

# MEMORY-BASED LANGUAGE PROCESSING: Psycholinguistic Research in the 1990s

*Gail McKoon and Roger Ratcliff*

Department of Psychology, Northwestern University, Evanston, Illinois 60208;  
e-mail: g-mckoon@nwu.edu

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## ABSTRACT

There are two main domains of research in psycholinguistics: sentence processing, concerned with how the syntactic structures of sentences are computed, and text processing, concerned with how the meanings of larger units of text are understood. In recent sentence processing research, a new and controversial theme is that syntactic computations may rely heavily on statistical information about the relative frequencies with which different syntactic structures occur in the language. In text processing, recent research has focused on what information the words and ideas of a text evoke from long-term memory quickly, passively, and at low processing cost. Research in both domains has begun to use the information that can be obtained from large corpora of naturally occurring texts.

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## Introduction

I was still staring at the portrait when a door opened far back under the stairs. It wasn't the butler coming back. It was a girl.

She was twenty or so, small and delicately put together, but she looked durable. She wore pale blue slacks and they looked well on her. She walked as if she were floating. Her hair was a fine tawny wave cut much shorter than the current fashion of pageboy tresses curled in at the bottom. Her eyes were slate-gray, and had almost no expression when they looked at me. She came over near me and smiled with her mouth and she had little sharp predatory teeth, as white as fresh orange pith and as shiny as porcelain. They glistened between her thin too taut lips. Her face lacked color and didn't look too healthy.

"Tall, aren't you?" she said.

These sentences are from the beginning of *The Big Sleep* by Raymond Chandler (1939). They convey a "narrative world" (Gerrig 1993)—they convey atmosphere and emotion, place and time, and they portray the girl in rich complexity. Moreover, all this is accomplished with no apparent effort on the part of the reader. Whatever we do to experience this narrative world, beyond reading the 144 individual words of the 12 sentences, little of it is available to conscious awareness. It is the job of psycholinguistic research to describe and explain how our experience of passages like this one from *The Big Sleep* comes about.

Psycholinguistics as we know it today began about 35 years ago (e.g. Miller & Isard 1963). Since then, subfields have coalesced, each formulating its own favorite questions about language processing, and many things have been learned in the course of attempts to answer these questions. But it is a fair summary to say that most of what has been learned does not address the central issue of how readers come to experience narrative worlds. More optimistically, however, current theoretical ideas and empirical methods show promise of setting the stage to begin exploration of this issue.

The largest division among the different subfields of psycholinguistics is the one between "text processing" research and "sentence processing" research. In the 1960s, psycholinguistics was an effort to document the psychological reality of the syntactic theory proposed by Chomsky (see Fodor et al 1974). Around 1970, rejecting the overemphasis on syntax, a number of researchers began to study meaning (e.g. Anderson & Bower 1973, Bransford & Franks 1971, Kintsch & Keenan 1973, Norman et al 1975). As the study of meaning grew, so the objects of interest grew from the meanings conveyed by a single sentence to the interconnecting and interacting meanings conveyed by larger texts, paragraphs, and stories, and the research came to be known as "text processing" research (or, sometimes, "discourse processing" research). Meanwhile, research continued on how the syntactic structure of a sentence is

computed, and because syntactic processes are assumed to operate at the sentence level, it came to be known as “sentence processing” research.

The text processing and sentence processing domains are almost entirely separate from each other. They have separate journals (e.g. *Discourse Processes* and *The Journal of Psycholinguistic Research*) and separate conferences (e.g. the Society for Text and Discourse conference and the CUNY Sentence Processing conference). The research questions are different, and the methods used to answer the questions show little significant overlap.

In the past five years, both domains have witnessed major additions to the collection of theoretical ideas guiding research. In text processing, new consideration has been given to fast, passive, parallel retrieval processes that can make multiple complexities of meaning available to comprehension processes quickly and at low cost. In sentence processing, the new idea is that the frequency with which a particular syntactic structure occurs in natural language may be a powerful determinant of how easy it is to process. Neither of these new ways of thinking about language processing offers any immediate solution to the problem of how Raymond Chandler’s words convey so much about the girl introduced at the beginning of *The Big Sleep*, but both may represent some progress in an appropriate direction. In the sections below, these ideas are described and, as a by-product of the description, current work in text processing is contrasted with current work in sentence processing. The last section reviews the possibilities offered to the study of language by a new tool—large corpora of naturally occurring text.

### *Text Processing and Resonance*

In the 1970s and 1980s, most text processing experiments were concerned with whether some particular kind of inference was encoded during reading. If a fish swam under a rock and a turtle was sitting on the rock, does the reader encode that the fish swam under the turtle (Bransford et al 1972)? If a janitor sweeps the floor, does the reader understand that he uses a broom (Corbett & Doshier 1978)? If an actress falls from a 14-story building, does the reader understand that she will very likely die (McKoon & Ratcliff 1986)?

Sorting out the results of many such experiments led to an enhanced appreciation of what turned out to be a crucial methodological issue. The procedures used in most early experiments did not allow inferences that were generated at the time of reading to be distinguished from inferences that were generated at the time of the inference test. Suppose, for example, that after studying a list of sentences, subjects were given a list of words and asked to recall the sentence that went with each word. Given the word “broom,” for instance, the sentence to recall might have been “the janitor swept the classroom.” Recall of the sen-

tence could occur either because the subject had generated the connection between “broom” and the sweeping sentence when the sentence was read or because the subject generated the connection at the time the word “broom” was given in the recall test (see Corbett & Doshier 1978).

In response to this problem, experimenters moved to procedures by which inferences could be unequivocally attributed to processes that occurred during reading (e.g. Corbett & Chang 1983). To make the move, two theoretical ideas were borrowed from research on memory. The first was Tulving's (1974) notion of cue-dependent retrieval: A cue evokes information from memory directly and selectively; that is, it directly evokes traces of those past events of which it was a part. The second was Posner's (1978) separation of fast automatic cognitive processes from slower strategic ones. These two ideas in combination led to the use of speeded, single-word recognition as a procedure to examine inference processes. In a typical experiment, subjects read a sentence (or longer passage) and then, after some delay, one or more single test words are presented. For each test word, subjects are asked to make a recognition decision, that is, they are asked to decide whether the test word had appeared in the sentence, and they are asked to indicate their decision as quickly as possible. It is assumed that the recognition decision is based on cue-dependent retrieval: If the test word and/or its meaning was encoded as part of the studied sentence, then the test word will quickly evoke the information encoded from the sentence, allowing a fast positive response to the test word. For example, given the sentence “the janitor swept the classroom,” the test word “janitor” should quickly evoke the information from the sentence, and there should be a fast positive response. If an inference was encoded about the janitor sweeping with a broom, then “broom” as a test word should also quickly evoke the information from the sentence, leading to a fast positive response, a response that would be an error because “broom” did not actually appear in the sentence (for discussion of slow responses and the use of deadline methods to ensure fast responses, see McKoon & Ratcliff 1989b). The important point for interpretation of the results of recognition experiments is that, following Posner, fast responses are assumed to come from automatic processes, processes that are not under the subject's strategic control. Because the processes are not under strategic control, it is further assumed that responses reflect information that was encoded during reading, not information that was constructed by slower strategic processes occurring at the time of the test.

Applying this reasoning, experiments looked more analytically than had been done in the past at what kinds of information were encoded during reading in circumstances in which subjects were given no special goals to encode any particular types of information. One outcome was the conclusion that in the absence of special goals, relatively few of the inferences that had been ear-

lier studied so extensively were actually generated during reading. This conclusion was summarized by the “minimalist hypothesis” (McKoon & Ratcliff 1992a), the hypothesis that the only inferences encoded during reading, in the absence of special strategies, are those that depend on information that is easily and quickly available from memory and those that are needed to make the text that is being read locally coherent. This conclusion was not shared by all text processing researchers, and considerable debate ensued (e.g. Graesser et al 1994, Graesser & Zwaan 1995, McKoon & Ratcliff 1995, Singer et al 1994). Efforts to map out what kinds of nonminimalist inferences are generated during reading, especially those that create causal links between pieces of text information, continue (e.g. van den Broek et al 1996).

Although the new focus on fast, parallel, and passive evocation of information from memory was first reflected in new experimental procedures, a more important consequence has been its reflection in theoretical thinking. This change is part of a broader movement in cognitive psychology. In memory research, the global memory models (Gillund & Shiffrin 1984, Hintzman 1986, Murdock 1982) account for many and various empirical findings with direct access retrieval processes that are global, passive, fast, and automatic, explicit implementations of cue-dependent retrieval. In text processing, part of the minimalist hypothesis (McKoon & Ratcliff 1992a) is that not only a test word but also every word, concept, and proposition in a text evokes information from memory directly, globally, and quickly. Kintsch’s (1974) model for the representation of meaning in propositional structures has acquired processes (Kintsch 1988) by which information from long-term memory is made available by fast, passive retrieval processes. A crucial aspect of this new focus is that attention is directed at what is evoked from memory by a text rather than only at what inferences need to be generated to understand the text.

There has also been a change from interest only in the content of inferences to increased interest in the processes by which they are generated—an interest in processing issues as well as representational issues. In the 1970s and 1980s, text experiments could be summarized by a list of the conceptual contents of inferences: for example, instrumental (“broom” for sentences about sweeping), causal connections (“because” to connect events and their consequences; Keenan et al 1984, Trabasso & van den Broek 1985), and predictable events (“death” from falling from a high building). The 1990s have begun to see more thought given to separating those inferences that are generated quickly and passively from long-term memory from those inferences that require strategic processing by the reader. (For reviews and examples of this research, see Britton & Graesser 1996, Gernsbacher 1994, van den Broek et al 1995, Noordman et al 1992, Noordman & Vonk 1992.)

The new focus has been signaled with key terms. We (McKoon et al 1996) use the words “memory based” text processing to describe the idea that a text’s words, concepts, and propositions are understood in terms of the information they evoke from memory, individually and in combination. Myers, O’Brien, and colleagues (Albrecht & O’Brien 1993, 1995; Albrecht & Myers 1995; Albrecht et al 1995; Huitema et al 1993; Klin & Myers 1993; Myers et al 1994; O’Brien & Albrecht 1992) have brought back the term “resonance,” which describes Tulving’s original notion of cue-dependent retrieval (Lockhart et al 1976, Ratcliff 1978, Tulving 1974).

The long-term memory information that a piece of text evokes can be either general knowledge (of all kinds—lexical knowledge, world knowledge, semantic memory knowledge) or information from earlier parts of the text itself (McKoon & Ratcliff 1992a). Myers, O’Brien, and their colleagues have presented a number of experiments designed to demonstrate directly that pieces of information in a text evoke one another across large distances in the surface structure of the text. For example, in a story from an experiment by Myers et al (1994), a character refused to eat anything fried or cooked in grease but later ordered a cheeseburger and fries. These two pieces of information were separated from each other in the story, yet it appeared that associations among the concepts “fried,” “cooked,” “grease,” “cheeseburger,” and “fries” served to connect the two pieces of information together so that readers noticed the inconsistency. In a similar vein, we (Greene et al 1994, McKoon et al 1996; see also Grosz & Sidner 1986, O’Brien et al 1995) have shown that a pronoun can be understood to refer to a character that has not been mentioned recently in the text if the pronoun is used in a context in which the character has already been evoked by means of association to earlier encoded textual information.

Perhaps the most important feature of resonance is that the focus of attention turns to the question of what it is that a word, concept, or proposition evokes from general knowledge. With this focus, questions about whether one or another inference is required to understand a text become of secondary importance. Optimistically, the incorporation of information provided by general knowledge into the larger picture of meaning conveyed by a text, into the meaning that is constructed through a consortium of processes, might be one small step toward discovery of how it is that Chandler makes us see the girl in *The Big Sleep* so clearly.

Two different lines of research can be used to illustrate the shift toward general knowledge being investigated as a central component of comprehension: One is concerned with what information individual words evoke from general knowledge, and several examples of experiments of this type are reviewed first. The other is concerned with what information is evoked by combinations of words.

Individual words have, of course, always been assumed to evoke their meanings. What is especially new is the possibility that individual words, within themselves, also evoke structural information about their relations with the concepts that surround them. Consider the verb “cram,” a member of the class of locative verbs. Not only does it have the meaning of pushing lots of stuff into some space, it also carries implications about how affected the space is by the cramming, implications that depend on the syntactic structure in which it is used (Rappaport et al 1987). To “cram the closet with boxes” suggests that the closet is quite full; to “cram boxes into the closet” suggests that it is not so full, that more stuff might still be crammed in. Empirical evidence indicates that readers understand the implications of use of verbs of this class (McKoon & Ratcliff 1989a).

Another example is verbs of implicit causality. Although these have been studied by psycholinguists for some time (e.g. Garvey & Caramazza 1974), recently their contributions to immediate comprehension have been investigated. Verbs of implicit causality can be divided according to whether they attribute causality to their subject argument or to their object argument. “Annoy,” for example, attributes causality to its subject argument; if John annoys Mary, one normally assumes that the cause of the annoyance is some property or action of John’s. “Admire,” on the other hand, attributes causality to the argument in the object position; if Bill admires Nancy, it is usually some quality of Nancy’s that causes the admiration. Recent work indicates that causal verbs evoke lexical information about which of their arguments is likely to be causal, that they do so quickly and passively, and that the causal argument becomes more salient than the other argument (Garnham et al 1996, Greene & McKoon 1995).

The examples just described illustrate what could become a profitable trend in psycholinguistics in the 1990s—the convergence of meaning and syntactic structure in empirical research (see also Marslen-Wilson et al 1994). The lexical structures that are part of the evoked information about locative verbs like “cram” and verbs of implicit causality like “admire” are structures that are as important to syntactic processing as they are to comprehension of meaning. This strand of converging research appears again below in discussion of current work in sentence processing.

The shift in attention toward what information is evoked from general knowledge by the words, concepts, and propositions of the text is also apparent in research about combinations of words. Research on combinations of words is essential because it is combinations of words that make up context, and “context” is what surrounds the reader in a narrative world. The idea that one word “primes” or “activates” words related to it dates back to Meyer & Schvaneveldt’s early demonstration in 1971. In both cognitive psychology in

general and psycholinguistics in particular, the idea has been updated to combinations of words. In the global memory models, combinations of words (e.g. “mint money”) are familiar to the extent that the strengths of the connections between them in memory are high (McKoon & Ratcliff 1992b; McNamara 1992a,b, 1994a,b; Ratcliff & McKoon 1988, 1994, 1995). In research on semantic memory, it has been shown that which members of a category are evoked by a category label (e.g. “animal”) depends on the sentence context in which the label is given (e.g. “riding an animal” versus “milking an animal”; Roth & Shoben 1983). In text processing, one example of this trend is Kintsch’s (1988) context integration model. The words of a text are assumed to activate, in what can be described as a promiscuous fashion (Keenan & Jennings 1995), all the concepts in memory to which they are associated. Then activation recycles among all the concepts, those from the text and those from memory, in such a way that concepts with multiple strong connections become the most highly activated, and concepts with few and weak connections drop out. The result is that the meaning represented for the text includes concepts from long-term memory that are associated with combinations of concepts in the text; in other words, the meaning represented for the text reflects context. Another example is HAL, Burgess’s (Burgess & Lund 1995) model for semantic relations. In this model, words are semantically related to the extent that they have co-occurred in large corpora of text (e.g. 100 million words of on-line computer conversations). This measure of semantic relatedness predicts the ease of processing of word combinations in sentences, specifically noun-verb combinations (Burgess & Lund 1995).

All of the examples just discussed illustrate the move toward investigation of memory-based comprehension processes. The trend is encouraging because combining information from general knowledge and information from the text in a fast passive way must be at least a part of the experience of narrative worlds like Chandler’s. But there is a long way to go. One thing that needs to be worked out is how the structures implicit in single words like “cram” come to be integrated with the rest of the information in a text. Another problem is how to translate the idea of combinations of words evoking general knowledge into a satisfying description of the context evoked by a text and how it affects comprehension processes. Still another problem is that little attention has been paid to what emotional information is evoked during reading (but see Hirsch & Matthews 1997).

Not only is the resonance idea incomplete, there are also serious conceptual problems. Here, four are listed. First, text comprehension is much more than the product of resonance between combinations of the words of a text (elephant) and information in long-term memory. The word “elephant” in the last sentence evokes nothing relevant to the sentence but the meaning of “ele-



phant” itself. It does not combine or interact with the other elements of the sentence to contribute to the understanding of the sentence, yet it will probably be remembered better than the other elements. Likewise, for the girl in *The Big Sleep*, “predatory teeth” does not combine in resonance with her being “small,” “delicate,” and “floating,” yet “predatory teeth” probably has more to do with our picture of her than the other concepts that are more typically associated with beautiful girls. How to integrate the resonance idea with the prominence of never before or rarely encountered conceptual combinations is a problem that has not yet been adequately formulated.

Second, passive resonance must somehow be related to processes that yield active and conscious engagement of the reader (Gerrig 1993, Graesser et al 1994, Singer et al 1994). If there is some process by which combinations of Chandler’s words passively associate “beautiful” with the girl, and some other process gives prominence to her having predatory teeth, then still another process must lead to the reader’s strong feeling that she will be trouble for the Bogart-type hero of the story. In general, what is evoked passively from long-term memory must somehow lay a foundation that makes possible conscious involvement on the part of the reader.

Third, comprehension processes are able to circumvent passive resonance. Somehow, readers know and can keep separate which pieces of information are relevant to which circumstances and characters in a story. If we were to read on in *The Big Sleep*, comprehension processes would be able to keep separate what the reader is told about the girl from what the detective hero can know in the circumstances of the story (Gerrig et al 1997). By passive resonance, any mention of the girl ought to evoke all that we know about her in all circumstances (McKoon & Ratcliff 1992a), yet the reader knows which things the reader can know that the hero cannot.

In another way, however, the flow of information from long-term memory cannot be turned off. No matter how many times we read *The Big Sleep*, no matter how well we know what is going to happen, we still experience suspense and emotion; we still experience *The Big Sleep*’s narrative world. An experiment by Gerrig (1989) can be used to make the dilemma clear. In the experiment, subjects read texts that outlined circumstances that might have prevented well-known historical events from occurring. For example, one text outlined Washington’s reasons for initially refusing to accept nomination as a candidate to become the first president of the United States. On the one hand, this information should evoke from long-term memory the well-known fact that Washington was the first president. On the other hand, according to Gerrig’s empirical results, the pieces of information in the text about refusal to accept a nomination and the reasons for not doing so raise, in their combinations of meanings, some amount of interference. In the context of the story, the inter-

ference from these pieces of the text cannot be overridden by the sure knowledge that Washington did become president. That is, the comprehension system has both the information that, with absolute certainty, Washington was president as well as some amount of interference in verifying the proposition that Washington was president.

Overall, it is a reasonable expectation that the resonance, or memory-based retrieval, idea will lead to significant advances in research. Certainly, some part of the power of language must come from the facility with which words and the combinations of words that make up context evoke information and emotion from memory. However, we currently know almost nothing about the boundaries between resonance and other comprehension processes. Delineating the tasks served by memory from other, more constructive processes is an important task for future research.

### *Sentence Processing*

The central question that drives sentence processing research is how the human language processing system computes the syntactic representations of sentences. By definition, this area of research is not concerned with the narrative world readers experience when reading Chandler. Nevertheless, recent ideas and empirical findings in sentence processing show promise of being useful to explorations of readers' experiences.

From the 1970s (Bever 1970, Frazier 1978, Frazier & Fodor 1978) until the early 1990s, most research in sentence processing was guided by the hypothesis that the syntactic processing of a sentence precedes semantic processing and occurs in isolation from it (Fodor 1983). Empirical work concentrated on demonstrating the psychological validity of this claim for sentences with various types of syntactic structures. Recently, however, a competing viewpoint has been strongly advanced: The processes that compute the syntactic structures of sentences make use of "constraints" from all types of information, including semantic information and information about the frequencies with which syntactically relevant structures occur in the language (MacDonald et al 1994, Trueswell et al 1994).

The types of linguistic information used by constraint-based processes are assumed to be stored in a lexicon, the entry for each word in the lexicon having stored with it the word's possible arguments, its possible syntactic structures, and the frequencies with which the arguments and syntactic structures occur for that word. Arguments are the participant roles that can be associated with a word; for example, "eat" has associated with it an agent role, the entity who does the eating, and a theme role, the entity that gets eaten. "Eat" can participate in two possible syntactic structures, either with a subject and an object (the transitive use) or with only a subject (the intransitive use). With each argu-

ment and each syntactic structure is associated the frequency with which it occurs with “eat.” So, for example, for the sentence “John ate,” the lexical entry for John includes (among other things) the information that “John” is very frequently an agent noun phrase, and the lexical entry for “ate” includes that “ate” can take a noun phrase as its agent and that “ate” is more frequently used in the transitive than in the intransitive construction. The absence of a direct object in the sentence would force the intransitive construction, and the fact that it is less frequent would lead to a slight cost in processing time.

Many aspects of how a constraint-based model would actually work are unclear. Frazier (1995; see also McKoon et al 1993) has pointed out the nontrivial nature of the problem of building syntactic structures for whole sentences when all the processor has to work with are the chunks of syntax stored in the lexicon for individual words. Until a simulation model can be developed to actually produce whole-sentence syntactic structures for a large variety and number of words and constructions, satisfactory evaluation of the constraint-based approach is not possible. However, the aim here is not to present a critique of constraint-based models but rather to compare advances in the sentence processing domain to advances in the text processing domain.

In virtually all sentence processing research, it is implicitly assumed that each word in a sentence evokes all the linguistic information stored about that word in the lexicon. No discussion or investigation is devoted to the processes by which the information is evoked nor to the issue of how all the evoked information is stored and/or kept available in the course of computation. Nevertheless, the theme that a word, within itself, evokes not just its meaning but also complex structures of interrelated entities and meanings (see Stevenson 1993) is the same theme discussed above as being prominent in text processing research.

However, how this theme is carried through is considerably different in sentence processing research than in text processing research. One critical difference is that text processing researchers treat combinations of words as well as individual words as capable of evoking information from memory. “Animals” in the context of “giving milk” evokes different information than either “animals” in the context of “riding” or “animals” alone. In contrast, in sentence processing research, for the sentences “a cow milked” and “a farmer milked,” exactly the same information is evoked for “milked” (but see Britt et al 1992, Taraban & McClelland 1988). The point is that for text processing, the context in which a concept appears controls the information evoked from memory; for sentence processing, the context in which a concept appears does not affect what is evoked from the lexicon (for related discussion of this issue with respect to constraint-based models, see Frazier 1995). This contrast is a fundamental theoretical difference in how the two fields of research regard the processes by which information is retrieved from memory.

There is also a critical gap in the domains of study between where sentence processing research leaves off and text processing research begins. In sentence processing research, there is typically little consideration given to the consequences of syntactic structures for understanding meaning. Consider, for example, the verbs of implicit causality. Text processing studies of these verbs make heavy use of the notions that verbs have associated argument structures, and that the verbs' agents are likely the syntactic subjects of their sentences and that the experiencers of the verbs' actions are likely in object position. This sounds like syntactic, that is, sentence processing, research. But in sentence processing research, there is nothing in the information that is assumed to be evoked from the lexicon by verbs that would indicate which argument is likely to be the cause of the action denoted by the verb.

How the gap between typical sentence processing research and meaning might be addressed is illustrated by a set of studies by Birch & Garnsey (1995; see also McKoon et al 1993). Their studies used sentences like "there was this painting that was on display in the museum," in which "painting" is put into focus by "there-insertion," and they found that in-focus concepts were better remembered than out-of-focus concepts. This is a finding about the consequences for comprehension of meaning of one aspect of syntax. Much more research of this type needs to be undertaken. Specifically, how does the syntactically relevant information encoded in the lexicon for individual words (as opposed to specialized structures like there-insertion) affect comprehension of meaning and get incorporated into meaning?

In sum, the goal of sentence processing research has usually been to develop models that can produce the syntactic structures of sentences. The goal has not been formulated to be the development of models that produce all of the syntactic information that is useful for understanding the meanings of sentences. Either semantically relevant syntactic information needs to be added to the information used by the processors of current syntactic models or new models need to be developed to link the products of current parsers to semantically relevant syntactic information. The aim would be to explore how syntax puts together and organizes concepts in context to make a contribution to the overall meaning of a text. It is likely that part of the power with which Chandler makes us "see" the girl at the beginning of *The Big Sleep* comes from the way he uses syntactic structures to organize the information he presents.

There is an additional difference between text processing research and sentence processing research that should be mentioned. Typically, the goal of sentence processing research is to develop models that can produce the *correct* syntactic structures of sentences. This is sometimes stated explicitly (MacDonald et al 1994, p. 686), and it is almost always implicit in designs of experiments and discussions of theoretical interpretations of data. The underlying as-

sumption is that human comprehension processes produce a correct and complete syntactic interpretation of a sentence (but see Frazier & Clifton 1996). In contrast, the history of text processing research has been, in the main, an effort to find out what is understood as well as how it is understood. Therefore, for any piece of implicit information, it is always assumed that there is some possibility that a reader does not correctly or completely comprehend it. The consequences of this difference in assumptions show up empirically. In text processing research, even when processing time is the measure of main interest, there is usually some check to determine whether or not subjects actually understand correctly whatever aspect of the text is under investigation. For example, it might be hypothesized that “Jack threw a snowball at Phil, but he ducked” was more difficult to comprehend than “Jack threw a snowball at Phil, but he missed.” More difficult comprehension would be predicted to lead to longer reading times, but in addition, relative success of comprehension of the pronoun would be measured by recognition response times for the single probe word “Jack” or “Phil” presented immediately following the sentence (see, for example, Corbett & Chang 1983). In contrast, in sentence processing research, processing time is the most common measure, and there is usually no check for comprehension accuracy for the aspect of the text under investigation.

Text processing research, at least implicitly, allows subjects the possibility of engaging in speed/accuracy trade-offs. Subjects might read faster but understand less, or they might read slower and understand more. Or they might understand so little that they skip rapidly through the sentence. For instance, most readers of this chapter will read “colorless green ideas sleep furiously” very quickly but claim that they understood little. Only with some measure to check comprehension can the experimenter know the difference between fast reading with excellent comprehension and fast “reading” with little comprehension.

Although the differences just outlined between text processing research and sentence processing research are important ones, there are at least hints of shared interests between the two domains, mainly in the interplay between syntactic structures and the contributions they might make to comprehension of meaning. Payoffs from research in this area might lead to progress on a wide range of different issues in text processing, issues for which a syntactic contribution may not have been contemplated previously.

### *Large Corpora*

For neither text processing nor sentence processing research can a review of recent developments neglect the increasing availability and use of large corpora of naturally occurring samples of language. For example, the Penn Treebank project (Marcus et al 1993) provides one widely available (but expensive) corpus of over three million words of text from the *Wall Street Journal*.

There are a number of different ways corpora can be used, and they are briefly listed here.

One use to which corpora are put is the calculation of statistics about frequencies of occurrence of linguistic constructions. For syntactic constructions, frequencies of occurrence assume central theoretical importance for constraint-based models of syntactic processing, as mentioned above. The constructions easiest to process are assumed to be those that occur most frequently in the language. For example, a verb will be easier to process in a transitive construction than in an intransitive construction if the verb occurs more frequently as transitive.

The assumption of such a large explanatory role for statistical information is controversial (see Frazier 1995). Consider how the processing of verbs of implicit causality might be explained. Empirical data (Caramazza et al 1977) show that, when presented with an incomplete sentence like "John admired Mary because...", subjects tend to respond with a completion that attributes causality to the object (as in "because she is so smart"). Most theorizing about this class of verbs has postulated that the linguistically relevant structure encoded in lexical memory as part of a causal verb's meaning includes information about causality, such as which argument is the direct initiator of the action described by the verb. It is also assumed that the initiator argument is given greater prominence in the representation of the sentence constructed by comprehension processes, and it is assumed that it is this prominence that leads to the initiator being chosen as the subject of a "because" clause following the verb as well as to a number of other linguistic and psycholinguistic effects (Edwards & Potter 1993, Greene & McKoon 1995, McKoon et al 1993). Replacing this chain of theoretical constructs with the simple explanation that the argument of the verb that will be used as the subject of the "because" clause is the one that has been used most frequently as the subject of the "because" clause in the past is unsatisfactory for many researchers.

In text processing, the role of statistical information has been different. The frequencies of co-occurrence of conceptual combinations are computed as the number of times two (or more) words, such as "mint" and "money," occur in the same "window" of text together, where the window might be defined as some number of consecutive words or a whole sentence. Frequencies of co-occurrence fit naturally with the text processing notion that concepts and combinations of concepts in a text evoke all the information with which they are associated in long-term memory. Frequencies of co-occurrence provide a natural empirical measure of what information is likely to be evoked during reading (Burgess & Lund 1995, Landauer & Dumais 1997). How the associations reflected in co-occurrence frequencies are handled theoretically is a separable issue from their empirical use: A theory could assume that frequencies of co-

occurrence are represented directly in memory, or it could be assumed that the frequencies are derived from some other theoretical construct (such as relatedness in terms of some type of semantic features).

Setting theoretical uses aside, large corpora are extremely valuable for other purposes. Perhaps most important, they provide examples of linguistic constructions. If it is hypothesized that some linguistic construction is disallowed in English, then finding examples of the construction in corpora provides disconfirmation of the hypothesis. If the theorist seeks to find the range of uses of some word, corpora can provide the relevant examples. For example, it is often said that the verb “put” requires as arguments both an object to be put and a place to put it. However, a search of any large corpus will quickly turn up such uses as “put the question,” “put it” (as in “put it succinctly”), “put into question,” “put it together,” “put on” (as in “put on a show”), “put an end” to something, and so on. A theorist seeking a theoretical description of the use of “put” would need to consider these examples in addition to the more typical uses.

Finally, it should not be overlooked that corpora can be a source of materials for use in experiments. In both text processing and sentence processing research, the criticism is often made that the materials used in some experiment are not natural, and therefore any conclusions drawn from the results of the experiment are suspect. Basing experimental materials on corpus examples obviates this criticism.

### *Conclusion*

Obviously, we are a long way from solving the problem of how readers enter narrative worlds. As with any research domain, psycholinguistic research has oscillated over time between central questions and more peripheral ones. During some periods, the major topics have been methodological ones. It could be said, however, that considerable expenditure of energy on methodology made possible current attempts at progress on more substantive issues. On another front, convergence between the currently separate domains of syntactic processing research and research more concerned with meaning might pay off in the future. We may come to see more research more directly related to the central questions of what readers understand, what they experience, and how understanding and experience come about.

Four salient avenues that might lead to significant progress present themselves: investigating interactions between syntax and meaning, investigating interactions between passively retrieved information from long-term memory and newly constructed information, investigating how emotions are evoked by texts, and testing theoretical ideas of all sorts against empirical data offered by

large corpora of naturally occurring text. What progress will actually be made is an open question: Language and how it is understood present problems as difficult as any in psychology.

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#### Literature Cited

- Albrecht JE, Myers JE. 1995. The role of context in accessing distant information during reading. *J. Exp. Psychol.: Learn. Mem. Cogn.* 19:1459–68
- Albrecht JE, O'Brien EJ. 1993. Updating a mental model: maintaining both local and global coherence. *J. Exp. Psychol.: Learn. Mem. Cogn.* 19:1061–70
- Albrecht JE, O'Brien E. 1995. Goal processing and the maintenance of global coherence. In *Sources of Coherence in Reading*, ed. RF Lorch Jr, EJ O'Brien. Hillsdale, NJ: Erlbaum
- Albrecht JE, O'Brien E, Mason R, Myers J. 1995. The role of perspective in the accessibility of goals during reading. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 364–72
- Anderson JR, Bower GH. 1973. *Human Associative Memory*. Washington, DC: Winston
- Bever TG. 1970. The cognitive basis for linguistic structure. In *Cognitive Development of Language*, ed. JR Hayes. New York: Wiley
- Birch G, Garnsey S. 1995. The effect of focus on memory for words in sentences. *J. Mem. Lang.* 34:232–67
- Bransford JD, Barclay JR, Franks JJ. 1972. Sentence memory: a constructive versus interpretive approach. *Cogn. Psychol.* 3: 193–209
- Bransford JD, Franks JJ. 1971. The abstraction of linguistic ideas. *Cogn. Psychol.* 2: 331–50
- Britt MA, Perfetti CA, Garrod S, Rayner K. 1992. Parsing in discourse: context effects and their limits. *J. Mem. Lang.* 31:293–314
- Britton B, Graesser A, eds. 1996. *Models of Understanding Text*. Hillsdale, NJ: Erlbaum
- Burgess C, Lund K. 1995. Automatic extraction of high-dimensional semantics from large corpora: a model of human syntactic processing constraints. In *Proc. Annu. CUNY Conf. Hum. Sent. Process.*, 8th
- Caramazza A, Grober E, Garvey C, Yates J. 1977. Comprehension of anaphoric pronouns. *J. Verbal Learn. Verbal Behav.* 16: 601–9
- Chandler R. 1939. *The Big Sleep*. New York: Avenel
- Corbett AT, Chang FR. 1983. Pronoun disambiguation: accessing potential antecedents. *Mem. Cogn.* 11:283–94
- Corbett AT, Doshier BA. 1978. Instrument inferences in sentence encoding. *J. Verbal Learn. Verbal Behav.* 17:479–91
- Edwards D, Potter J. 1993. Language and causation: a discursive action model of description and attribution. *Psychol. Rev.* 100:23–41
- Fodor JA. 1983. *The Modularity of Mind*. Boston: MIT Press
- Fodor JA, Bever TG, Garrett MF. 1974. *The Psychology of Language: An Introduction to Psycholinguistics and Generative Grammar*. St. Louis: McGraw-Hill
- Frazier L. 1978. *On Comprehending Sentences: Syntactic Parsing Strategies*. Bloomington: Ind. Univ. Linguist. Club
- Frazier L. 1995. Issues of representation in psycholinguistics. In *Speech, Language, and Communication*, ed. JL Miller, PD Eimas. San Diego, CA: Academic



- Frazier L, Clifton C. 1996. *Construal*. Cambridge, MA: MIT Press
- Frazier L, Fodor JD. 1978. The sausage machine: a new two stage parsing model. *Cognition* 6:291–325
- Garnham A, Traxler M, Oakhill J, Gernsbacher MA. 1996. The locus of implicit causality effects in comprehension. *J. Mem. Lang.* 35:517–43
- Garvey C, Caramazza A. 1974. Implicit causality in verbs. *Linguist. Inq.* 5:459–64
- Gernsbacher M. 1994. *Handbook of Psycholinguistics*. New York: Wiley
- Gerrig RJ. 1989. The time course of sense creation. *Mem. Cogn.* 17:194–207
- Gerrig RJ. 1993. *Experiencing Narrative Worlds*. New Haven: Yale Univ. Press
- Gerrig RJ, Ohaeri JO, Brennan SE. 1997. Illusory transparency. Revisited. manuscript
- Gillund G, Shiffrin RM. 1984. A retrieval model for both recognition and recall. *Psychol. Rev.* 91:1–67
- Graesser A, Zwaan R. 1995. Inference generation and the construction of situation models. In *Discourse Comprehension: Essays in Honor of Walter Kintsch*, ed. CA Weaver, S Mannes, CR Fletcher. Hillsdale, NJ: Erlbaum
- Graesser AC, Singer M, Trabasso T. 1994. Constructing inferences during narrative text comprehension. *Psychol. Rev.* 101: 371–95
- Greene SB, Gerrig RJ, McKoon G, Ratcliff R. 1994. Unheralded pronouns and the management of common ground. *J. Mem. Lang.* 33:511–26
- Greene SB, McKoon G. 1995. Telling something we can't know: experimental approaches to verbs exhibiting implicit causality. *Psychol. Sci.* 6:262–70
- Grosz B, Sidner C. 1986. Attention, intentions and the structure of discourse. *Comput. Linguist.* 12:175–204
- Hintzman D. 1986. "Schema abstraction" in a multiple-trace memory model. *Psychol. Rev.* 93:411–28
- Hirsch C, Matthews A. 1997. Inferences when reading about uncertain emotional events. manuscript
- Huitema JS, Dopkins S, Klin CM, Myers JL. 1993. Connecting goals and actions during reading. *J. Exp. Psychol.: Learn. Mem. Cogn.* 19:1053–60
- Keenan JM, Baillet SD, Brown P. 1984. The effects of causal cohesion on comprehension and memory. *J. Verbal Learn. Verbal Behav.* 23:115–26
- Keenan JM, Jennings TM. 1995. Priming of inference concepts in the construction-integration model. In *Discourse Comprehension: Essays in Honor of Walter Kintsch*, ed. CA Weaver, S Mannes, CR Fletcher, pp. 233–44. Hillsdale, NJ: Erlbaum
- Kintsch W. 1974. *The Representation of Meaning in Memory*. Hillsdale, NJ: Erlbaum
- Kintsch W. 1988. The role of knowledge in discourse comprehension: a construction-integration model. *Psychol. Rev.* 95: 163–82
- Kintsch W, Keenan JM. 1973. Reading rate and retention as a function of the number of propositions in the base structure of sentences. *Cogn. Psychol.* 5:257–74
- Klin C, Myers J. 1993. Reinstatement of causal information during reading. *J. Exp. Psychol. Learn. Mem. Cogn.* 19:554–60
- Landauer TK, Dumais ST. 1997. A solution to Plato's problem: the latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychol. Rev.* 104:211–40
- Lockhart RS, Craik FIM, Jacoby L. 1976. In *Recall and Recognition*, ed. J Brown. London: Wiley
- MacDonald MC, Pearlmutter NJ, Seidenberg MS. 1994. Lexical nature of syntactic ambiguity resolution. *Psychol. Rev.* 101: 676–703
- Marcus MP, Santorini B, Marcinkiewicz MA. 1993. Building a large annotated corpus of English: the Penn Treebank. *Comput. Linguist.* 19:313–30
- Marslen-Wilson W, Komisarjevsky TL, Waksler R, Older L. 1994. Morphology and meaning in the English mental lexicon. *Psychol. Rev.* 101:3–33
- McKoon G, Gerrig RJ, Greene SB. 1996. Pronoun resolution without pronouns: some consequences of memory based text processing. *J. Exp. Psychol.: Learn. Mem. Cogn.* 22:919–32
- McKoon G, Greene SB, Ratcliff R. 1993. Discourse models, pronoun resolution, and the implicit causality of verbs. *J. Exp. Psychol.: Learn. Mem. Cogn.* 19:1–13
- McKoon G, Ratcliff R. 1986. Inferences about predictable events. *J. Exp. Psychol.: Learn. Mem. Cogn.* 12:82–91
- McKoon G, Ratcliff R. 1989a. *Inferences based on lexical information about verbs*. Presented at Annu. Meet. Psychonomic Soc., 30th, Atlanta
- McKoon G, Ratcliff R. 1989b. Semantic association and elaborative inference. *J. Exp. Psychol.: Learn. Mem. Cogn.* 15:326–38
- McKoon G, Ratcliff R. 1992a. Inference during reading. *Psychol. Rev.* 99:440–66
- McKoon G, Ratcliff R. 1992b. Spreading acti-

- vation versus compound cue accounts of priming: mediated priming revisited. *J. Exp. Psychol.: Learn. Mem. Cogn.* 18: 1155–72
- McKoon G, Ratcliff R. 1995. The minimalist hypothesis: directions for research. In *Discourse Comprehension: Essays in Honor of Walter Kintsch*, ed. CA Weaver, S Manes, CR Fletcher. Hillsdale, NJ: Erlbaum
- McKoon G, Ratcliff R, Ward G, Sproat R. 1993b. Syntactic prominence effects on discourse processes. *J. Mem. Lang.* 32: 593–607
- McNamara TP. 1992a. Priming and constraints it places on theories of memory and retrieval. *Psychol. Rev.* 99:650–62
- McNamara TP. 1992b. Theories of priming: I. Associative distance and lag. *J. Exp. Psychol.: Learn. Mem. Cogn.* 18:1173–90
- McNamara TP. 1994a. Priming and theories of memory: a reply to Ratcliff and McKoon. *Psychol. Rev.* 101:185–87
- McNamara TP. 1994b. Theories of priming: II. Types of primes. *J. Exp. Psychol.: Learn. Mem. Cogn.* 20:507–20
- Meyer DE, Schvaneveldt RW. 1971. Facilitation in recognizing pairs of words: evidence of a dependence between retrieval operations. *J. Exp. Psychol.* 90:227–34
- Miller GA, Isard S. 1963. Some perceptual consequences of linguistic rules. *J. Verbal Learn. Verbal Behav.* 2:217–28
- Murdock BB. 1982. A theory for the storage and retrieval of item and associative information. *Psychol. Rev.* 89:609–26
- Myers JL, O'Brien EJ, Albrecht JE, Mason RA. 1994. Maintaining global coherence during reading. *J. Exp. Psychol.: Learn. Mem. Cogn.* 20:876–86
- Noordman L, Vonk W. 1992. Reader's knowledge and the control of inference in reading. *Lang. Cogn. Process.* 7:373–91
- Noordman L, Vonk W, Kempff H. 1992. Causal inferences during the reading of expository texts. *J. Mem. Lang.* 31:573–90
- Norman DA, Rumelhart DE, LNR Research Group. 1975. *Explorations in Cognition*. San Francisco: Freeman
- O'Brien E, Albrecht J, Hakala C, Rizzell M. 1995. Activation and suppression of antecedents during reinstatement. *J. Exp. Psychol.: Learn. Mem. Cogn.* 21:626–34
- O'Brien EJ, Albrecht JE. 1992. Comprehension strategies in the development of a mental model. *J. Exp. Psychol.: Learn. Mem. Cogn.* 18:777–84
- Posner MI. 1978. *Chronometric Explorations of Mind*. Hillsdale, NJ: Erlbaum
- Rappaport M, Laughren M, Levin B. 1987. *Levels of Lexical Representation*. Lexicon Proj. Work. Pap., MIT
- Ratcliff R. 1978. A theory of memory retrieval. *Psychol. Rev.* 85:59–108
- Ratcliff R, McKoon G. 1988. A retrieval theory of priming in memory. *Psychol. Rev.* 95:385–408
- Ratcliff R, McKoon G. 1994. Retrieving information from memory: spreading activation theories versus compound cue theories. *Psychol. Rev.* 101:177–84
- Ratcliff R, McKoon G. 1995. Sequential effects in lexical decision: tests of compound cue retrieval theory. *J. Exp. Psychol.: Learn. Mem. Cogn.* 21:1380–88
- Roth EM, Shoben EJ. 1983. The effect of context on the structure of categories. *Cogn. Psychol.* 15:346–78
- Singer M, Graesser AC, Trabasso T. 1994. Minimal or global inference in comprehension. *J. Mem. Lang.* 33:421–41
- Stevenson S. 1993. A competition-based explanation of syntactic attachment preferences and garden path phenomena. In *Proc. Annu. Meet. Assoc. Comput. Linguist.* 31st. Palo Alto, CA: Assoc. Comput. Linguist.
- Taraban R, McClelland J. 1988. Constituent attachment and thematic role assignment in sentence processing: influences of content-based expectations. *J. Mem. Lang.* 27:592–632
- Trabasso T, van den Broek P. 1985. Causal thinking and the representation of narrative events. *J. Mem. Lang.* 24:612–30
- Trueswell JC, Tanenhaus MK, Garnsey SM. 1994. Semantic influences on parsing: use of thematic role information in syntactic disambiguation. *J. Mem. Lang.* 33: 285–318
- Tulving E. 1974. Cue-dependent forgetting. *Am. Sci.* 62:74–82
- van den Broek P, Risdan K, Fletcher CR, Thurlow R. 1996. A 'landscape' view of reading: fluctuating patterns of activation and the construction of a stable memory representation. In *Models of Understanding Text*, ed. BK Britton, AC Graesser. Hillsdale, NJ: Erlbaum
- van den Broek P, Risdan K, Husebye-Hartmann E. 1995. The role of readers' standards for coherence in the generation of inferences during reading. In *Sources of Coherence in Reading*, ed. RF Lorch Jr, EJ O'Brien. Hillsdale, NJ: Erlbaum