CHAPTER ONE

OVERVIEW AND HISTORY OF MEMORY RESEARCH

Memory is perhaps the most central aspect of human thought. Any question about human behavior, cognition, development, and nature requires an understanding of memory. Our memory makes us who we are, and it is one of the most intimate parts of ourselves. This may be why when we get close to someone, when we want them to know who we are and we want to know who they are, there is a sharing of memories. Many feel that the study of human memory is the closest one can get to a systematic study of the human soul. The aim of this book is to provide you, the student, with a survey and guide to what is known about human memory. As with most courses, there are a number of facts and ideas to learn. However, as any good professor will tell you, the slow accumulation of facts is not the main point of course work. The primary aim is to provide you with a deeper understanding and appreciation of some aspect of the world—and, hopefully, yourself. I trust that the ideas presented in this book will be useful in your life after this course is completed.

A SMATTERING OF DEFINITIONS

Before diving into the subject matter, we need to establish some points. Specifically, we need to define how the terms *memory* and *learning* are used. The primary subject of this book is, of course, memory. So what is *memory*? Well, the problem, and the beauty, of this term is that it has many meanings.

Memory

The word **memory** has three primary definitions (Spear & Riccio, 1994). First, memory is the location where information is kept, as in a storehouse, or memory store. Second, memory can refer to the thing that holds the contents of experience, as in a memory trace or **engram.** In this sense, each memory is a different mental representation. Finally, memory is the mental process used to acquire (learn), store, or retrieve (remember) information of all sorts. Memory processes are acts of using information in specific ways to make it available later or to bring back that information into the current stream of processing, the flow of one's thoughts.

Learning

The other term that needs to be defined is **learning,** which is any change in the potential of people to alter their behavior as a consequence of experience. Obviously, learning and memory are closely related: For something to be remembered, it must first be learned. Because of historical circumstances, however, these terms have become somewhat disconnected in the language of psychology. "Learning" has come to refer more to the acquisition of associations, often in the context of studies of conditioning. Moreover, these studies are often performed on animals, such as a rat learning a maze. This is not the learning people often refer to when they are in school. In this book I use the term the way it is conventionally used, although I may occasionally use the more restricted sense.

Synopsis

The terms *memory* and *learning* are used in specific ways in experimental psychology. In general, *memory* refers to the storage of information and the processes used to retrieve it. When referring to research, there is a greater likelihood that this will be work with humans. *Learning* is a term that has a greater association with studies of conditioning that are more likely to involve animals. However, both are clearly relevant to the topic of this book.

METAPHORS FOR MEMORY

There are several striking things about the human mind. One is that it is the part of ourselves of which we have the most intimate awareness. Our experiences are our thoughts. Another is that many, if not most, of the operations of the human mind are not open to direct inspection. You can't see thinking. In addition, there is the problem that every experience that the mind has changes it in some way. By reading this sentence, you are changed. These issues lead to a number of problems in trying to understand memory. One has to be clever and develop ways to assess how memory works. Many issues involved in the study of memory are covered in Chapter 3. More relevant here is the idea that there is no simple and direct way to talk about what memory is and how it works. Because of this, people often talk about it in indirect ways, using **metaphors.**

Roediger (1980) has compiled a list of metaphors that have been used over the centuries to capture various aspects of memory (see Table 1.1). Some of these metaphors express the idea that memory is a recorder of experience, such as a wax tablet, a record player, a writing pad, a tape recorder, or a video camera. Other metaphors imply that different types of memories, different types of knowledge, and different times in our lives are stored in different places. These include such metaphors as memory being like a house, a library, or a dictionary. In contrast to the idea that some memories are somehow distinguished from one another, another concept is that they can also become intertwined and interconnected, like a switchboard or network.

Memory is not passive. Some metaphors capture some of its more dynamic characteristics. For example, the process of retrieving a specific memory from the chaotic jumble we have accumulated during our lives has led to the idea of searching for memories as being something like trying to catch birds in an aviary or searching for something in a junk

TABLE 1.1 Metaphors Used to Describe Memory

METAPHOR	EXAMPLES
Recorder of Experience	Wax tablet, record player, writing pad, tape recorder, video camera
Storage Locations	House, library, dictionary
Interconnections	Switchboard, network
Jumbled Storage	Bird in an aviary, pocketbook, junk drawer, garbage can
Temporal Availability	Conveyor belt
Content Addressability	Lock and key, tuning fork
Forgetting of Details	Leaky bucket, cow's stomach, acid bath
Reconstruction	Building an entire dinosaur skeleton from fossils
Active Processing	Workbench, computer program

drawer, or even a garbage can. This also goes along with the idea that memories become harder to get at over time, as if they were being led away on a conveyor belt. Often a search is required to find the appropriate memories that match or meet the current need, like a lock and key. Memory retrieval is further complicated by the fact that much of what gets stored is forgotten, leaving only a portion of the original, like water in a leaky bucket. This loss of knowledge requires people to re-create the missing pieces of a memory, using a constructive process, perhaps like reconstructing a whole dinosaur from the fragments of bones left behind. Finally, metaphors capture the active nature of memory in manipulating information, as if it were a workbench or a computer program.

The large number of metaphors should give you the idea that memory is a complex thing that we have only begun to understand. Because of its ephemeral nature, we must rely on our knowledge of other more concrete and better understood concepts to help us make sense of it. Probably the most dominant metaphor for memory is the literacy metaphor (Danziger, 2008). The advent of written language led the ancients, and most people since, to view memories as something that are written down and put somewhere. This leads to the near-universal (though not necessarily completely accurate) conception of memory involving encoding, storage, and retrieval, much like writing books and storing them on a shelf. This metaphor treats memories as discrete packets, like books or papers, which may or may not correspond to how the brain parses up our experiences. The dominant modern version of literary metaphor is the computer metaphor which drove and dominated the cognitive revolution of the mid-twentieth century.

Before moving on, let's look at one more metaphor for memory that is very inaccurate: the idea that memory is a muscle. The idea is that the more you use your memory, the better it will be. In other words, simply memorizing information will make memory better in the future. There is no evidence to support this idea. Instead, it is not how much you use your memory but how much information you have in it that is important. So, memory is not like a muscle, but more like a key collection. The more keys you have, the more locks you can open.

Synopsis

Memory is not open to direct inspection. As such, we must use a variety of metaphors to capture its various aspects, such as its recording of experience, its organization, and its chaos. While each of these metaphors carries a degree of imprecision, each one effectively captures some characteristics of memory that makes it easier for us to understand.

HISTORY OF MEMORY RESEARCH

Questions about the nature of memory extend back millennia to the ancient philosophers. However, a true systematic, quantified, and rigorous assessment of the nature and limits of human memory did not begin until the end of the nineteenth century. In this section, we review some of the major players in the history of memory research starting from the ancients and leading up to about the mid-twentieth century.

From the Ancients to Modern Precursors

A great deal of scientific thought about memory has developed over time or has been influenced by people from the great philosophers of ancient Greece to more modern times. This began with Plato (428?–347? B.C.), a rationalist philosopher who emphasized rational thought as a means of understanding of the world. For him, memory serves as the bridge between the perceptual world and a rational world of idealized abstractions (Viney & King, 1998). Plato's ideas were further developed by other rationalists philosophers, including Rene Descartes (1596–1650) and Immanuel Kant (1724–1804). Plato's most prominent pupil was Aristotle (384–322 B.C.); he was an empiricist who believed reality itself was the basis of inquiry.

One of Aristotle's most powerful contributions is the idea that memories are primarily composed of associations among various stimuli or experiences. Aristotle's ideas later worked into grand form by the British empiricists, including George Berkeley (1685–1753), John Locke (1632–1704), John Stuart Mill (1806–1873), and David Hume (1711–1776). As you will see, there are many theories of memory that are associationistic, such as accounts of priming, interference, or even the creation of false memories that use Aristotle's ideas of how various elements are mentally linked to one another. These linking relationships often follow Aristotle's three laws of association: similarity, contrast, and contiguity such that memory associations link ideas that are similar in nature, are the opposite on some critical dimension (and thus a form of similarity in that the dimension is present and is important), or occurred near one another in time. In medieval times, St. Augustine (A.D. 354–430), in Book X of his *Confessions,* considers the topic of memory in a way that would be familiar in modern times. More recently Robert Hooke (1635–1703) developed a theory of memory with a surprising number of modern insights. However, his work was generally overshadowed by his rivalry with Sir Isaac Newton, which further hurried his ideas into obscurity (Hintzman, 2003).

Charles Darwin's (1809–1882) ideas also had an impact on scientific thinking about human memory (see the entire February–March 2009 issue of *American Psychologist*). Many memory theorists are guided by the idea that it has developed through the process of evolution to capture major characteristics of the environment and to perform specific tasks (Glenberg, 1997; Klein, Cosmides, Tooby, & Chance, 2002; Shepard, 1984). This evolutionary aspect of human memory has an influence on how people think about the mind, behavior, and genetic influences. It is important to note that in some sense all human behavior has a genetic component (Turkheimer, 1998). The existence of our brains requires that we have brain-building DNA and all of our thoughts depend on this brain. Thus, our memories have a genetic component. However, our DNA does not directly cause our brains to have the exact configuration that we happen to have at the moment, but this is due to our history of experiences.

Early Memory Researchers in Psychology

Psychology as an independent discipline arose in the latter half of the nineteenth century. Since then many people have influenced memory research. While we cover a few prominent ones here, it should be kept in mind that the study of memory did not always move at a steady pace. Sometimes in science people develop ideas that move the field forward but, for whatever reason, are not noticed at the time. These theories fall by the wayside, never to be heard again. However, a few may capture the attention of future generations, who discover in the earlier, neglected work parallels to modern ideas. For example, in memory research, Richard Semon (1859–1918) developed a theory of memory in the first decade of the twentieth century that incorporated many ideas about the process of retrieval. However, his contemporaries largely ignored these ideas, and his insights were not appreciated until 70 years later (Schacter, Eich, & Tulving, 1978). Now let's look at some people whose work had a more immediate impact.

Ebbinghaus. One of the first true students of memory in a scientific form was Hermann Ebbinghaus (1850–1909). He is best known for his 1885 publication *Memory: A Contribution to Experimental Psychology* (*Über das Gedächtnis* in the original German). This work conveyed his detailed studies of memory, using himself as both experimenter and subject, because formal methods of obtaining research participants were not available at that time. Also, this was a time of psychological research when the study of one's self was more acceptable. Currently, it is viewed as more objective if the experimenter tests another person who knows little to nothing about the experimental hypothesis. There are still a few people who do test their own memories, but these efforts are quite rare. Soon after Ebbinghaus's work, researchers at the University of Göttingen developed Ebbinghaus's methods into the experimenter-participant model we know today (Danziger, 2008).

Ebbinghaus tried to study memory in as pure a form as possible, in the absence of an influence of prior knowledge. To do this, he devised a form of test stimulus called the **nonsense syllable,** which is a consonant-vowel-consonant trigram that has no clear meaning in the language. Nonsense syllables for English would be PAB, SER, and NID. Ebbinghaus created and used about 2,300 of these. These nonsense syllables had a tremendous effect on the study of human memory for many decades. Researchers not only used nonsense syllables but also spent a great deal of effort studying them, even to the point where nonsense syllables were rated for meaningfulness (Glaze, 1928). People recognized that some nonsense syllables were more word-like than others. For example, "BAL" is rated high in meaningfulness (because of "ball"), whereas "XAD" is rated very low.

Ebbinghaus spent a lot of time memorizing lists of nonsense syllables of various lengths, under various learning conditions, and for various retention intervals before he tested himself. (In some of his later studies he did allow some real words to enter his lists on the premise that it would have little effect.) For memory retrieval he would give himself the first nonsense syllable, and he would then try to recall the rest in the series. Using this simple approach, he was able to discover a wide range of basic principles of human memory that have withstood the test of time. Some of the more important ones are the concepts of the learning curve, the forgetting curve, overlearning, and savings. It should be noted that although Ebbinghaus discovered these using nonsense syllables, these same patterns are observed with all types of information.

The **learning curve** reflects the idea that there is a period of time needed for information to be memorized, such as the number of times a person needs to practice information, and it can be affected by a number of things, such as the amount of information to be learned. The learning curve is a negatively accelerated function in which most of the action occurs early on, with smaller and smaller benefits gained later on. So, the largest amount of information is learned in the first segment. In the second, although more is learned, the gain is not as much as during the first. A similar description applies to the third segment, and so on. Thus, through this process, information is gradually committed to memory. Furthermore, Ebbinghaus showed that how a person went about learning, in terms of the distribution of practice, influenced how well information was learned. Specifically, memory is better when practice is spread out over time, rather than lumped together—a distinction that is currently known as **distributed practice** and **massed practice.**

The **forgetting curve** is the opposite of the learning curve, and yet it is strongly similar to it. It conveys the loss of old information rather than the acquisition of new information. However, the forgetting curve is like the learning curve in that it is also a negatively accelerating function. As we'll see in Chapter 3, most of what is forgotten is lost during the initial period. As time goes on, the process of forgetting continues but at a slower pace. The more time that passes, the slower the rate of forgetting.

Forgetting is clearly the most problematic aspect of memory, and the forgetting curve suggests that we are doomed, sooner or later, to lose just about every memory we acquire. However, it should be apparent that this is not strictly the case. There are some pieces of knowledge that you've had for years and are unlikely to ever forget. One way to do this is by a process called **overlearning,** in which a person continues to study information after perfect recall has been achieved. This continued learning insulates a person against forgetting. If there is substantial overlearning, forgetting may be delayed for quite some time, perhaps indefinitely.

When information has been forgotten to the point that no pieces can be recalled with accuracy or reliability, it might seem that a person must start at square one and repeat all of the previous effort. However, this is not the case. Ebbinghaus found that after seemingly complete forgetting, subsequent attempts to relearn the information required less effort than the first time. This difference between the amount of effort required on a subsequent and prior learning attempt is called **savings.** The existence of savings is very important. For one thing, it demonstrates that knowledge that appears to be lost may be residing somewhere in the darkened corners of our mind. It is no longer consciously available, but it can still exert an unconscious influence on behavior—in this case, serving as a platform on which to build a new set of consciously available memories.

Bartlett. Another major figure in the study of human memory is Sir Fredrick Bartlett (1886–1969). Bartlett was, in some ways, the opposite of Ebbinghaus. Whereas Ebbinghaus was interested in the operations of memory independent of prior knowledge, Bartlett was directly interested in how prior knowledge influenced memory. He found that prior knowledge has a profound influence on memory. Specifically, he suggested that what is stored in memory is often fragmentary and incomplete. When people are remembering, in some sense, they are reconstructing the information from the bits that are stored and from other prior knowledge that they have about such circumstances. This reconstruction is guided by what Bartlett called "schemas" (a theoretical construct also used by Gestalt psychologists, such as Kurt Koffka). Schemas are general world knowledge structures about commonly experienced aspects of life. (There will be more about schemas in Chapter 9.) To illustrate the effects of schemas, Bartlett had people read a story and then later try to recall it anywhere from immediately after they read it to several months or years later. What he found was that as memories for the story became more fragmented, the story content was altered to make it more consistent with a stereotypical story.

James. One of the most prominent of the early psychologists was William James (1842–1910). James is so highly regarded that, even among current researchers, it is not usual to find a quote by James leading off a research or review article, particularly by Americans. Much of this influence comes through his famous textbook, *The Principles of Psychology* (1890/1950). In general, James was a primary mover in the functionalist movement in early psychology. In terms of memory, James was able to provide descriptions that are remarkably similar to theories in use today. For example, his distinction between primary and secondary memory closely parallels the distinction between short-term and long-term memory. Similarly, he was one of the first academics to describe memory retrieval problems, such as the tip-of-the-tongue phenomenon (see Chapter 14) in which a person is not able to remember something, such as someone's name, but there is this strong feeling that retrieval is imminent.

Gestalt Psychology

Modern views of memory were influenced by a number of movements in psychology. Two important ones were the Gestalt and behaviorist movements. The **Gestalt** movement, mostly advanced by German researchers such as Wolfgang Kohler (1887–1967), Max Wertheimer (1880–1943), and Kurt Koffka (1886–1941), suggested that strictly reductionistic approaches to mental life were incomplete. Instead, one needed the idea that complex mental representations and processes have a quality that is different from the component parts that make them up. This is not to say that the Gestalt psychologists completely rejected reductionistism. They most certainly did not. Instead, they argued that an understanding of more complex phenomena was important in its own right because it could be qualitatively different. For example, a melody is something that is qualitatively different from the individual notes that make it up, although it is certainly very dependent on them.

One of the ideas of the Gestalt movement that has influenced thinking about memory was that the whole is different from the sum of its parts. This idea can be seen in modern views that memories are built up of a configuration of simpler elements to take on a new quality. For example, the finding that people remember the causally important elements of a story better than others (Trabasso & van den Broek, 1985) is directly in line with this idea. Gestalt psychologists also stated that the observed behavior of a person depends on both the context in which people find themselves as well as a frame of reference. This is reflected in the context effects that are observed in memory and perspective effects, such as the hindsight bias. Moreover, because our context and goals can change, the way we use and organize our memories were thought to change according to these demands as well (Danziger, 2008).

A final concept to come out of the Gestalt movement is the idea that mental representations are isomorphic. That is, their mental structure and operation are analogous to the structure and function of information in the world. The influence of this idea is clearly seen when spatial memory is discussed (see Chapter 8). The idea is that the structure of a memory trace reflects the structure of the event, as it would be experienced, although in not as complete a form. It should be noted that for the Gestalt psychologists this isomorphism was a functional one. The memory trace functioned "as if" it has the same structure as external events, not that it actually did.

Behaviorism

As we will see in Chapter 6, there are many aspects of memory that operate on a basic and unconscious level. Some of these involve the encoding, storage, and retrieval of relatively simple contingencies that fall under the heading of "conditioning." This was the domain of the behaviorists. **Behaviorism** is a school of thought that originally sought to bring greater credibility to psychology as a science. It was a line of thinking that had a strong grip on psychology for much of the early- to mid-twentieth century. Part of this effort was to avoid mentalistic constructs because they could not be objectively observed and to focus entirely on observables. Although the workings of the mind could not be observed, behavior could be. So, much of the experimental work that was done during the behaviorist era did not directly address issues of memory. However, there were some important insights and discoveries that are relevant here.

Two of the more salient forms of conditioning are classical and operant conditioning. Classical conditioning is a form of memory that allows one to prepare for contingencies that are present in the environment, whereas operant conditioning allows one to remember the consequences of one's own actions. Both of these concepts came into the vocabulary of psychology early on in the twentieth century. Classical conditioning was first described by the Russian physiologist Ivan Pavlov (1849–1936), who had won the Nobel Prize for his work on digestion. Operant conditioning was first described by an until then little-known American named Edward Thorndike (1874–1949), who discovered these principles because, in part, he wasn't able to do what he really wanted to do as a graduate student: study hypnosis.

The discovery and study of these forms of conditioning are important because for decades they shaped much of the research in learning and memory. There was great interest in studying the principles that guided these forms of learning and the implications they had on behavior. One of the salient qualities of classical and operant conditioning studies is that one can take these principles pretty far without having to posit much about what is going on mentally. One can just observe the stimulus conditions and the responses produced by an organism.

Despite this generally antimentalistic view during the behaviorist era, there were some behaviorists who had important insights into issues of memory. Perhaps the most prominent of these was Edward Tolman (1886–1959), who did a number of studies with rats running through mazes. According to strict behaviorist analyses of maze running, what the rat is learning is to make specific turns at specific junctures. Each turn that the rat makes in the maze would either be reinforced or not. If this is true, then any change in the maze should result in the rat needing to learn the route all over again. However, Tolman observed that rats often did not need to undergo a relearning but adapted to changes very quickly. This observation led him to suggest that rats had a mental representation in memory for that spatial location. Tolman called this the "mental map." The rats presumably could consult this mental map in memory to adapt to the changes in the maze. Thus, working within the behaviorist context, people such as Tolman were able to bring a discussion of memory and mental activity back into mainstream psychology.

Tolman was a molar behaviorist, although the term he preferred was *purposive behaviorism*. That is, he was interested in larger behaviors as opposed to the more microscopic behaviors that interested many of his behaviorist colleagues. An example of a molar behavior might be something like getting to the end box of a maze or going to a movie, whereas a microscopic behavior might be an action like "turn left." This interest in molar behavior can be seen in an approach to memory that takes into account the goals and context of a person in the memory situation.

Verbal Learning

The **verbal learning** tradition existed in the context of a behaviorist psychology and stemmed from Ebbinghaus's work with nonsense syllables. The term *verbal learning* itself reflects the behaviorism of many of its practitioners, although what was being studied was a form of memory. Because the verbal learners were behaviorists of a sort, the studies they did often had clearly defined stimulus and response components. Memorization was referred to as "attachment of responses to stimuli," and forgetting was "loss of response availability." (For a nice summary of verbal learning and its relationship to memory, see Tulving & Madigan, 1970.) The verbal learning tradition gave psychologists a way to study memory during the antimentalistic era of behaviorism.

One of the dominant methods in the verbal learning tradition is the **paired associate** learning paradigm. In this approach, people memorize pairs of items, often words, letters, or nonsense syllables. An example of a pair would be something like "BIRD-FANCY." During testing, people would be presented with the first item of the pair and would be asked to produce the second (e.g., "BIRD-?"). The first item served as the stimulus and the second as the response.

There were many variations on this theme. The simple A-B paradigm would present people with a list of paired associates and have them recall the B items in the presence of the A cues. This is clearly memory in a behaviorist guise. Other paradigms are more complicated, where people must learn a second list of items. If this second list was unrelated to the first, this was called an A-B C-D paradigm (easy). An example of this would be learning the pair "BIRD-FANCY" in the first list, and "TABLE-ARROW" on the second. If the second list retained the initial cues with the first list, it was called an A-B A-D paradigm (hard). An example of this would be learning the pair "BIRD-FANCY" in the first list, and “BIRD-ARROW” on the second. Alternatively, one could have the second list be combinations of the A items with synonyms of the B items, called an A-B A-B' paradigm (very hard). An example of this would be learning the pair “BIRD-FANCY” in the first list, and “BIRD-DRESSY” on the second. Finally, there could be a recombination of the A and B items from the first list, an A-B A-Br paradigm (very, very hard). An example of this would be learning the pairs “BIRD-FANCY” and “TABLE-ARROW” on the first list and “BIRD-ARROW” and “TABLE-FANCY” on the second. Often what researchers were doing was looking at the effects of interference of prior learning on new learning. Issues of interference continue to be of interest to memory researchers, and some still use paired associate learning paradigms. We’ll see that some of the ideas developed by the verbal learners explored in the sections on interference in Chapter 7.

Early Efforts in Neuroscience

Memories are stored in the brain, but the brain is a complex and busy place. So where exactly is each memory stored? Is it possible to locate individual memories in the brain? This is the basic question asked by neuropsychologists such as Carl Lashley (1890–1958). Lashley (1950) did a series of studies in search of what he referred to as the “engram”—the neural representation of a memory trace. Lashley first trained rats to run through a maze and then surgically removed part of their brains. After the rats recovered from the surgery, they would be placed back into the maze. If memories for the maze were localized in one part of the brain, then destroying that part would destroy the memory, and the rats would then run the maze just as if they were entering it for the first time. The major outcome of these studies was that no matter what part of the brain was removed, the lesioned rats were still able to perform better than control rats that were placed in the maze for the first time. The critical factor was how much tissue had been removed, not where (see Figure 1.1). (A similar study was done by J. P. Flourens, with pigeons, in the nineteenth century, as reported by Danziger, 2008.) This led Lashley to conclude that engrams were not localized in one part of the brain but were distributed throughout the cortex. While more recent studies have shown that some forms of memory may be localized in different parts of the brain, the general conclusion that many different and distributed parts of the brain are used during memory processing is well supported.

In addition to understanding what different parts of the brain do, it is important to understand how the brain works. That is, how do the interconnections among neurons influence the processing of information? One of the pioneers along this line of research was Donald Hebb. Hebb’s classic contribution was his book *The Organization of Behavior* (1949). Hebb is one of the forerunners of computational neuroscience—mathematical modeling of brain activity. According to Hebb, memories were encoded in the nervous system in a two-stage process. In the first stage, neural excitation would reverberate around in cell assemblies. A collection of cells that corresponds to a new pattern or idea would be stimulated, and this stimulation would continue for some time. In the second stage, the interconnections among the neurons would physically change, with some connections actually growing stronger. This is similar to the idea of long-term potentiation, discussed in Chapter 2. According to Hebb, it takes some time for memories to move from stage 1 to stage 2. This is why if people suffer some sort of trauma to the brain, such as a blow to the head, they may lose recent memories. (We will discuss this in Chapter 16

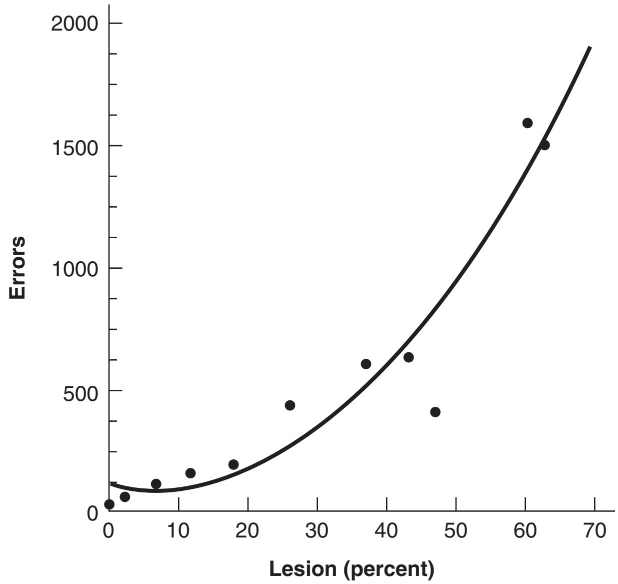

FIGURE 1.1 Results of Lashley's Experiment

Source: Lashley, K. S. (1950). In search of the engram. Symposia of the Society for Experimental Biology: Physiological Mechanisms of Animal Behavior (Vol. 4). New York: Academic Press.

when we examine amnesia.) In addition, these ideas of neural organization and change help lead to the development of computational models of the nervous system, such as the parallel distributed processing (PDP) models, discussed in Chapter 10.

The Cognitive Revolution

Over time, psychologists became frustrated with the constraints imposed by behaviorism. There was a desire to study mental activity as mental activity, not simply as a black box between the input of the stimulus and the output of the response behavior. The so-called **cognitive revolution** of the 1950s and 1960s marked a return of mental states to legitimate study. It made the study of memory a palatable topic once again.

Many people contributed to the cognitive revolution. We focus here on one whose efforts serve as an example of the work and ideas that brought about this change. George Miller provided a number of important findings for memory research, such as his work on the capacity of short-term memory in his paper "The Magical Number Seven: Plus or Minus Two" (Miller, 1956). This work took the idea of mental processing seriously and demonstrated how it was a limited system, much a like a computer's processing is limited by the amount of memory it has. These studies were some of the first to show that memory could be studied with the methodological rigor that the behaviorists were so fond of.

Miller also showed that how people mentally organized information has an influence on memory. Specifically, the more highly organized a set of information was, the better the memory. In other words, how information is actively thought about can affect later memory. In addition, the knowledge that a person has stored in long-term memory can influence current memory performance in profound ways. Thus, work by Miller, and people like him, showed that in order to understand how memory works in the current situation, one must understand how it is structured over the long term.

Synopsis

The study of memory has a long history stretching back to ancient times. There have been a long line of thinkers who have revealed important characteristics of memory that we continue to uphold. While this history is long, it has not always been smooth. Even in recent times, there have been conflicting opinions about the importance and nature of various aspects of memory. By examining how we have progressed through time, we can better understand why we find ourselves in the state that we do.

THE MODAL MODEL OF MEMORY

The standard model of memory, or the **modal model** (Atkinson & Shiffrin, 1968), is a heuristic guide for understanding how memory works. It has been successful enough that it has limped along for years as one the guiding frameworks for discussing issues about how information is stored over time, so it is worth discussing. This model has four primary components: (1) the sensory registers, (2) short-term store, (3) long-term store, and (4) control processes. An outline of the model is shown in Figure 1.2.

The first component of the model, the **sensory registers,** is best thought of as a collection of memory stores. Each of these stores corresponds to a different sensory modality. For example, there is one sensory register for vision, one for audition, one for touch, and so forth. The world is full of information that is in a constant state of flux. Our sensory registers allow us to hold on to this information for brief periods of time to determine if it is worthy of further attention. If we did not possess such memory stores, our minds would be constantly locked into only the very current state of affairs. In such a situation, we would not be able to detect patterns that involve very brief memories, such as determining that two frames of a film can be interpreted as continuous movement or that a sequence of sounds forms a word.

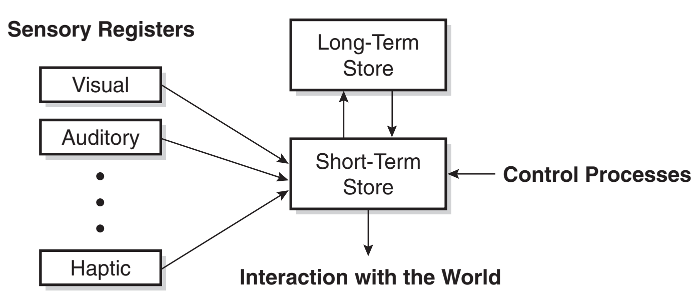

FIGURE 1.2 The Modal Model of Memory

Source: Reprinted from *The Psychology of Learning and Motivation,* 2, Atkinson, R.C., & Shiffrin, R.M., Human memory: A proposed system and its control processes, pp. 89–195, 1968, with permission from Elsevier.

Once information has been attended to, it needs to be kept in the current stream of thought. Because what we are currently thinking about can change and drift relatively quickly, this information needs to be kept available for a short period of time. This part of the standard model is a **short-term memory** that generally retains information for less than a minute if nothing is actively done with it. If consciousness is associated with any part of memory, it would be the information in short-term memory. This is knowledge that is either currently in conscious awareness or just beyond it. Another characteristic of short-term memory is its capacity—the amount of information that can be held in an active state. This amount is humblingly small—somewhere on the order of seven items. Issues dealing with the sensory registers and short-term memory are considered in more detail in Chapter 4.

The third component of the modal model is the idea that there are also control processes that actively manipulate information in short-term memory. This can include processes from rehearsing information to transferring knowledge to or from long-term memory, or perhaps even reasoning. This component of memory makes it an active participant in reality rather than just a passive absorption and retrieval mechanism. The idea that control processes in short-term memory work with knowledge in the service of some goal has led to the idea that short-term memory should be considered more of a working memory system. Issues of working memory are considered in detail in Chapter 5.

The fourth component of memory—the one that interests most people and that much of this text is devoted to—is long-term memory. **Long-term memory** encompasses a wide variety of different types of long-term knowledge and different ways of using that knowledge. Issues of long-term memory are covered extensively in Chapters 6 through 17.

Again, it should be noted that this model is a heuristic for thinking about the broad memory system, but no one uses this as an accurate theory of memory. For example, incoming information does not need to pass through short-term memory to actually reach long-term memory. Instead, the information appears to activate knowledge in long-term memory, and this activated knowledge is actively manipulated in short-term memory (van der Meulen, Logie, & Della Sala, 2009).

Synopsis

The modal model of memory is the standard heuristic that is used to guide discussions of memory. One component of this model is the sensory registers, which are brief memory systems that hold sensory information. Short-term memory holds small amounts of information for short periods of time, usually under a minute. The control processes are used to actively manipulate information. Finally, long-term memory is responsible for storing information for very long periods of time.

MULTIPLE MEMORY SYSTEMS

As is illustrated by the modal model, memory is not a unitary thing. Instead, it has several different subcomponents. Each subcomponent has evolved, as a result of selection pressures, to handle a different job (Klein et al., 2002; Sherry & Schacter, 1987). Some of our long-term memories are implicit and act on us outside of consciousness. In contrast, others are explicit and can enter conscious awareness. Long-term memories can also differ in whether they refer to specific events or to general knowledge.

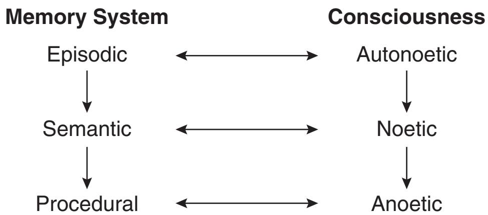

FIGURE 1.3 Tulving's Triarchic Theory of Memory

Source: Tulving, E. (1985a). How many memory systems are there? *American Psychologist*, 40, 385–398.

A number of different classifications of long-term memory can be identified. One organizational guide is Tulving's (1985) *Triarchic Theory of Memory,* shown in Figure 1.3. This view divides long-term memory into three classes: procedural, semantic, and episodic. These divisions reflect the different tasks required of memory, as well as different levels of control and conscious awareness.

Procedural memory is an evolutionarily old memory system. Even relatively primitive organisms have some kind of procedural memory. More recently, people have referred to this as the nondeclarative memory and have grouped semantic and episodic memory in a declarative memory. This more elaborate view of the organization of long-term memory is illustrated in Figure 1.4, which first reflects the **declarative-nondeclarative distinction.** Declarative memory refers to memories that are easy for a person to articulate and talk about. In contrast, nondeclarative memory refers to information in long-term memory that is difficult to articulate but that still has profound influences on our lives. As can be seen in Figure 1.4, nondeclarative memories can be divided into various types, and in Chapter 6 we discuss many of these. One type of nondeclarative memory is the procedural memory of Tulving's classification. This is memory for how to do things, like ride a bicycle or speak your native language. However, other types of memories are included in this category, including condition responses and priming effects. This memory system is described as "anoetic" in Tulving's system because it does not require conscious awareness.

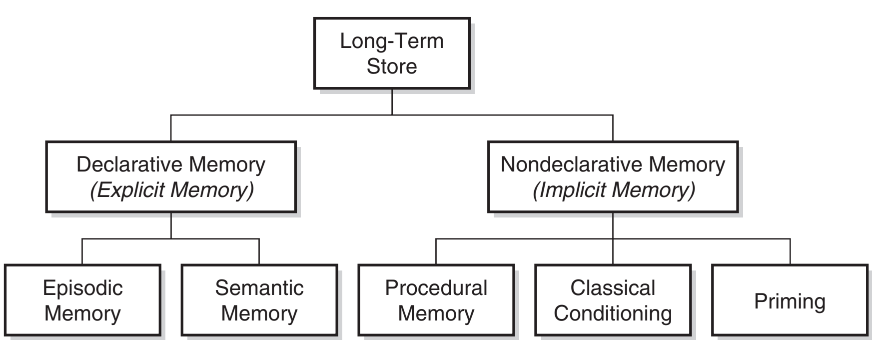

FIGURE 1.4 The Division of Long-Term Memory Systems

Source: Squire, L. R. (1988). Mechanisms of memory. *Science*, 232, 1612–1619.

As shown in Figure 1.4, declarative memory can be divided into two categories as defined by the **episodic-semantic distinction** (Tulving, 1972). Semantic memories are generalized and encyclopedic and are not tied to a specific time or place. This is stable knowledge that you share with your community. For example, knowing what a bird is, what a stop sign means, and what you do in a restaurant are all semantic memories. Semantic memories are highly interrelated and are forgotten rather slowly once established. In **Tulving's Triarchic Theory,** semantic memory is noetic because it requires conscious awareness. You have to be consciously aware to know that an object is a bird or a tree and that it is similar to other members of that category.

In contrast, episodic memories refer to specific episodes or events in our lives. They are tied to the time and place in which the information was learned. For example, where did you go on your first date? Who told you that funny joke? Did you just see the word *apple* in a list of words. Also, unlike semantic memories, episodic memories for each event are compartmentalized and forgotten very rapidly. Episodic memory uses autonoetic knowledge in Tulving's Triarchic Theory because it requires knowledge of the self. For example, in order to know whether you've recently seen an action film, you need to have some memory of yourself as a separate identity to which past events can be referenced. In fact neurological measures, such as ERP recordings (see Chapter 2), show different types of brain activity for memories that refer to the self in some way compared to more semantic memories (Magno & Allen, 2007).

In addition to the different types of memory systems, we can also point out differences in how people use their memories. One of the more prominent of these is the **explicit-implicit distinction** (Schacter, 1987), which roughly corresponds to the distinction between declarative and nondeclarative memories. The important point here is how information is retrieved from memory, not the content of the information.

Explicit memory refers to when a person is actively and consciously trying to remember something. When you are trying to recall someone's name or when you recognize a suspect in a police lineup, this is explicit memory. Implicit memory refers to when a person is unaware that memory is being used. Even though most of this book is dedicated to issues of explicit memory, much of our lives, both thinking and action, are governed by implicit memory. Familiar things that are recognized more quickly, are preferred in choices, and guide our thinking are all examples of the influence of implicit memory operating.

Synopsis

Human memory is not a unitary thing. Instead, there are multiple memory systems that perform different tasks and are responsible for different types of information. Often these capture various levels of involvement of conscious awareness, such as the Triarchic Theory of memory, the declarative-nondeclarative, and implicit-explicit distinctions. Other divisions capture the type of knowledge that the memory systems are processing, such as the episodic-semantic distinction.

RECURRING ISSUES

Before we move on to the specific topics, there are some issues that bear clarification. These issues reoccur throughout the chapters, so it would be helpful if you are alerted to them. In general, these issues have been lurking in the background of most memory research but are now coming to the forefront.

Neurological Bases

It is important to understand the neurological bases because memory exists as a property of the nervous system. The better one understands how the nervous system operates, the better one's insight into human memory. Early in the "cognitive age," much of the study of human thought, including memory, was dominated by the computer metaphor. Part of this metaphor was the distinction between the hardware and the software. The idea was that a person could have an understanding of how software operates with little knowledge of the underlying hardware. For example, some programming languages, such as C and JAVA, are designed to be hardware-independent. To an extent, human memory and thought, the software, can be studied without a detailed understanding of the neural hardware (sometimes called "wetware") on which it is instantiated.

However, some aspects of memory can be understood only if one is familiar with the underlying neurophysiology, and there are many aspects of memory that are better understood or defined when the neurological underpinnings are made clear. Finally, if nothing else, knowing that a theoretical mental process can be associated with a real neural process lends confidence to one's findings and ideas. As we advance into the future, cognitive neuroscience becomes more and more important.

Emotion

A growing trend in cognitive psychology is to look at issues of emotion, which is a critical component of our everyday experiences. More and more memory researchers are incorporating emotion into their theories (see Kensinger, 2009). The importance of emotions has been shown in both behavioral and neurological data. We will discuss the use of emotion to study human memory from time to time throughout the book to better capture its intertwined involvement with memory. Certain sections will present findings that are critically dependent on the emotional state of a person. In this way you will be able to see how these issues of memory, in general, that are often described apart from emotional experience are an important part of a larger psychological system.

Multiple Memory Sources

Another idea is that memory often uses multiple sources rather than a single source on nearly any memory task. Some of the clearest examples of this idea are what are known as **fuzzy trace theories** (e.g., Brainerd, Reyna, & Mojardin, 1999). According to this view, there are at least two memory traces involved in any act of remembering. One is a memory trace that contains detailed information about a specific instance. The other is a more general, categorical trace that captures general information. What is remembered reflects a combination of these. Information in the detailed memory trace dominates when a person has a good memory of a specific event and is trying to remember what happened during that one event. In contrast, information in the general memory trace dominates when a person's memory for a specific event is poor or if knowledge is used in a general way, such as trying to remember what a flywheel is.

Embodied Cognition

Recently, there has been increased interest in **embodied cognition.** While this phrase can mean many different things (Wilson, 2002), there are clear ways that this perspective can have particular influences on the study of human memory. Although the term *grounded cognition* (Barsalou, 2008) may be more descriptive and inclusive, we use the phrase embodied cognition to be consistent with the majority of the literature on this topic. The basic idea is that mental activity does not occur in a vacuum but is grounded in the type of worlds our bodies inhabit and the ways we can use our bodies in this world. Thought is affected by how we interact with the world. This can be seen when memory is affected by the situations people find themselves in. That is, people use context to help guide the encoding and retrieval of information. Second, memory often operates in real time as events are unfolding. As anyone taking a college exam knows, memories often need to be adequately retrieved in a set time limit. Finally, memory is influenced by both the structure of the perceptual information it receives as well as the types of activities a person will likely need to perform in the future—for example, remembering how to navigate around town. All of these ideas are consistent with an embodied cognition perspective.

Scientific Rigor and Converging Evidence

Memory is a tricky thing to study. Each person's memories are different in important ways from everyone else's. There are also different aspects of memory that are qualitatively distinct. However, to have the clearest picture of what our memories are like, and who we are, we need to take as objective a view as possible. We need to avoid being led astray by our biases, momentary intentions, and other prejudices. Taking a rigorous, scientific approach can do this. Psychology, after all, is a science. To emphasize this, various approaches or methods of looking at the data from memory experiments are presented throughout the book to illustrate how the data from memory studies can be analyzed and interpreted to gain a more refined insight into the depths of our mental storehouses. Also, we will see that opinions and theories formed as a science are better supported when evidence comes from different methods of collecting and analyzing data. If these multiple sources of information are all consistent with the same explanation, this gives us greater confidence that the theory is closer to the truth. This is something known as *converging operations*.

Synopsis

While the focus of this book is on the various aspects of memory, there are a number of recurring threads that will reappear across the various topics that represent emerging ways of thinking about memory. These include an increased desire to understand the neurological underpinnings of memory, the involvement of experienced emotions, the division of information across multiple memories, and a need to understand how memory operates in the real world. All of these, as well as every other topic in memory, are approached from a scientific perspective that seeks to derive answers about memory that help us have an accurate and durable understanding of ourselves.

SUMMARY

Understanding human memory is one of the most introspective tasks we can undertake as a species. By looking at how our own memories are created, structured, stored, and retrieved, we can gain a great deal of insight into who we are collectively and as individuals. The study of memory, however, is difficult. Memory is a very complex thing, incorporating issues of representation, storage, and process. People have been trying since ancient times to uncover the mysteries of human memory. Throughout history, particularly since the advent of psychology proper and especially since the advent of the cognitive revolution, we've gained a clearer and more consistent picture of what memory is all about, but much of the canvas is still obscured. Although there are many different theories about the nature of memory, many people at least implicitly follow the idea that short-term and long-term memory have different characteristics and that the operation of memory can be intimately influenced by the mental processes applied to the contents of memories. Moreover, different types of knowledge are handled by different memory systems. From this background, we will survey various aspects of memory, often touching on common themes of neuropsychological issues, emotions, multitrace influences, and issues of scientific rigor.

STUDY QUESTIONS

1. What do the terms *learning* and *memory* mean in the context of this chapter? How are they referring to similar things? How do they diverge?
2. Why do we need metaphors for memory? What are some metaphors? What do they tell us about the nature of memory?
3. What were some of the major figures and some of the major schools of thought that dominated thinking about human memory? What were the contributions of each?
4. What are some of the major divisions of human memory? What sort of processing is done by each of those divisions?
5. What are some of the emerging themes that will be recurring at various points in our discussion of memory?

KEY TERMS

behaviorism, cognitive revolution, declarative-nondeclarative distinction, distributed practice, embodied cognition, engram, episodic-semantic distinction, explicit-implicit distinction, forgetting curve, fuzzy trace theories, Gestalt psychology, learning, learning curve, long-term memory, massed practice, memory, metaphors for memory, modal model, nonsense syllable, overlearning, paired associates, savings, sensory registers, short-term memory, Tulving's Triarchic Theory, verbal learning