HUMAN MEMORY

STRUCTURES AND PROCESSES

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HUMAN MEMORY: Structures and Processes

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PREFACE

Each of us has a memory. We use it with such ease that it rarely occurs to us to marvel at our capacity for knowledge and the ways in which it is used. But the human memory is a remarkably complex entity, and although psychologists have studied it for many years, they are only beginning to describe and understand its complexities. Still, in the last two decades or so, research on human memory has provided an ever clearer representation of the memory system; it is that emerging representation which this book attempts to describe.

Memory is discussed in this book in an information-processing framework, one in which the memory system is depicted as continuously active in receiving, modifying, storing, and retrieving information. It is a view that includes perception and learning as part of memory, and topics in those areas are discussed. Although no attempt is made to cover every topic of interest to researchers in the field, those that are covered have been selected to provide a fairly broad treatment of the current state of memory research and theory. The discussion begins with perception, continues through topics subsumed under the general label "short-term memory," and concludes with "long-term memory"—including semantic memory, models of encoding and retrieval, and forgetting.

In writing this book, I was greatly aided by my reviewers. I gratefully acknowledge the reviewing assistance of Richard Atkinson, Robert Crowder, Douglas Hintzman, Earl Hunt, James Juola, Thomas Landauer, and Edward E. Smith. Their comments were not always favorable, but they were invariably helpful, and I know that the book benefited from my having their advice. I was aided as well by the support and guidance of Buck Rogers, and I thank him. I am grateful to Jim Geiwitz, who provided understanding, encouragement, and friendship throughout the course of the project.

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INTRODUCTION

What does it mean to remember? The famous psychologist William James once said that to remember is to think about something which we previously experienced, and which we were not thinking about immediately before (James, 1890). James' definition has intuitive appeal; still, the concept of memory is not readily captured in a single phrase.

This book is concerned with what it means to remember. It will address such specific questions as how we mentally represent our knowledge about the world, how we get access to that knowledge when we need it, why we may fail to get access to it, and how we integrate new information with our existing body of knowledge. Each of these problems is a part of the study of memory, and this book will discuss some of the ways that psychologists have conducted that study. In doing so, it will present a variety of topics and ideas, each related to the central question—what does it mean to remember?

The approach to human memory taken by this book is often given the labels "cognitive psychology" and "the information-processing approach." These labels become more meaningful if we compare the cognitive approach of this book to an older, and still viable, approach to the study of memory. This older approach is that of stimulus-response (S–R) theory, or associationism. According to the S–R approach, the ability to remember depends on the formation of associations, or bonds, between stimuli and responses—the strength of those bonds (called habit strength) determining the ability to remember. If a particular bond is sufficiently strong (as the bond between "2 + 2 =" and "4" usually is) we can be said to have a memory; the nature of the memory depends on the stimuli and responses involved.

For example, most of us remember to stop our cars at red lights most of the time. This habit can be attributed to our having an association between a stimulus (a red light) and a response (stopping the car). Of course, our example is rather simple—almost any organism can learn to stop at a red light, and in that sense, has a memory. But associationists argue that the S–R theory can also account for more subtle and complex human behaviors. One way in which this is accomplished is by assuming that there are *internal* stimuli and responses. In essence, what this means is that there are stimuli and responses that are not directly observable (and are thus unlike red lights and the pressing down of brake pedals). In fact, many human responses to the environment are probably internal or, if external, too small to be noticed. These hidden responses may serve as stimuli for other responses, and in this manner, unobserved S–R chains could come to exist. By this means, more complex mental events can be brought into the framework of S–R theory.

There are, however, problems with the associationist approach. For one thing, the associationists focus on the contingencies between stimuli and responses and on the principles of conditioning (which describe how associations are formed and how habit strength can be manipulated). They have little to say about the events that intervene between stimulus and response. Furthermore, the associationist approach has seemed inadequate to bring us any closer to understanding many of the most interesting events related to memory—how we form hypotheses and test them, why we wrestle with memories that seem to be just on the tip of our tongue, how we conjure up familiar faces, and so on.

The cognitive approach to memory has a considerably different emphasis from the associationist approach. The word cognitive, which is derived from cognition, meaning *knowledge,* emphasizes mental activities, not just stimuli and responses. It is precisely this shift of emphasis—away from a passive system that accepts stimuli and automatically produces S–R chains, and toward a notion of mental action—that characterizes cognitive theories. According to Neisser, whose book *Cognitive Psychology* (1967) gave real impetus to the approach, the focus of a cognitive theory is knowledge—how it is acquired, modified, manipulated, used, stored; in short, how it is processed by the human organism. Thus, information processing (a term cognitive psychologists have borrowed from computer scientists) broadly refers to the human being's active interaction with information about his world. Of central importance in this processing are the mental activities that occur between a stimulus and a response. Those activities are not viewed simply as links in an S–R chain (although, as we shall see later, the concept of association does have a place in cognitive psychology).

Haber (1969) has pointed out some basic assumptions of the information-processing approach in psychology. Slightly modified, his assumptions can be called (1) the stage assumption and (2) the limited-capacity assumption—and, as a corollary, the continuity assumption.

First, let's examine the stage assumption. We assume that our area of study—the processing of some information—can be broken down into subprocesses, or stages. That is, the time between the S and the R can be divided up into smaller intervals, and each of those corresponds to some subset of the events that intervene between S and R. We shall see that information can be remarkably transformed as it goes from one stage to another. To return to our red-light example, we might break up the total process as follows: First, the light registers in our visual system. Second, we recognize the visual sensation for what it is—a red traffic light. (To do this, we must use information stored in memory; that is, knowledge about what a red traffic light looks like.) Third, we apply a rule that we have in our memory—stop the car when you see a red light. Of course, we could break the process down further if we wished. But note that in the course of the stages we have already described, the original information—a visual event—has undergone successive transformations. From a visual event, it was changed to a recognized category (red lights), then changed again to a condition for applying a rule (stop the car when . . .). This illustrates a general point: isolating a stage of information processing is not done arbitrarily; rather, a stage of processing (sometimes called a *level* of processing) generally corresponds to some representation of the stimulus information. As the information goes from one stage to another, its representation changes accordingly.

The limited-capacity assumption can also be applied to the red-light example. At each stage of processing, we can identify limits on the human capacity to process information. For example, if we add to our red light a traffic policeman, several careless pedestrians, and an ambulance, we might have too many stimuli to register in the visual system at the same time. This results in an overload on capacity, and overloads can lead to all sorts of complications. For one thing, some information may not enter the system (we may never see one of the pedestrians or perhaps even the red light). Alternatively, we might *recode* the stimulus situation—that is, we might transform it to a new stimulus (perhaps with the label "dangerous situation"). Another option might be to process the information more selectively—we might just look at the policeman and ignore the light, the pedestrians, and the ambulance.

The two basic assumptions just described lead to an important corollary. It is that when we take an information-processing approach, we are bound to get into some areas of psychological study that have been traditionally kept separate from the study of memory. Learning, for example, can be viewed as the process of adding to or modifying the human memory system. Perception, or the original registration of the stimulus, is also inseparable from memory and can be considered to be the first stage in the continuous processing of information.

Why is the label "cognitive psychology" applied to the approach we have been describing? The cognitive character of the approach lies, as we have mentioned, in the view of the human organism as an active seeker of knowledge and processor of information. That is, humans are seen as acting on information in various ways. For example, the processor can decide whether or not to recode information from one form to another, to select certain information for further processing, or to eliminate some information from the system. We shall see that this view of the human as an active information processor permeates the newer theories about memory. Cognitive theorists conceive of perceiving and remembering as acts of construction, by means of which people actively build mental representations of the world.

BASIC CONCEPTS AND DEFINITIONS

Before we begin our study of memory, it is important to establish a few basic concepts and definitions. First, we must establish a set of distinctions among three basic terms drawn from the field of information processing and applied to human memory: encoding, storage, and retrieval. *Encoding* refers to putting information into a system. The process of encoding may include modifying the information so that it is in an appropriate form for the system, human or mechanical, it is being put into (for example, information may be encoded for a computer by punching holes into IBM cards). Information in an encoded form is often referred to as a memory "code." *Storage* refers to just that—storing information in a system. Of course, things may happen to stored information. It may be affected by subsequent information, or it may be lost. *Retrieval* refers to the action of getting at the stored information. Any of these three processes may break down for some reason—in human memory, this results in the failure to remember. It follows that all three processes must be intact in order for us to remember: we have to encode the information, store it until it is called for, and then be able to retrieve it.

Another term that will be used frequently in this book is "model," as in "model of memory." As used here, the term refers to a theoretical model. Thus, we might say that in the previous discussion, we built a model of the mental processes that occur when someone stops for a red light. Sometimes, a theoretical model becomes a "mathematical model"—that is, it incorporates mathematics in order to describe processes in more detail. One advantage of having a model of a mental process is that you can use the model to make predictions about behavior. These predictions can then be compared with how people actually behave, and, if the predictions are not supported, we know it is time to build a new model.

List-Learning Procedures

In discussing human memory, we will describe the results of many experiments using common experimental procedures. Our last set of preliminary definitions will cover some of these basic laboratory procedures. These are not the only ones that will be discussed in this book; however, they are to some extent standard and are used in a great number of experiments. These procedures have in common a basic form: in each, a subject (the person in the experiment) learns a *list of items.* The items might be single words, pairs of words, or "nonsense syllables." (Nonsense syllables are also called CVCs, for Consonant-Vowel-Consonant, which is the form they take. Examples are DAX, BUP, and LOC.) The learning of the list takes place over a series of *trials.* Each trial consists of a presentation of the items to the subject and a test to see what has been learned.

These list-learning procedures began with the work of Hermann Ebbinghaus (1885), who was the first person to study learning and forgetting in a systematic way. Ebbinghaus conducted a long series of experiments on a single subject—himself. In his experiments, he learned lists of nonsense syllables. In fact, it was Ebbinghaus who invented the syllables; he did so because he wished to eliminate what he considered an undesirable experimental factor—*meaning.* Ebbinghaus reasoned that if he used actual words in his lists, the meanings of the words would influence the results of his experiments. But Ebbinghaus wanted to study the formation and retention of *new* associations, independent of the existing ones. To avoid this unwanted source of variation, he chose to use nonsense syllables, intending them to be relatively free from meaningful associations.

Ebbinghaus constructed lists of nonsense syllables that he presented to himself at a constant rate. He read the lists until he thought he knew them; in some cases, well after he could recall them perfectly. Later, he tested himself again on the lists. His measure of how much had been retained in memory was a measure of *savings*, that is, how much work was needed to relearn the lists after a given amount of time had elapsed. The amount of savings indicated how much of what was learned had been saved.

Ebbinghaus made many contributions to the study of memory. Not only did he devise experimental techniques in which sources of error were controlled, but he used those techniques to discover a great deal about human memory and learning. One important discovery made by Ebbinghaus was that if a list was short enough—say, seven or less items—he could learn it in just one reading. If the list increased to eight or more items, the learning time increased dramatically. In fact, there was a discontinuity at around seven items—below it, there was immediate learning; above it, learning took several trials—the number of trials increased with the number of items. The seven-item limit is called the *memory span*, and we shall discuss it in more detail in Chapter 2.

A second major discovery made by Ebbinghaus was that the amount of savings was markedly affected by the *retention interval* (the time between initial learning and later testing). He found that savings were great with a short retention interval and decreased regularly as the interval increased; that is, the amount forgotten increased as time passed. The course of forgetting is illustrated in Figure 1.1. There is very rapid forgetting over the first few minutes (that is, the amount of savings decreases rapidly), but gradually the rate of forgetting decreases (the amount of savings decreases more slowly).

Ebbinghaus's original list-learning procedure was similar to what is today called *serial learning*. Serial learning is characterized by the fact that the subject must learn the list of items in a given order. Suppose, for example, that our list, a very short one, is: BOOK, PIPE, CONE, BOARD, SHEET. Those five words would be presented to the subject, and then he would attempt to repeat them in order. If he forgot one of the words, or gave it out of order, he would be said to have made an error.

There are really two ways of testing a subject in serial-learning tasks. One is to give him the entire list, and then test his memory of it. That is called the *study–test procedure*, since the subject studies the list and then is

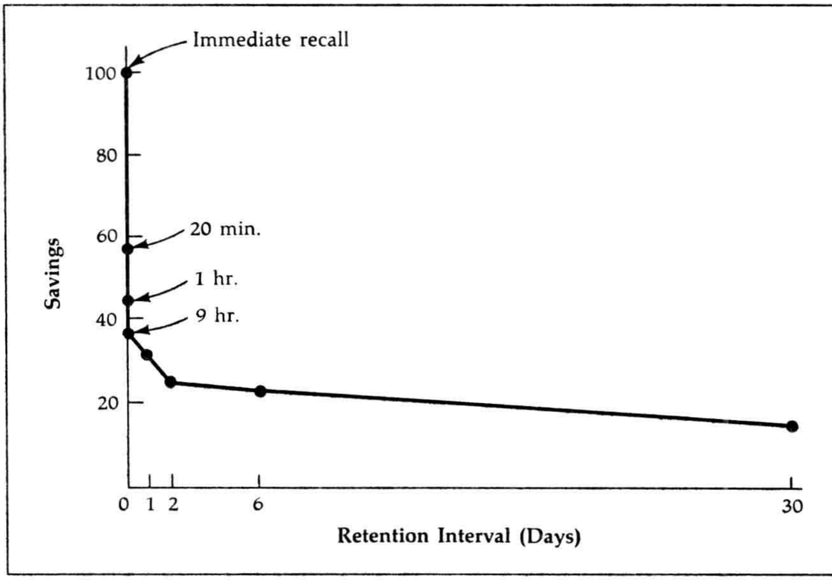

FIGURE 1.1

Ebbinghaus's forgetting function. Retention of previously learned lists of nonsense syllables, as measured by savings, is plotted as a function of the retention interval—the time between initial learning and the retention test. [After Ebbinghaus, 1885.]

tested on all of it. Alternatively, we could use the *anticipation procedure*—instead of studying the entire list and then being tested on all of it, the subject is tested on and studies one item at a time. This is accomplished by having him attempt to anticipate each item before he sees it. The subject starts out by being presented some marker (for example, an asterisk) indicating the beginning of the list. Seeing the marker, the subject tries to state the first item on the list. (That is the test of the first item.) Then, he is given the first item (the study), and he tries to state the second, (the test of the second), and so on throughout the list. The first time through the list, of course, he will almost certainly be unable to state any of the items, but eventually, after several trials, he will be doing well.

Many variables have been found to influence serial learning. One is the rate at which items are presented. (Ebbinghaus, you may recall, used a constant rate of presentation.) In general, slower rates lead to faster learning. Another important finding about serial learning is that the serial position of items affects learning. The serial position of an item is simply its order number in the list, the first item having serial-position one, the second having serial-position two, and so on. The number of errors is greater for items in the middle of the list than for items at either of the ends. This is the serial-position effect, and it holds true for lists of any length beyond the memory span.

A second procedure that has been used very often in memory experiments is *paired-associate learning;* this procedure is characterized by the fact that each item is really a compound; that is, it has two parts. For example, an item might be a word and a number, like BOOK–7. The subject learns to report the second part of the item given the first (so that he can respond "7," given "BOOK"). Usually, the items are not learned in a fixed order in paired-associate learning, unlike the serial-learning procedure. Thus, the order of the items can change from one trial to another, but the pairs themselves do not. For example, the items BOOK–7 and DOG–8 might occur one after another on one trial and be several items apart on another trial; however, BOOK would always be paired with 7; DOG would always be paired with 8.

Like the serial list, the paired-associate list can be learned with either a study–test procedure or an anticipation procedure. If the study-test procedure is used, all the items are presented, and then all are tested. A test usually consists of the presentation of only the first parts of the items. The subject attempts to give the second parts as his response. For example, the experimenter presents BOOK–? and the subject says "7." If the anticipation procedure is used, as in serial learning, each item is tested and then presented before the next is tested and presented, and so on. The test anticipates the study. For example, the subject is given BOOK–? as the test of the BOOK–7 item. Then he is given BOOK–7 (the chance to study). Next, he may be tested on DOG–?; then given DOG–8, and so on.

One supposed advantage of paired-associate learning is that a single item can be considered as a stimulus (the first part) and a response (the second part). Some theorists have assumed that the procedure allows associations between stimuli and responses to be studied directly. We will see, however, that just because an item is learned, it does not mean that what is learned is a simple bond between the stimulus and the response. Subjects often learn the item by a technique of *mediation,* which involves idiosyncratically changing the items in some way. For example, an item JAK–B may be mentally changed to "Jack and the Beanstalk." In this instance, what is learned is quite different from the direct association of "JAK + B."

A third experimental procedure is that of *free recall.* In free recall, unlike serial recall, the subject is free to report the items in any order he chooses. If the same list is used for several trials, its order of presentation changes from one trial to another. (Free recall generally takes the form of study–

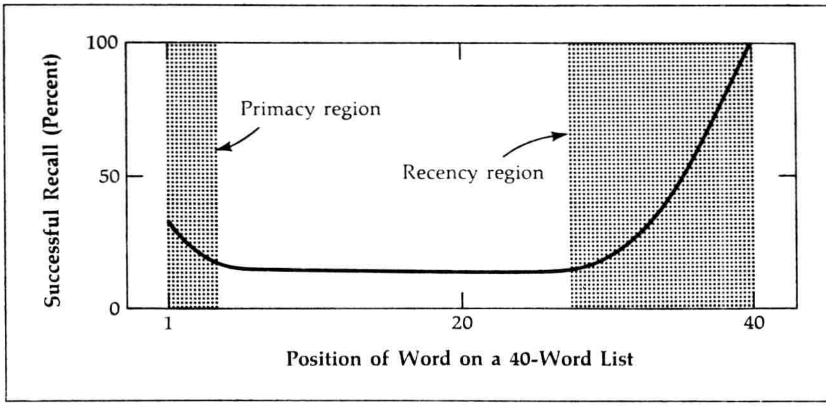

FIGURE 1.2

The serial-position function for free recall. The percent of times that words were recalled, for words in each position in a forty-word list. The function is divided into a primacy region, a recency region, and a flat central region. [Data after Murdock, 1962.]

test, because the anticipation method determines the order in which list items are reported—exactly what is *not* wanted for this procedure.)

Like serial recall, free recall produces a serial-position effect, as shown in Figure 1.2. That is, the percentage of the time that items in a given position are recalled is highest for items in the beginning and end positions and lower for the items in the middle. As indicated in the figure, the various portions of the serial-position curve (obtained when Percent Recall is plotted against Position of Word) are given different names. The first portion of the curve, showing recall of items from early in the list, is given the name *primacy* effect. The last portion of the curve, showing recall of the last few items, is called the *recency* effect.

Another of the list-learning procedures is recognition testing. In recognition tasks, what is distinctive is the form of the test. The subject is given items from a list of words he has studied and is asked to indicate whether or not he recognizes them as having been part of the list. Thus, the recognition paradigm is characterized by the fact that the subject sees the list items when he is tested instead of having to recall them. Of course, if he is given only items from the list, he can just say "Yes, that was on it" to each one and be correct. In order to test his ability to recognize items from the list, we must introduce into the test items called "distractors"—items that were not on the list.

For example, the subject might be given a yes/no test. For the test he would see a series of items, one at a time. Each time an item appeared, he would say "yes" if he thought it had been on his list and "no" if he thought it had not been. Usually, half the items on the test would be from the list and half would be distractors. The yes/no test is analogous to the true/false testing we encounter in school.

Another form of recognition testing is the forced-choice test. In a forced-choice procedure, the subject sees two or more items at a time, not just one. One of those items was on the list; the rest were not. His job is to pick out the item that was on the list. If the subject sees two items at a time, then the test is called a "two-alternative forced choice"; if three, a "three-alternative forced choice," and so on. As you may have noticed, the forced-choice test is a kind of multiple-choice test.

Finally, a recognition test can use a batch-testing procedure, in which everything—all the list words and all the distractors—is presented at once. The subject then tries to indicate which words were on the list. Often, all the test items are printed on a page and the subject circles those he thinks are from the originally presented list.

It is important to note that recognition testing is sometimes used in combination with the other procedures described above. For example, we could combine the recognition procedure with the paired-associates procedure by testing each stimulus term with a set of response alternatives. A subject who had first been presented with DAX-7 might be tested with:

DAX-?   5 8 7 1 *(Pick one)*

Recognition can also be combined with serial learning. In that case, we might ask the subject to recognize which ordering of a set of items corresponded to the order in which they had previously been presented.

These, then, are the definitions related to the basic list-learning procedures. (1) In serial learning, items are learned in a particular order. (2) In paired-associate learning, the list items come in pairs. (3) In free recall, the list items can be reported in any order. (4) In recognition, the subject sees the list items when he is tested. Although we will have little to say about serial learning in this book, we will find the other procedures important to our discussion. For example: paired-associate tasks are important in the study of forgetting (Chapter 9), free-recall testing has been extensively used in experiments on the organization of memory (Chapter 10), and recognition tests will be important in our discussion of retrieval theories (Chapter 11).

2

OVERVIEW OF THE HUMAN INFORMATION-PROCESSING SYSTEM

In the first chapter, humans were characterized as processors of information, and human memory was called an information-processing system. We noted that two important characteristics of such a system are (1) that it can be broken down into a series of stages, and (2) that processing at each stage is limited. In the present chapter, we shall look at the human information-processing system in more detail. A theoretical model of this system will be proposed and considered. In subsequent chapters, this initial model will be greatly expanded, but it is important at this point for us to get an overview of the system.

THE SYSTEM AND ITS COMPONENTS

A model of the human-information processing system is illustrated in Figure 2.1. What the figure shows, essentially, is what happens to information about a stimulus from the "real world" as it passes through the system.

In the first stage of information processing following stimulus presentation, a certain amount of information about the stimulus (which has just occurred outside the system) is registered, or entered, in the system. "Sensory register" is the name given to the site of that registration. It is called a sensory register because the information enters the system by