4 Memory Models, Text Processing, and Cue-Dependent Retrieval

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An important concept championed by Tulving (1974, 1983) is the notion that retrieval conditions are critical in assessing memory: Memory cannot be assessed independently of retrieval, and a theoretical description of memory cannot be formulated without specification of the retrieval environment. In this chapter, we illustrate the profound influence that this view has had on the development and testing of memory models, and we show how the cue dependent view has begun to have an influence on research concerned with text processing.

MEMORY MODELS

There is a new generation of memory models that are more ambitious than models that were developed in the 1970s (with the notable exceptions of HAM [Anderson & Bower, 1973] and ACT [Anderson, 1976]). The new models attempt to deal with a range of phenomena across experimental paradigms at a level of detail that in the past has been found only in extremely limited models designed for a single task. In this chapter, five models that vary in their commitment to cue-dependent retrieval are considered and evaluated on the dimension of encoding/retrieval interaction. In models dealing with recall and recognition, the treatment of results from the recognition failure procedure is described because these results provide serious problems for superficial accounts of recognition and recall. In the models that do not deal with recall and recognition, the treatment of cue-target interactions is discussed.

In the recognition failure procedure, pairs of words are studied and then the second member of a pair is tested; in one test, the second member is presented by

itself for recognition, and in another test, the first member of the pair is presented as a cue for recall of the second. The result of most importance is that under a variety of conditions, there is significant recall of words that were not recognized (Tulving & Thomson, 1973; Watkins & Tulving, 1975). It is this result that poses a serious problem for simple models of recall and recognition, and so it is used to evaluate models in this chapter.

ACT*, Anderson (1983)

This model assumes two different sources of knowledge, a declarative associative memory and a procedural production system. The declarative memory system is a traditional associative memory in which concepts are represented by nodes, and associations between concepts are represented by links between nodes. To account for results that show cue-dependent retrieval, Anderson used the idea that different senses of a word have different representations and thus are represented by different nodes in memory (see Reder, Anderson, & Bjork, 1974). This view has not changed since the ACT (Anderson, 1976) incarnation of his model.[1] Thus, *black* in the context of *train* would evoke the sense of *black* that includes dark soot on a steam train, whereas *black* in the context of *white* evokes the sense of black concerned with racial differences or the color of text on a page. Because there are different senses, retrieval of an item in a retrieval context will be a function of similarity (number of connections or paths in the network) between the encoded sense and the sense activated at retrieval, (Note that it is not necessary that senses are equated with dictionary meanings, as in Tulving and Watkins, 1977. For example, although "coconut" has only one dictionary meaning, it can have different features in different situations and these can be considered different senses.) The ACT* account of retrieval is similar to Tulving's (Tulving & Thomson, 1973) in many ways. It provides a way of grading the similarity between trace information and cue information and so could be viewed as providing an implementation of Tulving's views within the framework of ACT*.

Wiseman and Tulving (1975; see also Flexser & Tulving, 1978) showed that across a range of experiments, the probability of recognizing the target member of a pair conditionalized on correct cued recall of the target was almost independent of the probability of recognition not conditionalized on cued recall. In Anderson's (1983, p. 196) framework, the probability of retrieving a trace in memory from the target is independent of retrieving it from the cue, so that independence is expected. Anderson argued that the slight lack of independence is due to cases where the trace was never formed, and neither recall nor recognition succeeds (see also Begg, 1979). He also argued that the ACT* explanation is largely the same as Flexser and Tulving's (1978) explanation.

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[1]Note that ACT is the 1976 memory model and ACT* is the 1983 memory model.

Diffusion Model, Ratcliff (1978)

Ratcliff developed a decision model designed to account for recognition performance across a range of experimental paradigms and several different measures. The model assumes that a cue (test probe) is compared with each item in memory in parallel. The goodness-of-match between the cue and each memory item drives a random walk (or in the continuous version, the diffusion process) so that the better the match, the faster the process moves to the positive boundary, and the poorer the match, the faster the process moves to the non-match boundary. Using the diffusion model, it is possible to account for reaction time, accuracy, the shape of the reaction time distribution, and growth of accuracy as a function of time, across a range of experimental paradigms (see Ratcliff, 1978; 1981; 1985; 1987; 1988; Ratcliff & McKoon, 1982).

The model is closely related to Tulving's view of cue-dependent processing because the model is phrased in terms of the goodness-of-match between the cue and each item in memory. In fact, the account is given in terms of a resonance metaphor in which the match between cue and target is used to drive the diffusion process. This is precisely the notion of cue-dependent retrieval. This model or closely related models (e.g., the discrete random walk) are candidates for integration with models of memory representation (like those considered next) because they allow a continuous source of goodness-of-match information to be integrated over time (the diffusion model) or allow a feature matching process to be used to determine goodness-of-match (simple random walk).

MINERVA 2, Hintzman (1986a)

Hintzman's MINERVA 2 (1986a) model is cue-dependent in that recall and recognition are both mediated by the relationship of a cue to all items stored in memory. The model represents an item as a vector of features. Each item is kept separate in memory, and at retrieval, the retrieval cue interacts with all items to produce an overall value of match. To understand how recognition failure of recallable words is explained, it is necessary to work through the details of recognition and cued recall. For associations, Hintzman assumed that the two items of a pair, the cue and target (A–B), are stored as separate parts of one memory vector. In pair recognition, the test vector (A–B) is compared to each vector in memory, and a value of similarity (essentially a correlation or dot product) is obtained. This similarity is cubed, and the resulting value is called activation. The activation values are summed over all items to give intensity, which is used in a standard signal detection procedure to predict recognition performance. For recognition of the B member of a pair alone, the B part of the vector is used as the probe with the rest of the vector being set to zero. The intensity is calculated in the same way as for pair recognition.

In cued recall, the A member of a studied pair is used as a probe into memory, and activation values of all vectors in memory are determined. The activation value for each vector then multiplies each element in it's own memory vector, and these vectors are summed over all memory items to produce an output vector. This produces an output vector in which the memory vectors with the strongest associations to a member (largest activation values) produce the largest contributions to the output vector. The B part of the output vector is then correlated with the B part of each vector in memory, and the largest correlation determines the strongest B member and thus determines cued recall. So recognition conditionalized on correct recall depends on both intensity and recall, and recognition depends on the intensity value. When these values are calculated, it is found that, under most conditions, the two measures are independent.

Hintzman (1986b) described several simulation experiments that explored recognition failure further. He argued that in MINERVA 2 there are two factors that produce opposite correlations between recognition and cued recall. First, for recognition, the greater the echo intensity (the more target features encoded), the greater the recognition rate. For cued recall, the more target features stored, the better the cued recall. Thus, recognition and recall are positively correlated as a function of the number of target features stored. However, the more cue features stored, the more strongly the cue probe can activate memory. Because the number of cue features encoded is independent of the number of target features, the overall effect of the number of cue features serves to dilute, but not neutralize, the size of the correlation. To produce the behavior of near independence of the model (and thus counteract the source of positive correlation), another factor must be involved. Hintzman identified this as *intralist similarity*. If another item has a B member similar to the target B, it will increase activation for recognition of the B member (because activations are summed over all items), and so increase recognition performance. However, for cued recall, the existence of a similar item will reduce the probability that that item will be recalled (i.e., have a larger match to the test target), thus producing a negative correlation. In combination, these factors are shown to give the required low degree of association between the two measures.

TODAM, Murdock (1982, 1983)

Murdock's (1982; 1983; see also Eich, 1982) model assumes a vector/feature representation for an item. Unlike Hintzman's model, all items are combined into a single memory trace; at encoding, the features of each item are added to a single memory vector. Associations are stored in this same vector by convolving the A and B members of a pair together and adding this convolution (also a vector) to the memory vector. This model, therefore, does not explicitly represent individual items. It is only at retrieval that the interaction between cue information and memory produces either a value of match that can be used as the

basis for a recognition decision or a noisy vector that can be used to produce a name for recall.

For recognition, the interaction between the recognition cue and memory is given by the dot product between the test vector and the memory vector. In relating this scheme to cue-dependent retrieval, it can be seen immediately that it is impossible to determine what items are stored in memory independent of a retrieval cue. Thus, retrieval in this model is strongly dependent on an interaction between the retrieval cue and memory.

The situation is similar in cued and associative recall. For cued recall, the A member of the pair (given as a cue) is correlated with the memory vector to give another vector. This noisy retrieved vector must be compared with various candidates (in, for example, a lexicon that relates vectors to names of items) to obtain the name of the item—that is, it needs to be cleaned up. Again, independent of retrieval, there is no way to assess memory for this paired associate.

Murdock accounted for the phenomenon of retrieval failure of recallable words by noting that in his model, item information and associative information are independently computed and stored. So the relationship between the probability of recognition and probability of recognition given recall will be independent. Murdock argued that averaging over subjects with slightly different parameter values will lead to the slight correlation.

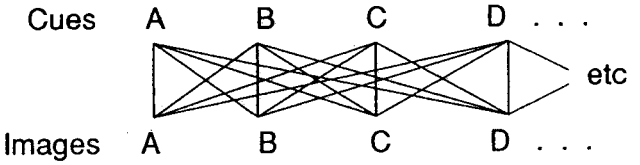
Murdock (1983) pointed out that the vector model is a concrete implementation of the cue-dependent view of memory, and that the only way to talk about encoded information sensibly is in terms of interactions with the retrieval cues. Because memory is a sum (combination) of items, each individually stored item is not itself present in memory but is only present in the memory vector. It is through the interaction of the retrieval cue with this memory vector that information about the presence or absence of the item in memory is obtained.

SAM, Gillund and Shiffrin (1984; Raaijmakers & Shiffrin, 1981)

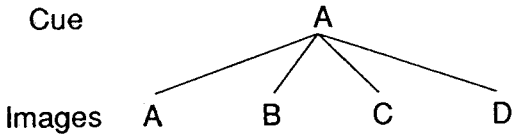
Gillund and Shiffrin's (1984) model can be interpreted as being radical, compared to the other models. It assumes that there are no associations between items ("images" in Gillund & Shiffrin, 1984; Raaijmakers & Shiffrin, 1981) in memory. Instead, associations are represented as strengths between retrieval cues and items in memory. It is worth stressing that this can be interpreted as meaning that there are no associations between images in long-term memory. Although no empirical or computational issues ride on this characterization, it is important to stress this point because it shows how the notion of cue dependence has become accepted theoretically.

Another way to describe this framework is in terms of a two-layer connectionist model. Cues at one layer are associated to items at another layer, but there are no connections between elements or nodes within a layer, no item-to-item

Retrieval Structure (Gillund & Shiffrin, 1984)

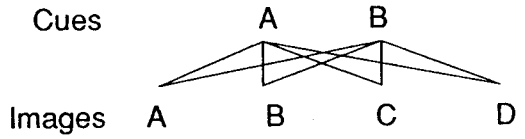


One Cue



$$\text{Familiarity} = \sum_{k} S_{ak} = S_{aa} + S_{ab} + S_{ac} + \ldots$$

Two Cues



$$\text{Familiarity} = \sum_{k} S_{ak}S_{bk} = S_{aa}S_{ba} + S_{ab}S_{bb} + S_{ac}S_{bc} + \ldots$$

FIG. 4.1. Familiarity computations in the SAM model of Gillund and Shiffrin (1984). S_{ij} represents the strength of cue i to target j (so S_{ab}, for example, represents the strength for the cue A to target B link).

connections or cue-to-cue connections (see Fig. 4.1). Encoding strengthens connections between layers as in standard connectionist models, but the model differs from connectionist models in its retrieval assumptions.

The retrieval structure is built up during encoding: When items are stored in the short-term memory buffer together, strengths are built up from each item as a cue to each item as an image for all items in the buffer. At recognition, for a single retrieval cue, the strength of that cue to each item is summed across items. For more than one retrieval cue, the strengths of each cue to an item are multiplied, and these are summed over items. Thus, the way to view this model is consistent with Tulving's view of cue-dependent retrieval. What is important is the joint effectiveness of the retrieval cues in their interaction with memory.

The recall process is a search process that involves both sampling processes and recovery processes. A cue is used along with context to sample memory. One item is selected by this process, and then a recovery process proceeds that will, with some probability, recover the stored name of the item. Both of these processes are stochastic and given some cue, there is some probability that the correct item will not be selected for sampling. Even if the correct item is sampled, there is still some probability that it will not be recovered.

To account for recognition failure of recallable words, two main factors have to be considered. First, as noted previously, the recall process is a stochastic process; that is, there is variability in which items are sampled and then variability in the recovery process. This means that the recall process will be somewhat independent of recognition across items. A second factor is the effect of different contexts in recall and recognition. In the recognition test, the context may induce a different meaning than that induced at recall, and this would increase the independence of performance on these tests. Gillund and Shiffrin (1984, p. 27) argued that these two factors are sufficient to account for the phenomenon of recognition failure.

SUMMARY FOR MEMORY MODELS

It is worth classifying these memory models with respect to how they deal with recognition failure, how they stand on the dimension of cue dependence, and other discriminating factors. Table 4.1 presents this classification. It is interesting to note how much the explanations vary within the frameworks of these models. This suggests that it may be possible to test among these different accounts by experimentally varying factors that are assumed to be important in some models and not others. One common factor that does run through these models is the assumption that item and associative information are (somewhat) independent or that there are differences in information used in recall and recognition that are attributed to differences in context. This factor is quite consistent with Tulving's notion of encoding specificity.

CUE-DEPENDENT PRIMING

A question that arises about these memory models is what they contribute to our understanding of memory phenomena beyond fitting the data and accounting for experimental results in their domain of application. One response to this question is that they provide criteria for development of further theory (and after all, development of theory is the major aim of the scientific enterprise). A second response to this question is that they can provide alternative frameworks for examining existing phenomena and so provide competing models. For example,

TABLE 4.1
Classification of Memory Models

	Vector/ Node	*Separate Items in Memory*	*Cue Dependent*	*Recognition Failure*
ACT*	node	yes	no but mimics by using multiple senses of words	different senses of words so that recognition and recall are nearly independent
Diffusion model	either	yes	yes	no recall component but an extension would assume independent item and associative info.
MINERVA2	vector	yes	close but not phrased in these terms	interaction of factors—no. of encoded features produces positive correl. interitem similarity produces negative correl.
TODAM	vector	no	specific implementation of cue dep.	independent item and associative information
SAM	node	yes	yes	combination of stochastic recall process and context differences in recall and recognition

when we began to think about some data from a priming experiment on discourse processing in the context of Gillund and Shiffrin's cue-dependent model, we were able to develop an account of priming phenomena (Ratcliff & McKoon, 1988) that is an alternative to the currently popular and almost unchallenged spreading activation theory.

Our model for priming assumes that the prime and target are combined in a compound cue as in pair recognition in Gillund and Shiffrin (1984). Essentially, the strengths of the two cues (the prime and target) to an item in memory are

multiplied and then summed over all items (see Fig. 4.1). So, if the prime and target are both connected to the same items in memory, then the result will be relatively large numbers multiplied together, leading to large values of familiarity. Thus, when the prime and target share associates, a large value of familiarity is obtained, and this in turn generates a fast reaction time (using a model such as the diffusion model, Ratcliff, 1978), that is, a standard priming effect in response latency. To have the subject respond mainly on the basis of the target and not the prime, the target is weighted more than the prime (see Gillund and Shiffrin's account of cued recognition, 1984). With these simple assumptions, it is possible to explain most effects within the priming literature by examining the contents of the compound cue (assumed to be the last two or possibly three items in short-term memory for single words, or the last few propositions for text).

Two variables that most directly illustrate the difference between the cue-dependent retrieval theory and spreading activation are the range of priming and decay of priming. Spreading activation is a mechanism that has been assumed to underlie retrieval of paths in memory that are then made available for evaluation (Anderson, 1976, 1983; Collins & Loftus, 1975). Thus, within the framework of a semantic network memory representation, the theory predicts that activation should spread for relatively long distances. On the other hand, the compound cue theory, as implemented in the Gillund and Shiffrin model, predicts that priming should only occur between items that have associates directly in common (items directly connected or connected by one mediating item). The data currently available (Balota & Lorch, 1986; de Groot, 1983) support the latter, that the range of priming only extends to near high associates. With respect to decay of priming, in most spreading activation models, rate of decay is a parameter that can vary over a range of values, but within the compound cue model, introducing an item between the prime and target will bump the prime out of the compound cue, and eliminate priming. In fact, many studies of priming show such rapid decay (e.g., Ratcliff, Hockley, & McKoon, 1985).

Although the priming model is formulated here within Gillund and Shiffrin's (1984) cue-dependent framework, it is possible to implement the model within other frameworks, such as Hintzman's and Murdock's (see Ratcliff & McKoon, 1988). To speak to the point concerning the use of these memory models, we reiterate that our compound cue model was only conceived in attempting to explain priming within the Gillund and Shiffrin framework. Although the Gillund and Shiffrin model was not developed to account for priming, it could be applied to priming in an insightful way. And, given this application, it became clear that the compound cue idea could also be implemented in the other frameworks.

Besides providing an illustration of the power of some current memory models, the compound cue theory also provides an alternative explanation of priming that is cue-dependent and thus consistent with Tulving's views on retrieval.

TEXT PROCESSING

Consideration of the interactions between encoding and retrieval processes leads to a broader range of issues in text processing research than in the more traditional areas of verbal learning. This is because the information relevant to a recognition or recall response is much less constrained when a studied text is the object of memory than when a list of words is the object. The information is less constrained because subjects, through early training and education, perceive their task as retrieving knowledge about a studied text, rather than retrieving an exact replica of the studied material. Thus, any particular retrieval decision will reflect some combination of information that was explicitly stated in a studied text and information that was contributed (inferred) by the subject.

The kinds of information that might be added by the subject to explicitly stated text information vary from inferences about the referent of a pronoun to inferences about "who did it" in a murder mystery. Intuitively, it seems that pronouns are understood quickly and easily during reading, and so we might like to argue that the connection between pronoun and referent (an inference) is explicitly encoded during reading. Then it would follow that this inferred information was no more subject to variable retrieval conditions than other information that was *explicitly* stated in the text. On the other hand, inferring the identity of a murderer is not easy; to do it, we have to stop reading, try to remember relevant information, and engage in active problem solving. We do not have the subjective feeling that the identity of the murderer is encoded into the text representation *during reading,* and we would expect that the probability of guessing the identity would vary widely as a function of different contextual cues.

To begin to study the large range of inference processes that lies between the extremes illustrated by these examples, it is useful to identify dimensions on which encoding–retrieval interactions can vary. In our work, we have made use of four such dimensions. The first is the *time course* of processing; the idea is that some kinds of inferred information are available relatively quickly at retrieval, whereas other kinds are available only after considerable processing time. Information that takes a relatively long time to generate at retrieval is usually information that involves additions at retrieval to what was understood during reading. Thus, to get a picture of the representation of a text without such additions, we often limit the retrieval time available to the subject.

When retrieval time is limited, then we can fill out the picture of a text representation by examining different *retrieval contexts* for specific test items. An example of this second dimension of encoding–retrieval interaction is that retrieval cues can vary in their specificity. With a retrieval cue that is not very specific, it is possible that no evidence at all will be obtained for some inference; it looks like the subject did not make the inference. But with a very specific retrieval cue, the same inference (whether it was made or not) might be uniquely

determined, and the system would act as though the inference had been made at encoding. In other words, evidence for the presence of inferences in a text representation can be manipulated by alterations in the retrieval environment.

The effect of variations in retrieval environment will depend, to some extent, on third and fourth dimensions, the *strength* of the inference in question and the *specificity* of the inference. Some inferences might be encoded so strongly during reading that they are indistinguishable from explicitly stated information, and so relatively less subject to variations in retrieval environment. Other inferences might be made only minimally (weakly), and so be much more subject to retrieval factors. In addition, some inferences may be made very specifically ("the butler did it") or some not specifically ("some person or thing in the manor did it").

In the sections that follow, each of these four dimensions is discussed and illustrated by examples from empirical findings. However, before this, a brief review of earlier work on retrieval aspects of inference in text processing is presented (to provide a retrieval context for the next sections).

Retrieval and Inference Processing

The issue of cue-dependent retrieval has often been ignored in the domain of memory for textual information. The general (implicit) assumption has often been that any measure—recall, cued recall, recognition, or story summarization—gives a direct reflection of the memory representation of a text. However, some researchers have strongly criticized this assumption (Baillet & Keenan, 1986; Corbett & Dosher, 1978; McKoon & Ratcliff, 1980, 1981; Ratcliff & McKoon, 1978; Singer, 1978, 1979), and several empirical demonstrations have reinforced the criticisms.

One such demonstration was provided by Corbett and Dosher (1978). It had previously been claimed that instrumental inferences were formed during sentence encoding; that the concept "hammer" was encoded as part of the memory representation of "John pounded the nail." The logic behind this claim was that "hammer" was a good retrieval cue for the sentence about "John," even though "hammer" had not been explicitly stated (Paris & Lindauer, 1976). Corbett and Dosher showed that "hammer" was also a good retrieval cue for the sentence "John pounded the nail with a rock," where "hammer" would not be inferred as the instrument. Thus, the finding that a concept is a good retrieval cue cannot be taken as evidence that the concept was inferred during encoding. Instead the suggestion is that, at the time of retrieval, subjects are able to make use of the interaction between the retrieval cue (hammer) and the explicitly stated information (pounding the nail) to construct information that leads to a response.

Further evidence for such an interaction is shown in results from an experiment by Singer (1978). He used materials that varied in forward versus backward associations: "soup" is given as a high associate to "ladle" but the corresponding high associate to "soup" is not "ladle" but "spoon." If an instrument is

inferred *during* reading of a sentence about stirring soup, then that instrument will be "spoon" (because "spoon" is a high associate of "soup") and "spoon" will be a good recall cue for the sentence. But if an instrument is not inferred during reading, but functions as a good recall cue because of retrieval processes, then the best cue will be one from which "soup" can be generated, that is, "ladle." In fact, in Singer's experiment, "ladle" was a better recall cue than "spoon."

These experiments provided evidence of the importance of retrieval processes to research on inference. However, they do not give any indication of how the retrieval processes are operating, that is, they do not give any clear picture of the text representation. For example, it might be that an instrument for stirring soup is encoded relatively strongly but unspecifically, so that retrieval processes simply add a bit of specificity. In this case, evidence for the inference would be expected to appear across a range of retrieval conditions. Alternatively, it could be that the instrument is encoded very weakly (or not at all), so that evidence for the inference would appear only with a relatively great amount of processing time or an extremely specific retrieval cue. Examples of empirical efforts to investigate these issues are the topics of the next sections.

Time Domain of Processing

One variable that is rarely used in research that examines encoding–retrieval interactions is the time course of processing (see Tulving, 1983, chap. 11). However, processes must evolve over time, and the more time available, the more processing will get accomplished. So, measures of response time and measures from procedures in which time for processing is controlled will provide important sources of information for theory development.

Procedures that limit the time available for retrieval processes are especially useful in text research because the range of such retrieval processes is so large. Without time pressure of any sort, that is with recall or story summarization, subjects are free at the time of the memory test to generate many *additions* to the information retrieved about a text, and to form many new inferences about the text. They are also free to delete or discount retrieved information from their responses (cf. Baillet & Keenan, 1986). If retrieval time is tightly restricted, then the possibility of such additions and deletions is reduced, and responses reflect more directly the information that was encoded at the time of reading.

One way to divide up the dimension of the time course of processing is to contrast automatic processes with strategic processes (Posner & Snyder, 1975). An automatic response to some test event does not require conscious processing, occurs relatively quickly, and occurs even when the probability of that type of event is so low that subjects would not be expected to develop a strategy for responses to the event. A strategic response does require conscious attention,

takes a relatively long time, and is more likely to occur when probability is high enough for subjects to develop strategies.

In much of our work, we have limited retrieval time in an effort to ensure that responses were the result of automatic, rather than strategic, processes. Specifically, we have used procedures that measure priming, defined as the amount of facilitation given by one item to the response to a subsequent item. For example, if subjects studied two sentences, "The baby hit the concrete" and "The freak met the debutante," then we might contrast recognition speed and accuracy for the target word "concrete" when it was primed by a word from the same sentence, "baby," and when it was primed by a word from another sentence, "freak." Typically, we find facilitation in the first case relative to the second. Three aspects of the procedure ensure that the facilitation is due to automatic processes: the time between presentation of prime word and target test word (SOA) is short (e.g., 150 msec); subjects are under speed instructions; and the probability that a prime and target come from the same sentence is relatively low so that subjects would not be expected to develop strategies based on expecting a target to be from the same sentence as a prime.

Given that the facilitation is automatic, then it can be used to measure the degree of association in memory between the two concepts represented by the prime and target words. For a studied text, the association might be between two explicitly stated concepts from a text, as in the "baby–concrete" example, between an explicitly stated concept and some other concept that was not stated explicitly but could potentially be inferred, or between an explicitly stated concept and some unstated concept related to the text by general knowledge (through *semantic memory,* in Tulving's terms).

If we accept the automatic–strategic distinction, then it provides a clear theoretical rationale for arguing that priming procedures can reveal the associations that make up the memory representation of the organization of concepts. If, instead, automatic and strategic processes are viewed as two ends of a continuum, on which automatic processing is simply the lack of time for much strategic processing to take place, then priming procedures still have validity. When there is little time for processing, then relative amounts of facilitation will reflect relative degrees of association between concepts.

In the following sections, empirical examples show that the evidence for some kinds of inferences changes as retrieval conditions are moved from fast and automatic to slower and more strategic, and that with automatic processing, inferences can be cue-dependent.

Elaborative Inferences

In our work on text processing, we were faced with the issue of cue-dependent retrieval most directly in attempts to study elaborative inferences. A frequent

question in text research has been whether readers make inferences of prediction: Given a sentence about an actress falling off a fourteenth-story roof, does the reader infer, or elaborate the text to include, the result that the actress died? The inference seems quite compelling, so it is plausible (and consistent with past theoretical claims) that the representation of the text encoded into memory would include the information that the actress died.

With respect to elaborative inferences of the kind given in the actress example, we examined three dimensions of retrieval conditions (McKoon & Ratcliff, 1986, 1987, 1988b); we varied the time available at retrieval for processing, we varied the retrieval context, and we varied the strength (and/or specificity) of the inference.

To vary the time available for retrieval processing, we compared the effects of a cue expressing the to-be-inferred event (e.g., the word "dead") on cued recall performance and speeded recognition performance (McKoon & Ratcliff, 1986). The idea was that subjects use much more time to make their responses in cued recall than in recognition. With cued recall, subjects read a list of sentences that included predicting sentences like the actress sentence, and control sentences that included many of the same words as the predicting sentences but did not predict the target events. After a delay of several minutes after list presentation, subjects were given a list of single word cues (the target events like "dead") and were asked to write down the sentence that corresponded to each cue. Subjects recalled 23 percent of the sentences that predicted the cue word, but only 4 percent of the control sentences. In the past, this kind of result has been taken to demonstrate that predicted events are inferred during reading of predicting sentences and encoded into memory with the sentences.

With speeded recognition, the same predicting and control texts were used with a study–test procedure. On each trial, subjects read two sentences, and then were presented with a list of test items. Each test item was made up of a prime word and a target word. The subjects were required to decide whether the target had appeared in one of the two studied texts, and to respond at a deadline of 650 msec after the target was presented. With this deadline, subjects can respond consistently at the required time, and differences across conditions show up in accuracy rates. For the target items that expressed predictable events (e.g., the word "dead"), the correct response was "no." With a neutral word as prime (the word "ready," used consistently throughout the experiment), the results were that there was little difference in accuracy between the predicting and the control sentences. Thus, the results suggest that subjects did *not* make an inference during reading about predictable events.

Obviously, the results of the cued recall and speeded recognition experiments are at variance. With cued recall, subjects have the time to employ strategies that lead to recall of the predicting sentences from the target cues. But with speeded recognition, subjects must rely on fast automatic processes, and they have insufficient time to add information to the cue to build the connection between the cue

and a studied sentence that would lead to successful retrieval. Of course, there were other differences in procedure between the cued recall and recognition experiments, but it is certainly plausible that the critical difference was the time available for retrieval processing.

One possible conclusion from these results is that elaborative inferences of the predictable events kind are not encoded during reading; the basis for this conclusion is that there is no indication of such inferences in speeded recognition; successful cued recall would be attributed entirely to strategic retrieval processes. However, this conclusion would ignore the importance of studying inferences under a range of retrieval contexts. Conclusions about the content of the memory representation of a text cannot be based on only one retrieval context. In fact, when the retrieval context was changed in the recognition experiment by using a word from the studied sentence (''actress'') as a prime instead of the neutral prime, the error rate on the predicted event targets (''dead'') was much higher for predicting study sentences than control study sentences.

The overall pattern of results for inferences about predictable events can be understood in terms of associations between retrieval cues and information in memory. The association between a predicted event by itself (or with a neutral prime) and a studied predicting sentence in memory is not strong enough to give errors in speeded recognition. But for a combined cue of the predicted event plus a prime from the sentence, the association is strong enough to give errors. The picture of the memory representation given by these associations is one in which the inference about the predicted event is encoded in some minimal way; for example, for ''death'', the encoded inference might be ''something bad.''

It was this idea, that inferences might be encoded minimally, that suggested to us that inferences might vary in strength, a third dimension in addition to the dimensions of the time course of processing and retrieval context. To test the strength notion, we used a new set of predicting and control sentences, in which there were many words that were semantically associated to the predicted event (McKoon & Ratcliff, 1988b). For example, the predicting sentence for the target word ''sew'' was ''The housewife was learning to be a seamstress and needed practice so she got out the skirt she was making and threaded her needle,'' and the control sentence was ''The housewife was a careless seamstress, and when she dropped an unthreaded needle on the floor, she didn't find it until she stepped on it days later.'' For these materials, there are the same words semantically associated to the target ''sew'' in both the predicting and control sentences, yet only in the case of the predicting sentence would the housewife actually be expected to sew. With the strong semantic associations to support the inference for the predicting sentence, the target word by itself (with the neutral prime) was strongly enough associated to the memory representation to give significantly more errors with the predicting sentences than the control sentences.

This work on elaborative inferences begins to address the issues of cue-dependent retrieval in text processing. We have obviously just begun to take the

first steps in examining the interactions of retrieval and inference processes, but so far, the results indicate that we can tease apart some of the factors that operate at the time of retrieval.

Aspects of Meaning

Another kind of inference that has received a great deal of attention in the text-processing literature concerns the different features of meaning of words. The features necessary for comprehension in one context may be different than in another context. For example, comprehension of a text about painting a picture of a tomato may be more likely to include the information that tomatoes are red than a text about rolling a tomato across the floor, when neither text states explicitly that "tomatoes are red." In studying this kind of inference, we were surprised to learn just how wide-ranging the effects of retrieval context could be.

In our experiments (McKoon & Ratcliff, 1988a; see Table 4.2), we were concerned with retrieval when processing was speeded, and varying retrieval context under this condition. On each trial of a study–test experiment, subjects read three short texts, and then were presented with a series of true/false test sentences. Some of the sentences could only be verified with respect to the studied texts, whereas others could be verified by general knowledge (i.e., without having read the texts at all). The interesting test sentences were those

TABLE 4.2

Matching Version:

This still life would require great accuracy. The painter searched many days to find the color most suited to use in the painting of the ripe tomato.
Target test sentence: Tomatoes are red. (True)
Priming test sentences:
The still life would require great accuracy. (True)
Newspapers are reading material. (True)
Filler test sentences:
The painter searched for many days. (True)
Balloons are heavy. (False)

Mismatching Version:

The child psychologist watched the infant play with her toys. The little girl found a tomato to roll across the floor with her nose.
Target test sentence: Tomatoes are red. (True)
Priming test sentences: The child psychologist watched the infant. (True)
Newspapers are reading material. (True)
Filler test sentences:
The little girl played with her toys. (True)
Balloons are heavy. (False)

that expressed features of meaning of nouns when the nouns had appeared in a studied text but the features of meaning had not been stated explicitly. The features of meaning either matched the meaning of the text (as "tomatoes are red" matches the text about painting a picture of tomatoes in Table 4.2) or did not match the meaning of the text (as "tomatoes are red" does not match the text about rolling a tomato). One retrieval context was an immediately preceding test sentence that had nothing to do with any studied text (e.g., "Newspapers are reading material," true by general knowledge). In this context, responses for the target sentences were equally fast in the matching and mismatching conditions. This might be taken to suggest that readers do not infer different aspects of meaning for different uses of nouns. But, as with predictable events, changing the retrieval context changes the picture of the memory representation. When the immediately preceding test sentence was from a studied story, then responses to matching target test sentences were faster and more accurate than responses to mismatching target test sentences. The difference between the matching and mismatching sentences was present both when the preceding test sentence was from the same text as the target and when it was from a different text.

Overall, as with the predictable events inferences, the picture given by varying retrieval conditions can be understood in terms of associations between retrieval cues and memory. A cue made up of a sentence like "tomatoes are red" plus another general-knowledge sentence (that has nothing to do with any studied text) is not strongly associated to information in memory about recently studied texts. On the other hand, a cue made up of "tomatoes are red" plus a sentence from any studied text is associated to recently studied information. The strength of that association depends on whether the two sentences refer to the same text and on whether "tomatoes are red" matches the meaning of a studied text.

Summary for Text Processing

For text-processing research, the most important consequence of considering the notion of cue-dependent retrieval is that the questions to be asked are completely changed. Previously, questions have always been concerned with whether readers make some specific kind of inference. Instead, as suggested by Tulving's theoretical work and the empirical work discussed previously, the questions must become what retrieval conditions give evidence for some kind of inference, and more generally, what retrieval factors are important for memory for textual information. This shift in research toward encoding–retrieval interactions leads to a greater emphasis on retrieval processes than has been the case in the past. For one example, further research is needed to investigate the dimension that ranges from fast automatic retrieval processes to slow strategic processes. For another, we need to try to understand how information that is not available easily and quickly, such as the connection between two thematically related stories, can

be calculated and become available with time (cf. Seifert, McKoon, Abelson, & Ratcliff, 1986).

CONCLUSION

The future of research in the two domains of memory models and text processing looks quite rosy. For memory, there are several competing models that do an impressive job of accounting for a wide range of data. These models are now being compared and contrasted, and attempts are being made to understand what features of the models provide predictive power in specific domains. Part of this development is the introduction of nonlinear processes into the models (e.g., Gillund & Shiffrin, 1984, products of strengths; Hintzman, 1986a,b, cubing strengths), and these new architectures provide challenges in understanding the bases of the predictions of the models. Along with this development of memory models, the parallel and more visible development of connectionist models and their nonlinear characteristics has also led to a rich theoretical domain of investigation. As noted earlier, within this domain of study, the issue of encoding–retrieval interactions is proving to be important in developing and evaluating the models.

The domain of text processing has been relatively inactive over the last few years (compared with the late 1970s). We feel that there will soon be a renaissance fueled partly by developments in theory in linguistics and, to a lesser extent, in computer science. In addition, the development of rapid priming techniques offers experimental procedures to test advances in theory. As illustrated previously, we expect that encoding–retrieval interactions will play an important role in advances in this area.

Although this chapter has reviewed these two areas of research somewhat independently, we find considerable cross-fertilization between the areas. One example was the new theory of priming phenomena, which was driven by data from text processing and theory from a current memory model (Gillund & Shiffrin; 1984). Often, we find heuristic value in qualitatively applying memory models to empirical data from text research to guide subsequent theoretical and empirical questions. Generally, an important target is the development of memory models that will apply not only to traditional memory paradigms, but also to empirical phenomena in the domains of text processing and text memory.

ACKNOWLEDGMENT

This research was supported by NSF grant BNS 85 10361 to Roger Ratcliff, NIH grant HD18812 to Gail McKoon, and NSF grant BNS 85 16350 to Gail McKoon.

We thank John Anderson, James Neely, and Henry Roediger for their useful comments on this chapter.

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