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5 Beyond Strategies: Implications of Memory Representation and Memory Processes for Models of Judgment and Decision Making

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ABSTRACT

It may seem desirable to study cognitive processes such as attention, memory, or decision making in isolation. However, we argue in this chapter that interconnections between these processes should not be ignored. First, we review ways in which decision researchers have and have not taken memory into consideration. Second, we present a complex pattern of empirical dissociations found between certain judgment and memory tasks and show how to account for these results with an elaborated version of one of a new class of process-level memory models which assume distributed representation of different types of information in a common memory store. Finally, we conclude with some general implications for future research that follow from the incorporation of memory processes into theories of decision making.

INTRODUCTION

Memory plays a fundamental role in decision making. In countless real-life decisions (e.g., where to go to school, which job to accept, whom to marry), the consequences of the alternative courses of action cannot be known perfectly in advance. No matter how extensive the effort to obtain relevant information, there will remain important matters that must be retrieved, inferred, or predicted by the decision maker on the basis of information stored in memory. Even when the consequences are completely described, as in many laboratory experiments, the significance or utility of each consequence must be retrieved or inferred by the decision maker. Moreover, the weighing and combining of the various considerations in a decision, the process of deliberation which is often the essence of decision making, takes place in and depends on the characteristics of working memory. Given the interconnections between memory and decision processes, memory researchers have long found it necessary to include decision processes in their models (e.g., Atkinson & Juola, 1973; Bernbach, 1967; Hockley & Murdock, 1987; Ratcliff, 1978; Wickelgren & Norman, 1966). We argue in this chapter that decision researchers need to follow suit by incorporating explicit hypotheses about memory processes into judgment and decision making models.

In this chapter, we will briefly review the ways in which decision researchers have and have not taken memory into consideration. Then, we will discuss the kinds of explanations that decision researchers typically consider as possible accounts of decision phenomena. We will argue that in some ways memory research casts doubt on certain presuppositions of decision researchers, and that a fuller consideration of memory processes can enlarge the set of explanatory constructs that researchers bring to bear on judgment and decision making. In particular, we will argue that some of the weighing and combining of information that decision researchers consider to be effortful and under the control of a decision strategy, might be regarded as the effortless consequence of superposition in a unitary memory store. To illustrate how decision researchers might draw upon such thinking in recent memory research, we will review some results on the relationship between memory and judgment, including a puzzling dissociation between serial position effects in recall and order effects in judgment. Then, we will introduce and adapt a new type of memory model that uses superimposed distributed memory representations (i.e., Murdock's, 1982, 1983, TODAM model) to account for the dissociation. This example will also illustrate how the notion of "strategy," which is a central explanatory construct in decision research, takes on a somewhat different meaning in the context of memory models.

USAGE OF MEMORY IN DECISION RESEARCH

Considerations of memory are not new to judgment and decision researchers. However, the integration of memory concepts into theoretical and empirical work on decision making has been extremely uneven, partly because decision research

is not a unified field of study, but attracts the attention of researchers from several subdisciplines of psychology, as well as from such fields as statistics, economics, and political science, among others.

Social Cognition

Social psychologists have probably utilized the implications of memory research most fully, particularly in their studies of the ways in which people make judgments about other people. Indeed, investigators operating within the framework of social cognition virtually define their field in terms of memory. In a recent review, Sherman, Judd, and Park (1989, pp. 281-282) described the social cognition approach as concerned with "three fundamental questions ... : First, what exactly is stored in memory that may mediate social behavior? ... Second, ... how does social information stored in memory affect subsequent information processing, judgments, choices, and behaviors? ... Third, how is stored information changed both by new information and by reflection, reappraisal, and similar processes?" In this spirit, questions about social judgment have been thoroughly intermixed with questions about memory. In fact, the two issues considered later at some length are drawn primarily from studies of social cognition: (1) the relationship between one's evaluation of an object (e.g., the likability of a person) and one's memory for the object's characteristics (e.g., the person's behaviors or traits, Hastie & Park, 1986), and (2) whether certain memory/judgment dissociations require one to postulate separate memory stores for information about the object and one's evaluation of it (N. H. Anderson & Hubert, 1963).

It is beyond the scope of this chapter to review the results of social cognition, even if restricted to its intersection with judgment and decision research. (For reviews of social cognition, see Higgins & Bargh, 1987; Markus & Zajonc, 1985; Sherman, Judd, & Park, 1989; Wyer & Srull, 1984.) Nevertheless, it seems fair to characterize its concern with memory as focusing on: (1) the nature, organization, and accessibility of the *content* of memory as it impacts on particular tasks, and (2) the use of memory measures as a *tool* to reveal the judgment processes that have taken place.

The work of Pennington and Hastie (1988) on juror decision making provides a good illustration of these two uses of memory. Pennington and Hastie argue that jurors do not evaluate the weight of each piece of evidence to be combined according to Bayes' rule (Schum & Martin, 1982), an algebraic formula (N. H. Anderson, 1981), or by sequential anchoring and adjusting (Hogarth & Einhorn, 1990). Instead, they suggest that jurors fit the evidence into a mediating structure in memory—a story—according to the requirements of causal schemata for the representation of narratives (Trabasso & van den Broek, 1985). To provide empirical evidence for their theory of "explanation-based" decision making, Pennington and Hastie (1988) provided jurors with the written transcript of a murder trial and then gave them a recognition test for sentences some of which had been in the transcript. Based on prior research with the same murder case (Pennington & Hastie, 1986), the authors knew that jurors retrospectively reported one of two "stories": a prosecution story indicating guilt or a defense story indicating innocence, where each story contained propositions inferred by jurors on the basis of their knowledge of human goals and actions, and never stated in evidence during the trial. As predicted, jurors falsely "recognized" new statements that were drawn from the story consistent with their chosen verdict far more often than statements drawn from the other verdict story. Moreover, the influence of a story schema, and not merely a tendency to falsely recognize items consistent with one's decision, was indicated by the finding that jurors' ratings of the importance of evidence items were well-described by the items' causal connectedness in a network representation of the appropriate story. Finally, to study the causal efficacy of the mediating story structure, Pennington and Hastie (1988) varied the order of evidential items to manipulate the ease with which jurors could construct the prosecution or defense stories. They found that, indeed, their order manipulation affected the verdicts chosen.

Other Areas of Decision Research

For researchers with intellectual roots in economics, perception, or problem solving, consideration of memory has not been nearly as pervasive as in social cognition. Nevertheless, at a general level, recognition of the limitations of working memory has had a strong influence on decision models. In large part because of these limitations, the typical decision maker is no longer depicted as a "rational calculator," but instead as a creature of finite resources forced to find practicable strategies for processing information in an adequate, if not optimal, fashion (Simon, 1955, 1956). In this way, memory considerations have contributed to much of the recent emphasis on decision heuristics (Kahneman, Slovic, & Tversky, 1982) and adaptive strategy selection (Johnson & Payne, 1985; Payne, 1980, 1982; Payne, Bettman, & Johnson, 1988, 1990).

Beyond these general influences, aspects of memory have been adduced as explanations for particular judgment or decision phenomena, or as part and parcel of the phenomena themselves. For example, Tversky and Kahneman (1973) have suggested that people judge the relative frequency of events according to their "availability;" that is, the number and ease with which instances can be retrieved. Thus, people wrongly judge there to be more English words beginning with the letter "r" than having "r" as the third letter, because lexical memory is organized to make words of the former type more accessible. Another example, the hindsight bias (Fischhoff, 1975; Hawkins & Hastie, 1990) refers to the distorted claims made by people in retrospect about the predictions they would have made in prospect (e.g., In 1987, what would have been your estimate of George Bush's chances of winning the 1988 presidential election?). The fact that people retrospectively claim to have had more knowledge than people actually making prospective predictions has been described as an issue of reconstructive memory; that is, an inability to reconstruct one's prior state of knowledge after additional information has been added. In a paradigm for studying the perseverance of beliefs (Ross & Lepper, 1980), people were first given a basis for some belief (e.g., rigged feedback suggesting that they are particularly good at some task), which was then discredited (e.g., in a debriefing that reveals the deceptive feedback). The finding that people do not entirely revert to the beliefs they held before receiving the discrediting information seems similar to the hindsight bias; that is, an inability to reconstruct one's prior state of mind. An alternative explanation, also relying on memory, holds that the to-be-discredited information is used as a selective retrieval cue that brings to mind valid information in support of the belief (e.g., recall of skillful performance at similar tasks), which remains in force after the discrediting.

Issues concerning memory are also raised when people fail to draw the proper conclusions from a collection of instances to which they have been exposed. Why don't people learn from experience the relationship between observed variables (Brehmer, 1980), or why are their predictions typically overconfident (Einhorn & Hogarth, 1978; Lichtenstein, Fischhoff, & Phillips, 1982)? Explanations typically mention the possibility of biased encoding and/or retrieval of the relevant information.

In sum, the use of memory in these non-social areas of decision research also concerns the nature, organization, and accessibility of the *content* of memory, but theories in these areas are less likely to hypothesize elaborate memory structures with well-articulated formal properties, presumably because they tend not to concentrate on any particular content domain. Also, by comparison with social cognition research, there is much less use of memory performance as a *tool* for inferring the mental processes of which memory is the residue. In neither of these broad areas does there seem to be much attention to memory at a fine-grained *implementation level*, with a focus on specific details of memory representation and the mechanisms of retrieval. We think this omission has important implications for the way that decision researchers go about explaining decision behavior. We take a closer look at these explanations in the next section.

LEVELS OF EXPLANATION IN DECISION RESEARCH

Very much like recent research in memory, numerous studies of decision making have shown that performance is sensitive to a variety of task and context effects. For example, people's decisions have been observed to depend on the characteristics of "irrelevant" filler alternatives (Beattie & Baron, in press; Goldstein & Mitzel, in press; Huber, Payne, & Puto, 1982), time pressure (Ben Zur & Bresnitz, 1981; Busemeyer, 1985), the description or framing of the alternatives (Slovic, Fischhoff, & Lichtenstein, 1982; Tversky & Kahneman, 1981), and the response mode subjects use to report their decisions (Goldstein & Einhorn, 1987; Huber, 1980; Lichtenstein & Slovic, 1971, 1973; Tversky, Sattath, & Slovic, 1988). These and other task effects have resulted in a proliferation of postulated "heuristics" (Kahneman, Slovic, & Tversky, 1982) and "decision strategies" (Svenson, 1983). That is, any variability in decision behavior is usually attributed to the operation of different rules and procedures for the selection, weighing, and combination of information.

In response, just as a number of memory researchers have argued that associations and dissociations of performance ought to be explained within a single, procedural theory of memory (e.g., Humphreys, Bain, & Pike, 1989; Weber & Murdock, 1989), there is a growing voice within decision research that calls for a unified overarching theory to deal with this proliferation of strategies. In particular, there seems to be a need to explain the meta-decision by which active, adaptive, and goal-directed organisms tailor their decision strategies to the information, constraints, and tasks at hand (Hogarth & Einhorn, 1990; Johnson & Payne, 1985; Klayman & Ha, 1987; Payne, 1982; Payne, Bettman, & Johnson, 1988, 1990). According to one widely-held theory of meta-decision making, decision strategies are selected on the basis of an error-effort tradeoff analysis (Payne, Bettman, & Johnson, 1988). Although measures of error and effort are problematic (but see Payne, Bettman, & Johnson, 1990, for an attempt to validate a particular measure of effort), the general idea is that if two strategies produce approximately equal (expected) error, then the strategy that requires less effort is likely to be implemented. Thus, not only has the concept of *decision strategy* come to be an indispensable explanatory construct of decision research, but the concept of *effort* also plays a critical role in current theories of human decision making (Beach & Mitchell, 1978).

Given the importance placed on the concept of *decision strategy*, it is unfortunate that the term is used in different ways by different theorists. Part of the ambiguity arises from the fact that decision researchers are interested in two conceptually distinct descriptions of decision behavior: (1) outcome models, that (mathematically) relate the characteristics of a set of decision alternatives to a person's choices or judgments, and (2) process models, that describe the sequence of mental operations by which the choices or judgments are reached. Historically, interest in outcome models came first, spurred by the seminal work of von Neumann and Morgenstern (1947) and Savage (1954), made widely available to psychologists by Edwards (1954). Most contemporary decision researchers, however, have some interest in both kinds of description, with varying degrees of relative emphasis. The rejection of a class of mathematical outcome models can often be extremely informative about the kinds of psychological processes that were or were not employed. Perhaps for this reason, the term "strategy" (with its overtones of psychological process) is frequently used somewhat misleadingly to refer to the combination function of particular outcome models, as when researchers contrast adding vs. averaging strategies. More properly, "strategy" refers to a systematic sequencing of the mental operations underlying a decision process, possibly in a pattern that places only minimal constraints on the resulting outcome model. For example, holistic and dimensional choice strategies are distinguished according to the order in which the attributes of two alternatives are considered. A holistic strategy is one in which each alternative is evaluated completely by itself, and it is the complete evaluations that are compared to determine the choice. By contrast, a dimensional strategy is one which proceeds by combining the information from a series of intradimensional comparisons between the alternatives. The fact that both holistic and dimensional strategies (in the process sense) can implement either adding or averaging strategies (in the outcome model sense) exemplifies the potential for confusion.

What is important for our argument is that, despite its preeminence as an explanatory construct, "strategy" in *either* sense of the word can *not* provide a *complete* account of decision making. We suggest that a fuller consideration of the explicit details of memory representation and processes can supply a set of theoretical constructs that complement decision researchers' current tools. First, by conceiving of decision strategies in the process sense as collections of rules for the sequence of mental operations that select, encode, and combine information, decision researchers overlook effects due to the system *implementing* the strategy. By contrast, research on memory processes can shed light on the possible decay, distortion, or confusion of intermediate computations in the execution of a decision strategy, and thereby reveal insights about the peculiarities and limitations of the system that implements the strategy.

Second, the current focus on decision strategies generally presupposes that the work of making decisions; that is, evaluating and combining the features of decision alternatives, takes place sequentially. Recent thinking about memory, on the other hand, has challenged the assumption of sequential rule-governed mental operations with the idea of massively parallel computations. Among other things, the possibility of parallel computations suggests that the concept of effort, which is central to theory about meta-decision making, may need to be rethought. The number (or weighted sum) of mental operations necessary to implement a strategy may be an inappropriate measure of effort if the mental operations can be executed in parallel.

Third (and related to the previous point), the components of a decision strategy that involve retrieval from long-term memory—including the evaluation of a feature's desirability and importance—may require a degree of effort that depends on the content of the information being retrieved. Current thinking about the effort of such decision components focuses on the number of times a strategy requires information to be retrieved, likening each retrieval to looking up a value in a table. However, this "table-look-up" metaphor does not differentiate according to what is being retrieved, or how, or according to the person's past history with that information.

Fourth, and perhaps most intriguing, memory considerations reveal that there are ways to accomplish the work of a decision strategy without any processing that we would normally consider to be strategy-guided. The combining of different sources of information into a composite impression of an alternative, which lies at the heart of many decision strategies, is in many ways similar to the formation of a prototype as a composite of multiple exemplars. Yet, in many current memory models, prototypes emerge without deliberate, conscious, or effortful computation, as the natural result of a unified memory store that retains traces of all exemplars superimposed in a highly distributed representation. In this way, memory models may provide an alternative to decision strategies altogether, as an explanation of the way that a person achieves an overall impression of an alternative.

To explore these ideas further, in the remainder of this chapter we will consider the relationship between memory and decision making. First, we describe a set of empirical dissociations found between certain judgment and memory tasks. In particular, we will emphasize the discrepancy between serial position effects in recall and the effects on judgment of the order of presentation of items of information. Second, we propose an account of the dissociation that stresses the nature of the memory store, rather than the decision strategy. In doing so, we rely on a framework that incorporates a parallel distributed processing model of memory, Murdock's (1982, 1983) Theory Of Distributed Associative Memory (TODAM). Among models of its type, TODAM is perhaps the best developed process model of memory and has received extensive empirical testing in a wide variety of different areas of memory. Finally, we discuss some general implications for areas of decision research that we think might benefit from a deeper consideration of memory.

DISSOCIATIONS BETWEEN MEMORY AND JUDGMENT

Most people have the intuition that there should be a strong positive relationship between a person's judgment of an alternative and the person's memory for the alternative's characteristics. In the first place, a person's opinion about an alternative can itself be used as a retrieval cue for the alternative's characteristics, and might be expected to facilitate retrieval of information consistent with the opinion. Conversely, according to information-processing accounts, a person's opinion is based on information that was brought into short-term memory and involved in mental operations. For either reason, or both, one would expect favorable opinions to be accompanied by recall of more (or more strongly) favorable than unfavorable items of information, and one would expect particularly memorable items to be those that had a particularly strong impact on the opinion.

The data, however, are decidedly mixed. Some studies (e.g., Beyth-Marom & Fischhoff, 1977) have indeed found a strong memory-judgment relationship. On the other hand, the lack of a reliable relationship between attitude change and recall of a persuasive message has been cited as the finding mainly responsible for changing the direction of attitude research (Lichtenstein & Srull, 1985, 1987). Hastie and Kumar (1979; see also Srull, 1981) even showed that there are circumstances under which people will have superior memory for items of information that are *inconsistent* with their opinions.

Hastie and Park (1986; see also Lichtenstein & Srull, 1985, 1987; Sherman, Zehner, Johnson, & Hirt, 1983) explain some of the variability in experimental results by differentiating between judgment tasks. They distinguish between *on-line* and *memory-based* judgment, according to the source of the information that is used at the time the judgment is made (see Carlston, 1980; Lingle, Dukerich, & Ostrom, 1983; Lingle, Geva, Ostrom, Lieppe, & Baumgardner, 1979; McArthur, 1980). To promote memory-based judgment, the subject is exposed to information without forewarning that a judgment will be requested. In fact, the subject may be misdirected about the task to prevent him or her from spontaneously forming a judgment as the information is encountered (on-line). For example, if the information consists of sentences describing the behavior of a hypothetical person, the subject may be given the sham task of assessing the grammatical correctness of the sentences. When subjects are surprised, later on, with a request for an evaluative judgment (e.g., of the likability of the person), they no longer have the relevant information available to them in an external display. Instead, they must retrieve whatever relevant information they can from memory, to form a judgment. Under these conditions, differential memory for the various items of information will shape the informational basis of the judgment, and produce the intuitively expected correspondence between memory and judgment (see Tversky & Kahneman, 1973).

By contrast, to promote on-line judgments, the subject is forewarned of the impending judgment, and instructed to form an impression. Presumably, then, the subject extracts the judgment-relevant aspects of the information, and updates his or her impression sequentially, "on-line," as the information is encountered. Under these conditions, the relationship between memory for the items of information and their impact on the judgment is much less clear, and Hastie and Park (1986) review a variety of theoretical accounts that would predict either a positive, negative, or zero relationship between judgment and memory performance.

While the distinction between memory-based and on-line judgment explains much of the variability observed in memory-judgment relationships, it cannot account for all results. Dissociations between serial position effects for memory vs. judgment tasks, for example, have been found even in experiments where subjects made only on-line judgments.

SERIAL POSITION EFFECTS IN MEMORY AND JUDGMENT

N. H. Anderson and Hubert (1963), as an early example, asked subjects to rate the likableness of a hypothetical character on the basis of trait adjectives. They found a recency effect for the recall of the adjectives, but a primacy effect for the adjectives' impact on the likableness ratings. More recently, Dreben, Fiske, and Hastie (1979) presented subjects with four items of information (sentence pairs describing a hypothetical person's behavior) and asked for both likability judgments and free recall of the items in five different (between-subject) experimental conditions, all of which involved on-line judgments. In Conditions 1-3, the instructions called for a new, updated judgment after the presentation of each item—a "step-by-step" (SbS) response mode. In Condition 1, the four likability judgments were obtained sequentially, without intervening tasks. In Conditions 2 and 3, the four likability judgments alternated with an additional unrelated task (trait ratings in Condition 2, and math multiplications in Condition 3). In Conditions 4 and 5, subjects reported their judgments only after all items of information had been presented—an "end-of-sequence" (EoS) response mode. After the final likability judgment, subjects in Condition 1-4 had to recall as much as possible about the stimulus person, as they had been forewarned.

For all SbS judgments (Conditions 1-3) there were strong recency effects on the judgments. (That is, in a weighted linear model of the serial positions, an item of information appearing in the final position received greater relative weight than an item in any earlier position.) By contrast, for both EoS judgments (Conditions 4-5) there was no recency, but some primacy. These results agree with the summary results reported by Hogarth and Einhorn (1990), in their extensive review of order effects in judgment tasks. Hogarth and Einhorn (1990) found that the following factors affect the nature of order effects: (1) response mode (SbS vs. EoS); (2) complexity of items of information (e.g., trait adjectives vs. lengthy paragraphs); and (3) length of the series of items to be integrated. In particular, for "short" series of "simple" items as those in the Dreben, Fiske, and Hastie (1979) study, order effects depend on the response mode: EoS induces primacy, and SbS induces

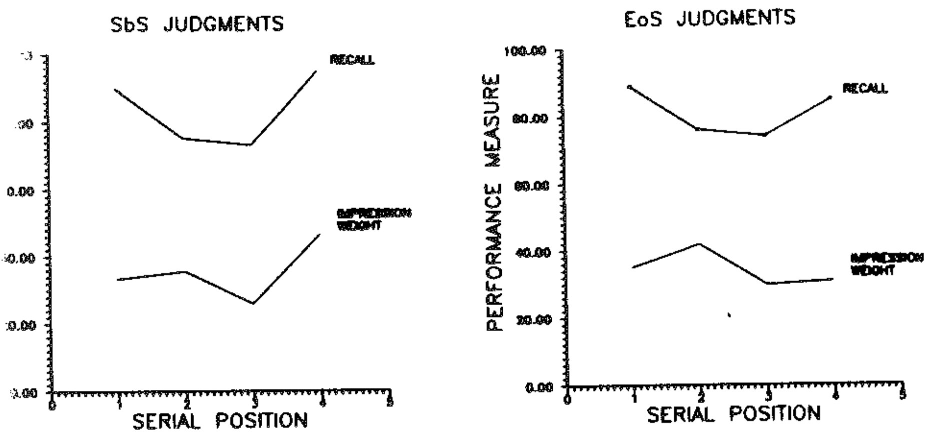

FIGURE 5.1 Effect of information as a function of serial position on two tasks (recall and likableness impression rating) under two different judgment conditions (SbS and EoS). Data reported by Dreben, Fiske, & Hastie (1979), Conditions 1 and 4.

recency. (The belief-adjustment model proposed by Hogarth & Einhorn, 1990, accounts for the various order effects found in some sixty studies of judgment but makes no predictions about serial position effects for memory tasks.)

The observed dependence of order effects on the response mode is particularly interesting, as the response mode is thought to be related to the distinction between on-line vs. memory-based judgment, discussed earlier as a factor that mediates the relation between memory and judgment. Specifically, the SbS response mode virtually ensures that people will use an on-line method of judgment, while the EoS response mode allows for both on-line and memory-based judgment, and can promote memory-based judgment for those types of judgment that are not spontaneously evaluated on-line. Therefore, given Hastie and Park's (1986) results, one might expect a greater correspondence between order effects in judgment and serial position effects in recall when the mode is EoS rather than SbS. However, Dreben, Fiske, and Hastie (1979) found that serial position effects in recall did not depend on the response mode and that there was little correspondence between judgment order effects and recall serial position effects for either response mode. Specifically, as shown in Figure 5.1, although judgment order effects showed either recency or primacy depending on the response mode, serial position effects in recall always showed both, regardless of the response mode.

To account for such dissociations, N. H. Anderson (1981; Anderson & Hubert, 1963) suggested that the encoding of information into LTM traces on the one hand, and the evaluation and integration of evidence into a judgment on the other hand, occur in different memory systems. Yet, Humphreys, Bain, and Pike (1989) argued that postulating different memory systems does little more than rename the phenomenon of interest. To illustrate the usefulness of concepts from recent memory research for judgment and decision making models, we will model the Dreben, Fiske, and Hastie (1979) dissociation results using Murdock's (1982, 1983) theory of distributed associative memory (TODAM). In particular we will see that a two-memory hypothesis is unnecessary to account for the data. With a memory representation like that of TODAM where different types of memory information reside in the same memory vector *and* the assumption that people strategically encode and retrieve information, dissociations in performance can arise from a single memory system (e.g., Weber & Murdock, 1989).

DISTRIBUTED MEMORY: TODAM

Recently, memory researchers have become interested in a new class of models called distributed memory models, which have several distinctive properties. First, the representation in memory of each experience is distributed across a large number of memory nodes (analogous to neurons), and each node is activated by a large number of different experiences. This builds redundancy into the memory system which makes it insensitive to minor encoding errors or localized memory damage. Second, all memories reside in a common store and can be activated directly by the content of a retrieval cue. The retrieval cue affects a large number of memory nodes simultaneously, activating them in parallel, and these memory nodes interact with each other and with still other memory nodes. This retrieval process increases the speed and processing capacity of the memory system, and makes it unnecessary to search through various locations in memory to find the best match. This is an important property in light of recent doubts on the concept of serial memory scanning (Hockley, 1984). One particular distributed memory model is Murdock's (1982, 1983) theory of distributed associative memory (TODAM).

Encoding

Following J. A. Anderson (1969, 1973), TODAM represents information (items or events) as a vector of component attributes or features. Anderson's assumptions stem from attempts to provide a plausible neural information processing model, where items and events are represented as vectors of the firing frequency of neurons. Similarly, the features of TODAM should be thought of more as quasi-"neural" micro-features than as aspects of an item or event that would be identified as "features" by a human observer. However, TODAM makes no claim to being a neural model, but is an abstract mathematical model.

In this model, a vector A represents an item A. (Later, we refer interchangeably to an item of information and its vector representation.) It is assumed that A is a doubly infinite vector, $A = (\ldots, A_{-2}, A_{-1}, A_0, A_1, A_2, \ldots)$, where only the central N elements of the vector are nonzero ((N-1)/2 elements with negative subscripts and (N-1)/2 elements with positive subscripts, assuming N to be odd). In a Bayesian approach to representing the investigator's uncertainty about the features of A, the N central elements of A are assumed to be independent random variables with identical normal distributions, each with mean 0 and variance P/N, where P is a constant. (Note that $P = E(A \cdot A)$, so P is the mean squared Euclidean distance of an item vector from the origin, which, without any loss of generality, is usually set to 1.)

Storage

A common memory vector **M** provides a cumulative store of both item and relational information. This useful property distinguishes TODAM from other memory models that otherwise have similar properties (e.g., Humphreys, Bain, & Pike, 1989). To store a new item **A**, the numerical value of each feature is added to the previous value in the corresponding element of the memory vector; that is, the updated memory vector is **M+A**. An association between two items, **A** and **B**, is represented by the mathematical operation of convolution, denoted **A*B**, which itself results in a vector. In particular, the value of feature x of the convolution of two vectors **A** and **B**, with component features A(i) and B(i), is defined as:

$$(A * B)(x) = \sum_i \{A(i)\, B(x-i)\} = \sum_i \{(A(x-i)\, B(i)\}. \tag{1}$$

Murdock (1982) and Eich (1982) provide further technical definitions and intuitive interpretations of the convolution (and correlation) operations. For our purposes it suffices to appreciate that the convolution of two or more vectors also results in a vector. Storage of an association, as with item information, is represented by vector addition with **M**; that is, **M+(A*B)**. Thus, item and associative information can be superimposed in the same memory vector.

To model the strategic allocation of attention to different kinds of information, different weights are placed on the vectors that are added to **M**. Moreover, to avoid saturation of **M** and to model forgetting, the current vector **M** is discounted by a forgetting parameter α $(0 \le \alpha \le 1)$ every time new information is added. Thus, to store the tth item on a list; that is, A_t, together with its association with some context item B_t (i.e., $A_t * B_t$) the memory vector would be updated as follows:

$$M_t = \alpha\, M_{t-1} + \beta\, A_t + \delta\, (A_t * B_t), \tag{2}$$

where α denotes the forgetting parameter, and where $\beta + \delta = 1$ to model the finiteness of attentional capacity.

Retrieval

TODAM provides for different types of retrieval in response to different memory tasks. Recognition is the process by which a probe item is compared with information in memory, resulting in a yes-no response. Cued recall is the process by which an item is generated in response to a question. Recognition is modeled by the dot-product of probe item **A** and memory vector **M** (i.e., **A·M**). The resulting value, which reflects the similarity between **A** and **M**, is fed into a two-criterion decision system very similar to the one proposed by Swets and Green (1961). More details can be found in Murdock (1982, 1983), with extensions that allow the system to make reaction time predictions in Hockley and Murdock (1987). To derive predictions for the decision stage of the model, one needs to know the expectation and variance of the dot-product similarity between probe and memory vector both for old (i.e., previously stored) and new item probes. Analytic derivations for these moments can be found in Weber (1988).

The generative process of cued recall is modeled by the correlation operation, which again results in a vector. The value of feature x of the correlation of two vectors **A** and **B**, with component features A(i) and B(i), is defined as:

$$(A \# B)(x) = \sum_i \{A(i)\, B(x+i)\} = \sum_i \{A(i-x)\, B(i)\}. \tag{3}$$

For cued recall, the probe **A** is correlated with the memory vector **M** (i.e., **A#M**). Since **M** is a sum of previously stored vectors representing items and associations, and since correlation is a linear operation, the correlation of **A** with **M** can be treated as the sum of the correlations of **A** with the vector constituents of **M**. Conceptually, the correlation operation is a sort of "inverse" of the convolution operation, in the sense that **A#M** produces an output closely resembling the vectors that have been previously convolved with **A**. Thus, for example, the *expectation* of the vector resulting from the correlation **A#(A*B)** across different **A**-vectors for a given vector **B**, will be vector **B**. (The expectation of a vector is the vector of the expectations of its components.) However, even if **M** consists only of the convolution **A*B**, any single correlation **A#M** (i.e., **A#(A*B)**), as opposed to its expectation, will result in a vector **B′** = **B** + noise. The correlations of a probe with components of the memory vector other than convolutions in which the probe is involved (e.g., **A#(B*C)**) have an expected value of zero (but non-zero variance). Thus, for any given correlation of a probe with a memory vector, for example, **A#M**, where **M** is a weighted sum of, say, item information **A** and **C** and associative information **A*B** and **C*D**, the component correlations **A#A**, **A#C**, and **A#(C*D)** will add additional variance to the result of the correlation.

Response

Conversion of the retrieved vector **B′** into an overt response requires an additional stage of processing outside the scope of TODAM. Murdock (1987) discusses several existing algorithms for this stage that he calls "deblurring" (e.g., Hopfield, 1982). While TODAM does not model deblurring at the process level, it does predict its probability of success. To predict recall performance, TODAM computes the probability that the vector retrieved by the correlation operation (e.g., **B′**) is more similar to the target item **B** than to any other item and that the retrieved information **B′** is within criterial range of the target. (For the exact mathematical expression see Murdock, 1982.) In their extensions of TODAM that allow it to make predictions about reaction times, Hockley and Murdock (1987) assume that it is this decision or response generation stage whose duration is sensitive to the particulars of the cognitive task, not storage or retrieval. It is reasonable to assume that differences in relative effort for different tasks also occur at this response generation stage and not earlier during storage and retrieval.

Memory Dissociations

TODAM allows for possible dissociations between recognition and cued recall by assuming independent memory representations of item information and associative information. Even though the two types of information are stored in the same memory store, M, thus eliminating search or homunculus problems, the information is independent in the sense that, on average, item information will not contribute signal strength in a cued recall task, nor will associative information contribute signal strength in a recognition task. Different tasks or strategic considerations will encourage the selective encoding of different types of information (e.g., item vs. associative).

Elaborations of TODAM

From its conception in the early 1980s, TODAM has become increasingly sophisticated. Elaborations of the model have been largely "data-driven," to account for a body of experimental results increasing in complexity and scope. Thus, TODAM models forgetting and serial position effects by the joint operation of the model parameter, $\alpha < 1$ (representing decay of the existing compound memory vector every time new information is added) as well as output interference (the addition of recalled items back into the memory store). Learning (i.e., the phenomenon that memory performance improves with repeated presentations of the stimulus) has been modeled by either a "closed-loop" version of TODAM (Murdock & Lamon, 1988) where additional information gets encoded only to the degree to which it is not already represented in memory, or by the probabilistic encoding of item features (Murdock & Lamon, 1988; Weber, 1988) where the probability of encoding a particular feature is a function of presentation duration. Another elaboration of TODAM has been the introduction of correlated as opposed to independent item vectors (Murdock, 1989).

TODAM ACCOUNT OF MEMORY-JUDGMENT DISSOCIATIONS

To model the types of judgments of the Dreben, Fiske, and Hastie (1979) study in the framework of TODAM, we have to expand TODAM even further. In particular, we have to provide it with a mechanism to generate an *evaluation* of a person or object along some dimension (e.g., likability or utility) on the basis of information about the person or object. This mechanism takes the place of both the "table-look-up" assumption and the algebraic information integration rules of current information processing models. However, as a process model, it explains how such evaluation comes about and also makes predictions about the relative effort of this operation under different conditions and levels of experience that are different from those of the table-look-up metaphor.

Evaluative judgments

We will assume that people encode emotional and other evaluative reactions as complex associations in memory. With experience, objects or events get associated with various emotional reactions, for example, degrees of likableness, disgust, or fear. When encountered, these reactions (together with the appropriate label of the evaluative dimension) are associated (convolved) with the cues that brought them about. Thus, the realization of a low degree of appreciation for anchovies would be encoded as the triple association: Anchovies*Likableness*Low which would be added to the memory vector M. The evaluative label "Likableness" is itself a vector, and we make the additional assumption that the vector representation of experiencing a "Low" degree of likableness is a vector that is "similar" to the Likableness vector to an extent that represents the experienced degree of likableness. "Similarity" is operationalized as the angle between the particular "degree of likableness" evaluation vector and the Likableness dimension vector, such that the length of the projection of the evaluation vector on the dimension vector represents the degree to which the particular instance scores on the likableness dimension. When subsequently a cue is presented with the request to evaluate it along a given dimension ("How likable are anchovies?"), we assume that the double association of cue and evaluative dimension is simply correlated with the memory vector (e.g., [Likableness*Anchovies] # M). The output will be a vector similar to "Low" if that likableness-evaluation has been the only one previously associated with "anchovies." If several associations (all of which would be represented by vectors) were stored with that tag, then the output will be a composite of those different associations. If an overt response is required, then the retrieved vector would undergo some response transformation (e.g., deblurring), the stage of the memory process whose effort depends on both the retrieved vector and the characteristics of the task. One implication of our assumption about the nature of evaluative judgments is that the effort in reporting the affective value of an object or event is *not* independent of the event or object. Instead it will depend on the past "memory history" of affective or evaluative associations experienced with that object or event (e.g., number and strength of associations, time since encoding, interferences, etc.).

Encoding

To apply TODAM to reproduce the serial position and order effects shown in Figure 5.1, we have to make a variety of encoding assumptions. When people are presented with four items of information (S_t, $t = 1, \ldots, 4$) about a hypothetical person (P), with the instructions to form a likableness judgment of the person (either after each additional item [SbS] or at the end [EoS]) and to recall the items of information after their final judgment task, we assume that they will try to make good use of their time by encoding at least the following two types of information. First (for free recall purposes), they will rehearse the S_t in working memory (most likely in the serial order t in which they come in). This will result (among other things) in the encoding of a chain of pairwise associations from serial position $t = 1$ to 4, for example, $S_{t-1}*S_t$ (see Lewandowsky & Murdock, 1989). Since there are fewer items in the rehearsal buffer (assumed to be of fixed size) for the earlier serial positions, there are more opportunities to rehearse and thus store S_1*S_2 associations into memory than later association pairs, for example, S_3*S_4. (We assume that performance improves with rehearsal because the $S_{t-1}*S_t$ get entered either in a closed loop form or via probabilistic encoding).

Second, people will use S_t information received at time t to generate an evaluative judgment, J_t, as described earlier. Thus, if one piece of information (S_t) describes individual P as arrogant, people will query their memory for past evaluations for the likableness of arrogance (i.e., [Likableness* S_t]#M_{t-1}) with resulting judgmental output J_t. As discussed by Hastie and Park (1986), some of these evaluative judgments are generated spontaneously and automatically by people, whereas others need to be prompted by task instructions. "Likableness" may belong to the former category, but in the Dreben, Fiske, and Hastie (1979) study, subjects also were explicitly instructed to evaluate people on the likableness dimension. For our model, we further assume that people will then associate their evaluation of the degree of likableness (J_t) of a given item of information with the person (P); that is, J_t * Likableness * P.

Other information that people could encode at each serial position includes item (rather than associative) information about S_t and the likableness evaluation, J_t, as well as S_t*P associations. None of these pieces of information are useful for the specified subsequent memory or judgment tasks, but people probably encode some of this information automatically or to hedge against later changes in task requirements. Thus we include an "other traces" component, O_t, to represent the sum of such additional memory components. Adding this component has no effect on the expected value of the "signal" components of memory nor judgment performance (because for the memory and judgment cues that we hypothesize later, the expectation of the correlation of the memory or judgment cues with O_t is zero). By increasing the "noise" component in all tasks, O_t will however decrease overall mean performance.

In summary, TODAM's memory vector at serial position t is assumed to be updated as follows:

$$M_t = \alpha\, M_{t-1} + \{\beta_t\, (S_{t-1} * S_t) + \delta_t\, (J_t * \text{Likableness} * P) + \phi_t\, (O_t)\}, \quad (4)$$

where α, as before, is the forgetting parameter, where β_t, δ_t, and ϕ_t are the relative attention weights given to the encoding of the corresponding memory vector components, and where $\beta_t + \delta_t + \phi_t = 1$ to model limited attentional capacity.

The attention weights β_t, δ_t, and ϕ_t are indexed by the serial position of the incoming information to allow us to model changes in relative attention over serial position. Attention decrements over successive items of information (i.e., serial position) have been suggested by Lewandowsky and Murdock (1989) for recall and by N. H. Anderson (1981) for EoS judgments. Such decrements in the strength of encoding parameter values over serial position could represent either voluntary and strategic shifts in attention from one component to another or the fact (discussed earlier) that rehearsal of information is more effective for earlier serial position than for later ones because less information resides in the rehearsal buffer for the earlier positions.

Recall

Free recall of the S_t items is mediated by the pairwise $S_{t-1}*S_t$ association part of the memory vector (see Metcalfe & Murdock, 1981, and Lewandowsky & Murdock, 1989). Subjects will output S_4 because it still resides in working memory. This gives rise to the recency effect for the last serial position as shown in Figure 5.1. That this effect is mediated by a "buffer dump" from working memory is further supported by the fact that the recency effect in Dreben, Fiske, and Hastie (1979) is smaller for those conditions where additional or more complex tasks intervened between presentation of the final item and free recall. After recalling S_4, subjects will also use it as a retrieval cue; that is, S_4#M, which results in output S'_3. If properly deblurred to S_3, this item is recalled and, in turn, becomes the next retrieval cue; that is, S_3#M, which results in output S'_2, and so on. If a retrieved item, for example, S'_3 cannot be properly deblurred, it will not be recalled, but can still be used as the next (even though less effective) retrieval cue; that is, S'_3 # M. Thus, the quality of retrieval cues can increasingly deteriorate the further back in the chain one gets, producing further recency. In addition, pairwise associations further back in the chain will have been subjected to more decay, since the memory vector M gets discounted by $\alpha < 1$ with each new entry, which also results in recency. On the other hand, for earlier associations subjects had the time to encode them more strongly (frequently), a force which can outweigh the negative effect of memory decay for the early items of information, thus accounting for the primacy effect of the serial position curve for free recall. (Another way of describing this last effect is in terms of an attention weight decrement of β_t over serial position.)

Likableness Judgment

Judgments of likableness are mediated by the part of the memory vector that associated the judged likableness of the information with the person; that is, J_t*Likableness*P. Prompting the memory vector with "what's the likableness of person P" (i.e., [Likableness*P] # M) after the Tth item of information, will result in retrieval of an evaluation $J_{\Sigma T}$ that is the composite or the weighted sum of all J_t previously associated with Likableness*P. It should be noted that the retrieved composite vector $J_{\Sigma T}$ is the "natural" product of routine memory updating. In other words, memory processes alone can generate a composite impression or judgment and thus replace (or, at least, give a new interpretation to) the notion of strategy-guided composition of information. In this memory framework, the effort in retrieving the composite $J_{\Sigma T}$ will *not* depend on the number of J_t items that were integrated into the composite. Instead, as discussed earlier, differences in relative effort will occur at the response generation or deblurring stage.

The deblurring or conversion of the retrieved $J_{\Sigma T}$ vector into a scalar value that reflects the composite degree of likableness is modeled by computing the length of the projection of $J_{\Sigma T}$ onto the Likableness vector. In other words, the response function R that maps the vector $J_{\Sigma T}$ into a scalar is given by:

$$R\,(J_{\Sigma T}) = (J_{\Sigma T} \cdot \text{Likableness})\,/\,\|\,\text{Likableness}\,\| \qquad (5)$$

Since $J_{\Sigma T}$ is a function of serial position and of the model parameters of Equation (4), so will be $R(J_{\Sigma T})$. Since we are dealing with a linear memory storage model, it is easy to compute the expectation of $R(J_{\Sigma T})$ as a function of serial position. In particular, for a given sequence of S_ts, for $t = 1$ to 4, the expectation of the likableness judgment of a given person P at position T is given by:

$$E[R(J_{\Sigma T}) = E\{R([\text{Likableness} * P]\ \#\ M)\} = R\left\{\sum_t \alpha^{T-t}\ \delta_t\, E\,(J_t)\right\}, \qquad (6)$$

because $E\{[\text{Likableness}*P]\#[S_{t-1}*S_t]\} = E\{[\text{Likableness}*P]\#O_t\} = 0$, and $E\{[\text{Likableness}*P]\#[J_t*\text{Likableness}*P]\} = E(J_t)$.

N. H. Anderson's (1981) attention decrement assumption for the δ_ts will predict the mild primacy in the likableness judgments for the EoS conditions, if the decrease in δ_t is fast relative to the forgetting rate α. For the SbS judgments on the other hand, it seems more appropriate to assume that δ_t = constant, in other words, subjects are forced to attend to each new piece of information, producing constant attention across serial positions. In this case, serial position effects are proportional to α^{T-t} for position t, producing recency effects.

DISCUSSION: GENERAL IMPLICATIONS FOR FUTURE JUDGMENT AND DECISION MODELS

In this chapter, we tried to raise several issues concerning the relationship between modeling in memory and in decision making. First, we tried to illustrate the advantage of developing more explicit procedural models of cognitive tasks. Only when one tries to simulate a particular process, does one realize how many subprocesses need to be specified at the micro- level. Also, several of the explanations or predictions for particular serial position effects in the judgment or memory tasks were direct consequences of micro-level representational assumptions (e.g., memory decay).

Second, we tried to outline different possible conceptualizations of information integration and cognitive effort. One of the more promising recent developments in decision research has been a renewed emphasis on people as adaptive and efficient information processors or problem solvers. Presumably, people perform the equivalent of effort-benefit meta-analyses to decide on optimal judgment and decision making procedures given task, contextual, and cognitive demands and constraints. However, current conceptualizations of "effort" make extensive use of several largely implicit information processing assumptions (e.g., discrete representation of information, sequential processing). This chapter tried to introduce a different framework that, in some situations, will make different predictions about relative effort.

Third, we discussed that, outside the field of social cognition, current judgment and decision models leave out much that is important for real decision tasks. One important aspect is memory retrieval, both in order to generate (i.e., retrieve or infer) consequences of possible choice alternatives and to evaluate their utilities. Avoidance of memory considerations by providing people with "complete" information in laboratory decision tasks or by modeling them with overly simplistic assumptions (e.g., table look-up) may not only be potentially misleading but also unnecessary. As illustrated in this chapter, process-level memory models exist that will allow us to make explicit and testable predictions about the nature of memory representations and processes and their effects on memory and judgment tasks alike.

Finally, we discussed the prevalence and importance of the concept of "decision strategies" in current theories and meta-theories of judgment and decision making and described two ways in which the term "strategy" is being used in current models. We suggested that the two meanings (outcome model strategies and process strategies) are quite distinct and should not be confused. More importantly, we tried to illustrate that in the context of judgment or decision models that incorporate memory encoding and processing assumptions, certain judgments (e.g., composite evaluations on some dimension) can be achieved solely through memory processes without any processing that relies on strategy in either of these two senses. Furthermore, "strategic" behavior can take on yet a third interpretation. In particular, we provided some examples of *strategic encoding* of information and *strategic use of memory cues* for recall or judgment. *Encoding strategy* in the context of a memory model like TODAM refers to the strategic allocation of attention to different types of information (e.g., item vs. associative information) or to changes in attention over time. We showed that such strategic changes in memory processes (during encoding and cue utilization) may be sufficient to explain dissociations between tasks, and no recourse to multiple memory systems nor other changes in processing strategies may be necessary.

The assumption of strategic differences in information encoding and memory retrieval provides for a variety of additional or alternative ways in which task and context effects can be incorporated into expanded procedural models of decision making. At the level of the encoding of the *content* of information, Markowitz's (1959) assumption that people may encode the outcomes of possible courses of action relative to different reference points (i.e., different "frames") has been an important explanatory feature of Kahneman and Tversky's (1979) prospect theory. Hogarth and Einhorn (1990) recently presented another good example of how the assumption of strategic *encoding* differences can provide a (perhaps more parsimonious) explanation for judgment data than the assumption of strategic differences in *integration rules* (i.e., strategies in the outcome model sense). In their belief-updating model designed to account for evaluative judgments of the type discussed in this chapter, the authors distinguish between the following two ways in which evaluative stimuli can be encoded: (1) relative to a fixed standard and (2) relative to a changing standard, for example, a moving average. Different judgment tasks (e.g., the SbS vs. EoS conditions of our example) may induce people to use different encoding strategies. Encoding relative to one's previous judgment in an anchoring-and-adjustment manner virtually suggests itself as the most efficient use of information in the SbS condition. On the other hand, absolute encoding (or encoding with a constant reference point) may be more natural for the EoS condition.

As discussed by Hogarth and Einhorn (1990), different encoding strategies (constant vs. variable standard) followed by the same integration or decision strategy (i.e., an adding model) will result in data that appear to have been generated by *different* information integration strategies. An adding model will fit data that were encoded with a constant standard, whereas data that were encoded relative to a variable standard are fit by an averaging model. Thus, an indeterminacy exists between differences at the encoding stage and differences at the integration stage. Furthermore, encoding differences of this type can provide yet another explanatory framework for differences in serial position effects for the two judgment conditions (e.g., N. H. Anderson, 1964). It is important to realize that task conditions that appear to be affecting information integration strategies may, in fact, have their effect at a different stage of the process. Converging validation from a variety of experiments and experimental methods (e.g., process tracing) may then be able to discriminate between the different types of explanations. For purposes of decision aiding, it would be crucial to know whether differences in judgments are due to people using different encoding procedures or different integration rules.

In summary, this chapter tried to outline some of the benefits of incorporating considerations of memory into models of judgment and decision making. In a hands-on example, we employed modeling components drawn from recent memory research in an analysis of a specific pattern of relationships between some judgment and memory tasks. The specific model was offered in the spirit of a demonstration of the advantages of such an approach and in the hope that it will encourage other researchers to take a more memory-oriented view of decision problems.

It seems desirable to avoid the fate of the six blind monks in the ancient Hindu story, who argue about the nature of an elephant they find in the forest. One monk feels the elephant's huge leg and is convinced that elephants are very much like tree trunks. Another monk, feeling the elephant's enormous back, proclaims that elephants are like large boulders. Upon feeling the elephant's trunk, a third monk warns the others that elephants are like large snakes. The obvious moral of the parable is that we may be misled by limiting our view to a single isolated part of a problem. As decision researchers, we should not overlook the importance of memory considerations, because, after all, elephants never forget!

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