Clearly, thematic processing depends at least partially on the output of syntactic processing, in so far as evaluating the fit of a constituent to a particular role depends upon having correctly parsed the constituent.

Also, thematic processing and syntactic processing clearly interact, in that syntactic information can be used to revise an incorrect thematic assignment, and vice versa. Our reading of the current literature is that there is evidence that thematic information can be used to select among competing syntactic analyses, on the assumption that there is a certain degree of (perhaps lexically based) parallelism in the system. We find little or no evidence suggesting that thematic analysis allows the processing system to bypass syntactic analysis. Likewise, there is no conclusive evidence that syntactic structures are actually proposed on the basis of earlier thematic commitments, although we would not want to rule out this latter possibility.

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