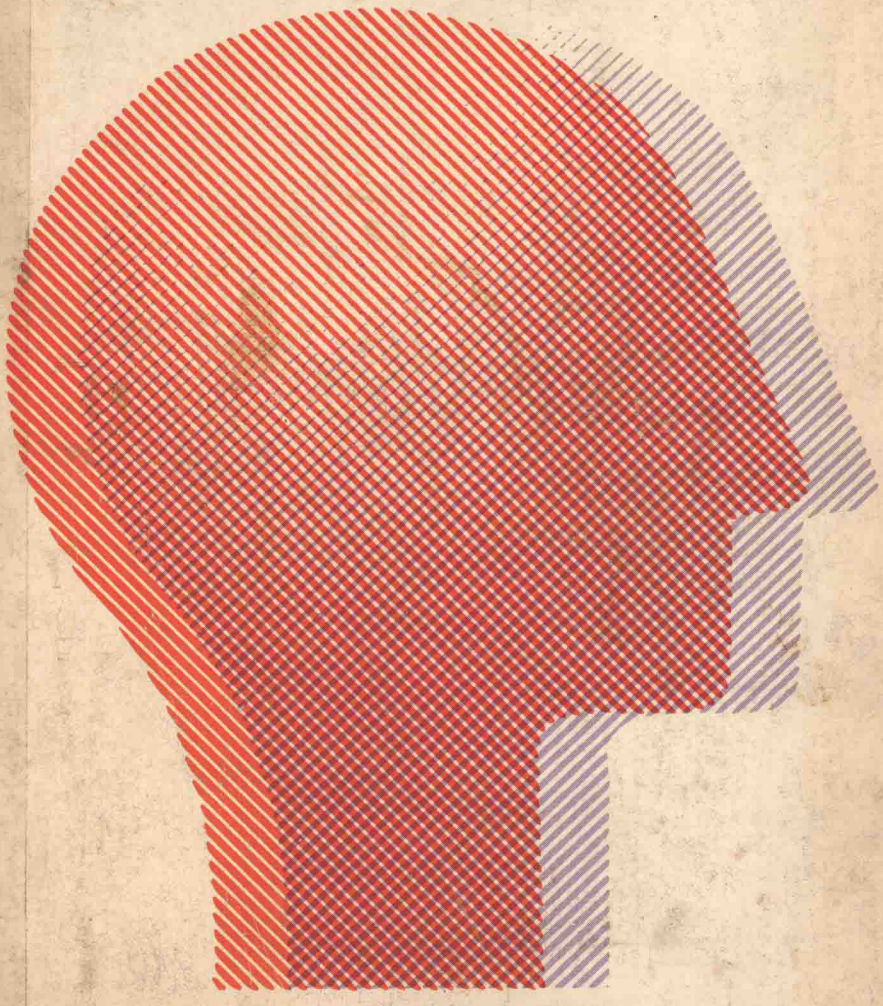
The Structure of Human Memory



The Structure of Human Memory

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THE PENNSYLVANIA STATE UNIVERSITY

W. H. Freeman and Company
San Francisco

Library of Congress Cataloging in Publication Data

Symposium on the Structure of Human Memory, New York, 1975.
The structure of human memory.

Includes bibliographies and index.
1. Memory—Congresses. I. Cofer, Charles Norval. II. Title. [DNLM: 1. Memory—Congresses. BF371 S9895s 1975]
BF371.S96 1975 153.1'2 76–2581
ISBN 0–7167–0705–5
ISBN 0–7167–0715–2 pbk.

Printed in the United States of America

9 8 7 6 5 4 3 2 1

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A Series of Books in Psychology

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An Historical Perspective

Charles N. Cofer

The study of memory by psychologists has a long history of experimental work, dating from the publication in 1885 of Hermann Ebbinghaus' monograph, *Memory.* However, consideration of memory has not been solely the province of psychologists. Memory has been a topic of interest to philosophy as early as the time of Plato and Aristotle; to psychiatry and neurology as part of the diagnostic examination; to psychoanalysis as represented in Freud's theory of forgetting as a consequence of repression; to literature as seen in Proust's *Remembrance of Things Past;* and, recently, to computer scientists and students of artificial intelligence, who must provide a "memory" or storage of facts, principles, and operations in order to write programs for complex processing by computer.

It is beyond the scope of this book to deal with memory as it concerns psychiatry, psychoanalysis, and literature. Philosophy does not enter directly either, although the thoughtful reader will discern in these pages a number of philosophical issues, largely in the form of implicit assumptions about memory and the ways in which human beings deal with and represent experience. Representations that endure after an actual experience has ended are, of course, the essence of memory. Memory is the name we give to our ability,

good or poor, to hold in mind both recent experiences and those which constitute our pasts. We remember what we learned in school, what we have read, what people have said, where we live and work, what we did yesterday and what we must do today or tomorrow. Of course, a common complaint is that we do not remember things well; this is one of the reasons for our interest in memory. Were our memories perfect, never failing us in time of need, we should probably not concern ourselves with memory at all.

The contributions to this book rest on the assumption that memorial processes can be studied. This assumption has underlain all experimental work on memory since it was initiated by Ebbinghaus in the years 1879–1880 (see Ebbinghaus, 1885, p. 33). Yet, in the last quarter century, the problems to which experimentation has been directed have shifted from those that concerned Ebbinghaus. While his emphasis on careful laboratory procedures and quantitive methods remains, recent investigators have identified new problems and devised new techniques for their study. The chapters in this book represent some of these conceptual and methodological developments. It will be instructive to discuss, in summary form, the concerns of students of memory throughout the history of its experimental study, the methods they have used in experimentation, and how both those concerns and those methods have altered as the decades have passed.

The Ebbinghaus Tradition

Ebbinghaus, in the introduction to his monograph (pp. 1–2), referred to certain effects of memory, which presumably spurred him to study memory. He pointed out three effects of memory: (a) we can "by an exertion of the will" recover lost states (i.e., reproduce them); (b) prior states can occur to us involuntarily (i.e., spontaneously); (c) even without the reproduction of "lost states," the states continue to have influence—they may govern "a certain range of thought" and they represent "the boundless domain of the effect of accumulated experiences. . . ." Ebbinghaus also spoke of the conditions on which memory depends, referring to differences among individuals and to differences in the contents to be regained. He suggested roles for attentiveness and interest, as well as for repetition, as conditions of memory. He pointed out how little was known about memory, and he saw a value in applying the methods of natural science to its study. Yet, he realized the difficulties. How, he asked, can we keep "constant the bewildering mass of causal conditions which, insofar as they are of mental nature, almost completely elude our control, and which, moreover, are subject to endless and incessant change?" Further, how can we "measure numerically the mental processes which flit by so quickly and which on introspection are so hard to analyze?" (pp. 7–8).

Ebbinghaus solved these methodological difficulties by setting up laboratory studies of memory on himself. He standardized conditions, invented materials to be studied, devised a procedure of investigation, and found ways of measuring his results in quantitative form.

The study of memory, as Ebbinghaus realized, is difficult, and he thought to circumvent these difficulties by the means just listed. It is not clear whether he felt that his studies contributed to the solution of the problems he raised in his introductory chapter. At any rate, he did not discuss his findings in relation to those problems.

How did he solve the problems of method he had set forth? Basically, he solved them by studying the retention of associations he acquired under strictly controlled conditions. First, he invented the nonsense syllable, a unit composed of a vowel surrounded by two consonants which was not a three-letter word. He made up over 2300 of these syllables and, for an experiment, assembled some of the syllables into a list to be learned in order from beginning to end. He used lists of varying lengths (e.g., 8 items or 32 items), read through each list a number of times, tested his ability to recite the items in order from memory, and concluded his study of a list when he could recite the items in order without error either once or twice.

As a measure of performance, Ebbinghaus simply counted the number of repetitions it took him to be able to recite the list without error; he also measured the time in seconds required for him to learn lists to this criterion of mastery. With this measure he could compare for difficulty lists of different lengths and could measure their retention over time. To assess retention, he relearned lists; if after a time interval he could relearn a list in fewer repetitions or in less time than had been required for original learning then there was a saving. He used the savings method to study retention or forgetting as well as to examine certain other problems (e.g., the formation of remote associations).

The methods introduced by Ebbinghaus dominated the study of memory (called verbal learning by Meumann as early as 1913) for 65 to 70 years. A basic feature of his methods is that material is presented *de novo* to a person who is to learn or remember it. As Meyer and Schvaneveldt point out in their chapter of this volume, some recent investigations of memory omit this step and use procedures to gain access to what a person already knows. However, before the developments to which Meyer and Schvaneveldt refer occurred, even investigators not sympathetic to the use of nonsense syllables, rote memory, or repetition in studies of memory (such as Bartlett, 1932) presented the to-be-remembered material to their subjects.

We cannot review here all of the work that was conducted in the Ebbinghaus tradition (see McGeoch and Irion, 1952). But the bulk of it was concerned with five main problems: (a) the conditions governing economy in learning; (b)

the differences in acquisition and retention occasioned by different sorts of materials, for example poems versus lists of nonsense syllables; (c) differences among people in learning and retention; (d) the conditions and the theory of forgetting; (e) the transfer of training, that is, the extent to which and the conditions under which learning one thing (e.g., one language) affects the learning of another thing (e.g., another language) either positively or negatively. Numerous variations in methods, procedures, and materials were introduced in the course of these various studies but their general tenor remained close to that of Ebbinghaus' work.

The Bartlett Tradition

In 1932 Frederick C. Bartlett reported experiments that deviated in several ways from those of the Ebbinghaus tradition. He did present a passage—a story—but usually only once. He tested for recall of the passage over substantial time intervals. Bartlett opposed the use of repetition and meaningless materials, although his famous story, "The War of the Ghosts," was a version of an Eskimo folk tale and contained a number of unfamiliar elements, such as unusual sequences, supernatural ideas, and actions (e.g., hunting for seals) not common in the experience of his experimental subjects, who were British. He published some of the "recalls" he obtained, and they displayed a great deal of error when compared with the original. They were abbreviated for one thing, but, more dramatically, they contained normalizations of the original content in the direction of making that content more compatible with the subject's knowledge and cultural experience. From these recalls, Bartlett concluded that memory is a schematic process—people remember a general impression of a passage they have read and a few details; out of these components they construct or reconstruct a version which they believe is a fair representation of the original.

Bartlett's findings have received a good deal of citation, but until recently they were not followed up very much by further studies or by theoretical analysis. Most of the work reported in this book is, however, more in his tradition than in the tradition of Ebbinghaus.

Structural Analyses of Memory

That memory may be viewed as a system of interrelated components is a structural idea. It is not an entirely new idea, as William James (1890, 1, pp. 643–648) distinguished between *primary memory*, one that endured for a very brief period of time, and *secondary memory*, "the knowledge of a former state of mind after it has already once dropped from consciousnesss . . ."

(p. 648). Meumann (1913, p. 317) made a similar distinction. Further, there have long been tests of an individual's *memory span*, that is, of the maximum number of digits, letters, isolated words, or words in sentences one can report in order after a single presentation. James' distinction, however, was essentially a phenomenal one, and the concept of memory span has been used mainly to test intelligence, compare the abilities of people of different ages, and study psychological and neurological disorders.

The recent development of structural models of memory was foreshadowed in Miller's (1956) paper. Miller used data from memory-span experiments to show that normal, adult, educated people can repeat back in order an average of only seven digits, letters, or words, despite the different informational loads that these kinds of material carry. He recognized, of course, that we are capable of much better memorial performances than this, and he suggested that the capacity of memory is augmented by coding or recoding devices. For example, we can perhaps remember 25 words rather than 7 if, say, the 25 words include 5 words from each of 5 categories, such as animals, weapons, articles of clothing, names of countries, and names of cities. As we listen to or read the list of words we can recode this input into the category names and, at recall, remembering the category names, produce the instances to which they are related.

In his paper Miller developed the notion of the organism as an information-processing device, with a limited capacity for handling information but with procedures for overcoming, at least to some extent, this limited capacity. Broadbent (1958) introduced an information-processing approach that contained explicitly a short-term memory (STM) of limited capacity. While information resided in this memory, it could be rehearsed and transferred to a more permanent store; alternatively, without rehearsal, it would be lost.

At about this time, Brown (1958), Peterson and Peterson (1959), and Sperling (1960) reported investigations of short-term memory. Peterson and Peterson showed that under certain conditions there is rapid forgetting of subspan items (like nonsense syllables), and Sperling suggested that after very brief visual presentation the information in the visual image is lost very rapidly. It seemed obvious to various writers that these observations required that there be not one but several memories in the human system, a very short-term memory as suggested by Sperling's findings, a short-term memory according to the Brown-Peterson experiments, and a long-term memory (LTM) to accommodate the obvious fact that all of us can and do retain enormous amounts of information over very long time intervals. Models of this kind are represented in Figure 2.1 (p. 18) of the chapter by Gilmartin, Newell, and Simon and in Figure 6.1 (p. 117) of the chapter by Norman and Bobrow.

Short-term memory has received much study over the years since it was first described in the late 1950s, and there has been a great deal of controversy over whether a multiple-component structure of memory is necessary or

whether a unitary model of memory is sufficient. This controversy revolves around the question of whether different processes must be postulated for short-term and long-term memories (almost everyone seems to accept the very short-term memory or sensory memory). The issue is complex and the experiments numerous; a full discussion is beyond the scope of this introduction. An alternative to the concept of different processes has been provided by Craik and Lockhart (1972) who analyze different depths of processing.

A major contribution of the work on short-term memory has been the study of the retention of single items (words or syllables) so that the list-learning technique introduced by Ebbinghaus is not necessary. On the other hand, the experimental study of short-term memory has been complex, typically involving the repeated testing of the same individual on different items in an experimental session. Many writers feel that this procedure introduces numerous complications, including interference effects from prior items and strategies employed by the research participants in their efforts to cope with the task. In their chapter, Gilmartin, Newell, and Simon consider explicitly the notion of strategies in the use of short-term memory. We can now summarize their chapter.

As can be seen in Figure 2.1 (p. 18), short-term memory (STM) is intermediate to the sensory stores (iconic, echoic, and the corresponding imagery stores) and long-term memory (LTM). Rather unusual in this model (compare Figure 6.1, p. 117, in Norman and Bobrow's chapter) is the explicit link provided between the imagery stores and LTM; this link provides for recognition of the information in the imagery store and the transfer of an appropriate symbol from LTM into STM. This linkage indicates the importance of LTM to the recognition and identification of items in STM experiments, usually ignored or implicitly assumed in other models. STM is conceived as a limited capacity store, and when new items enter it, the older items are bumped out unless rehearsal has reintroduced them at the front of STM. A grouping process can be employed in rehearsal and a group can be composed of items that are not adjacent in STM.

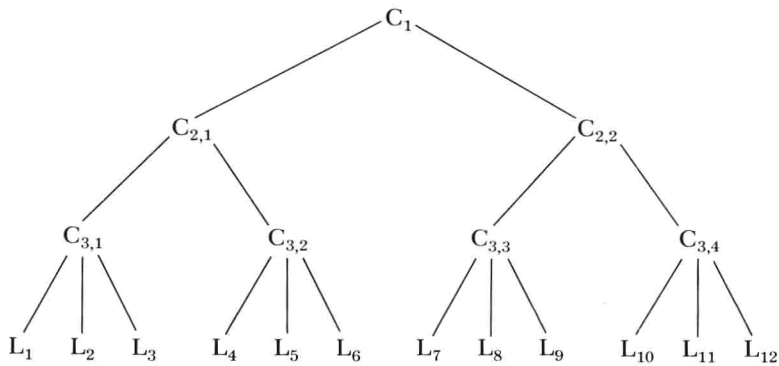
The components used in strategies are listed on page 22, and a strategy is outlined in Figure 2.4 (see p. 25; see also p. 24). Perhaps the most significant component of this strategy is the decision to rehearse the first two groups. Alternative decisions would have different consequences. Indeed, in the simulations (pp. 27–28), the effects of different decisions with respect to the size of the rehearsal groups can easily be seen.

It appears that Gilmartin et al. have assumed a particular structure for STM but have allowed through strategies various ways in which the processes in STM can be controlled, with varying effects. They propose structural arrangements to represent memory, but, through strategies, they permit a good deal of flexibility. The correspondence between the results of their simulations and the data obtained in experiments with human individuals is striking.

Structural models of memory represent a departure from simple associative models of memory. The latter, seemingly present in the works of such writers as Hobbes, Locke, Hume, and Ebbinghaus, represent the memorial process as a system of paths or chains of association that lead us from a question or some other cue to the answer or fact which memory contains. In his chapter, Estes indicates some of the difficulties that relatively recent research has provided for models stressing chains of associations. He points to the finding of backward associations and to the fact that the grouping of items in different ways (without changing their order or sequence) during the presentation of materials in a learning task makes their acquisition almost impossible.

Perhaps more significant than these findings, according to Estes, were the studies of free recall. This technique, in which a list of items (such as words) is presented one by one, has the essential feature that the subject can recall the items in any order in which they occur to him. Bousfield (1953) showed that if a set of words, each belonging to one of several mutually exclusive categories, is presented in random order, subjects tend to recall them, not in the order of presentation, but in groups or clusters of categorically related items. It is as if the instances are coded or recoded into category representations. One can think of these representations as occupying a level in a hierarchy higher than the instances themselves (as might be seen in a two-level tree structure, for example). The findings with the free-recall method accorded well with Miller's (1956) analysis of recoding, which, as he said, could occur at several levels. Mandler (1967, 1968) verified the plausibility of this sort of analysis in his empirical studies of free recall (see, also, Tulving, 1968).

Estes has tried to specify in his chapter (see, also, Estes, 1972) a reformulation of association theory that can account for some of these phenomena. His central idea is that when two events are experienced together they become associated with a *control element.* Further, control elements themselves can be associated with other control elements, so that a hierarchical structure can be built. Thus, in the presentation of a string of 12 letters segmented into groups of 3, we might have a structure like the following (Estes, 1972, p. 185):



In this diagram, L stands for a letter and C stands for control elements; the representation of the grouping is obvious. For reasons given in his chapter, and elsewhere, Estes believes that, within a general associative framework, his model can deal with grouping (or chunking), memory for the frequencies with which events occur, and information about the temporal order in which events occur. Explanations for some of these memorial capacities are not obvious in other theories. However, Estes does not propose that his hierarchical association model can handle everything, and he suggests that there may be levels of memory theory corresponding to different phenomena.

Structural accounts of memory can be more complex than those we have considered so far. For example, it may be desirable to subdivide the long-term-memory component already mentioned. Tulving (1972) made such a suggestion, pointing out that in our long-term memories we have available to us knowledge of the episodes in our pasts as well as knowledge of rules, facts, principles, and the like which have an existence independent of our own personal pasts. He suggested the terms *episodic memory* and *semantic memory* for these two classes of knowledge. One might distinguish them in the following way. My knowledge of how to take the square root of a number is representative of knowledge that is independent of me as an individual; it is part of arithmetic, a system of rules which anyone can learn. However, my memory or knowledge of having learned this skill—where and by whom it was taught to me or in what book I studied it—is more or less unique; it is a memory of an event or events that occurred in a time or place in my past. The rules for finding a square root are part of semantic memory; the remembrance of where, when, and how I learned those rules is part of episodic memory.

Tulving stressed differences between these two sorts of memories. One difference is that semantic memory is productive or generative, whereas episodic memory is not. Thus, I can apply the rules for taking a square root to any number, or my knowledge of the rules for alphabetizing words to any words. Memory for episodes does not have this character. There are, no doubt, parts of semantic memory which are not productive or generative either, like knowledge I may have of the succession of Presidents of the United States or of the sequence of the Kings and Queens of England. But much knowledge in semantic memory is potentially generative. This feature of semantic memory is elaborated to a large extent in the chapters summarized in the next section.

The chapter by Meyer and Schvaneveldt, however, represents another way of looking at semantic memory. These authors have measured reaction times for the verification of the truth or falsity of certain kinds of sentences and for the recognition or identification of words in various contexts. Performance in tasks like these is highly accurate, but consistent reaction-time differences do appear. Meyer and Schvaneveldt follow a view of the structural organization of semantic memory introduced by Quillian (1968; see Collins and