# History of Cognitive Psychological Memory Research

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# History of Psychological Approaches to Studying Memory

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## Introduction

Writings about memory date to the earliest written word, and doubtless people wondered about their memories for centuries before they were able to write down their observations. Aristotle and Plato wrote about memory in ways that seem surprisingly modern even today, although of course in the wisdom of hindsight many of their claims are off the mark. For example, Aristotle thought that the heart was the seat of learning, memory, and intelligence and that the brain existed to cool the heart. Today we agree that the organ underlying remembering is the brain, although we still talk about learning a poem "by heart" in deference to Aristotle. Later philosophers through the ages had their own theories of mind and memory, unfettered by much evidence except each person's experience, informed by reading about the ideas of previous scholars. Indeed, this was true of virtually every topic that today falls under the purview of science. Two Greeks, Leucippus and Democritus, writing around 500-600 BCE, discussed indivisible units, called atoms, that they believed made up all matter. But the atoms they envisaged share little with modern knowledge of atoms, except for the name.

The scientific revolution that began during the Renaissance in the 1500s started with the study of the natural world, initially excluding the study of people. The topics were primarily astronomy, physics, chemistry and geology, at first. Later biology and physiology became topics of interest to scientists. Finally, in the mid-1800s, experimental and scientific methods were applied to the study of people. Experimental psychology was born, and is often dated to, Wilhelm Wundt's first psychology lab established in 1879. Why so late? Scientists from Galileo and Copernicus on had run afoul of the dominance of religious authorities, and they were only studying astronomy. Studying *people* scientifically involved a whole new level of danger with church authorities, because the idea that the mind and behavior could be lawful conflicted with the doctrine of free will. If the immortal soul had free will, how could fledgling scientists attempt to discover principles, or even laws, of behavior with their puny instruments? But they did try and they accomplished their mission.

The earliest men (and a few women) who studied what today would be called psychology came from physics and physiology and applied their techniques to study people. The first topics were perception and attention: How does information flowing from the senses become registered in consciousness? How many things can a person attend to at once (the span of apprehension)? Wilhelm Wundt, often considered the founder of experimental psychology because of his early lab in Leipzig, decreed that higher mental processes like memory and thinking could never be studied scientifically, by empirical means. However, the year before, in 1878, a man named Hermann Ebbinghaus began a pioneering series of experiments that proved Wundt wrong. His work will be the first stop in our history, but first we must discuss another set of issues.

## Approaches to the Study of Memory

We write this chapter from the perspective of cognitive psychologists, and thus it is a partial and selective history of this one approach to the study of memory. We should acknowledge first that other valid approaches to the topic exist even though we cannot provide their history. All are empirical approaches, ones that seek systematic evidence of one sort or another. Philosophers remain interested in memory, but their writings today refer constantly to the research literature.

One approach is the study of the synaptic mechanisms and processes in simple organisms like snails, slugs and fruit flies. How does the nervous system change as a function of experience, the basis of learning? The only Nobel Prize given for the study of memory was awarded to Eric Kandel for his studies of the physiological basis of memory storage in the sea slug, *Aplysia Californica*. Another approach to learning comes from pioneering work by E.L. Thorndike, Ivan Pavlov, B.F. Skinner and many others on learning and conditioning in mammals, such as rats, pigeons and dogs. They were more interested in learning than in later retention, but they studied both. They hoped to find universal laws of learning that generalize across types of animals. The field in which interventions are made in the nervous system of such animals to study their effects on learning and memory is called behavioral neuroscience. Another interesting tradition is that of neuropsychology, the study of brain-damaged patients and their afflictions of memory (generally, various sorts of amnesia). The study of artificial intelligence and analogies between memory in computers and in humans represents yet another tradition.

Perhaps closest to the cognitive tradition is that of cognitive neuroscience. This is a broad field of great contemporary interest in which remembering is studied by measuring neural activity in humans (often using functional magnetic resonance imaging or fMRI) while they are performing various tasks (usually ones previously studied by cognitive psychologists). Further afield, the study of collective memory involves how groups of people remember their past (e.g., how Americans remember 9/11 or World War II), and historians, sociologists and others often lead these studies.

In short, many approaches exist to study memory. They should be seen as complementary rather than competing, each trying to provide insights into the mysterious workings of the mind and brain from their particular vantage point using their techniques.

What distinguishes the approach of cognitive psychologists? In general, as we will see, cognitive psychologists set tasks for people in which to examine their memories. They do not intervene in the nervous system, although some cognitive psychologists also employ methods of cognitive neuroscience. Cognitive psychologists have developed an armamentarium of clever tasks over the past 135 years and have gained much knowledge. Often their subject of convenience is the college student, and the field has been criticized for this choice. However, a defense can be made of the college students as ideal subjects. After all, through 12 years of school, these students have shown they can learn and remember well enough to be admitted to a college. They are highly selected subjects, ideal for studies of learning and memory, just as *Drosophila* ideal are for geneticists to work out the laws of genetics. However, cognitive psychologists have branched out, and studies of how memory develops in children and how it declines in old age are hot topics. So too is a tradition of studying memory in more natural settings than laboratory tasks (Neisser, 1976). Yet another issue the entire field of psychology confronts is the focus on WEIRD subjects, where WEIRD stands for Western, Educated, Industrialized, Rich and Democratic (Henrich, Heine, & Norenzayan, 2010). Most researchers are themselves WEIRD individuals, and most research on human memory is conducted in such countries, although brilliant exceptions exist. The field is beginning to ask if what is learned in WEIRD subjects generalizes to the greater part of humanity, people who do not live in WEIRD countries.

## Historical Beginnings

One approach to writing history is called the “great person” approach, in which great swaths of history are covered by a few leaders of the time. Such an approach (often a “great man” approach) unduly simplifies what is always a much more complex story. While realizing its deficiencies, we use it to orient our readers to two great traditions in the cognitive study of memory. Just as there are broad traditions within the study of memory across all disciplines, even within the cognitive tradition distinct approaches exist. Hermann Ebbinghaus and Frederic

Bartlett are initiators of two of the major traditions, so we treat their work (primarily captured in their books of 1885 and 1932, respectively) in some depth.

**Hermann Ebbinghaus (1850-1909)**

The first person to undertake the systematic, empirical study of memory was Hermann Ebbinghaus, a German scholar who taught at several universities. He is believed to have bought Gustav Fechner's 1860 book, *Elements of Psychophysics*, on a trip to England, and he became inspired by the methods Fechner had developed. However, the methods Ebbinghaus invented to study memory are quite different. One might think that, being first, the methods would not bear modern scrutiny, that they would be considered preliminary and sloppy by today's standards. That assumption would be dead wrong. Ebbinghaus developed careful methods and measurements, developed early statistics, and every one of the many discoveries he made has stood the test of time (Roediger, 1985, Slamecka, 1985). As Tulving (2007, page 53) observed, "Despite the pioneering nature of his work, he did just about everything exactly right by the standards of science." How he developed such elegant methods and conducted such powerful and convincing experiments is difficult to understand. He began his research in 1878, and he continued his set of pioneering experiments into 1879. A move to the University of Berlin caused a hiatus, but in 1883-1884 he replicated his prior experiments and added new ones. All this work culminated in his great book *Über das Gedächtnis*, in 1885, and it was favorably reviewed by William James in *Science* the same year. The book was translated into English in 1913 as *Memory: A Contribution to Experimental Psychology*. The research reported in this book began the laboratory tradition of studying human memory.

*Ebbinghaus's methods*. Ebbinghaus gave careful thought to the methods he developed. Common sense tells us that we either remember something (e.g., the capital of Ghana) or we do not. Ebbinghaus was the first to argue that this state of affairs was not accurate, and further, he successfully developed a method to tap into the strength of memories that could not be brought to conscious awareness. He rejected the use of measures of recall and recognition (the ones almost universally used today) as "introspective," and he argued that a better, more objective measure was needed. Ebbinghaus sought to develop methods whereby the residue of unobservable memory traces could be examined in behavior. The measures would need to be reliable (that is, repeatable) and to vary systematically as a function of the manipulation of variables. He succeeded in all three objectives. And he replicated all of his important experimental findings to convince himself and other scientists of their validity.

Along with nearly all philosophers of the time, Ebbinghaus assumed that learning occurs by building associations among elements to be learned and that forgetting is caused by the loss of those associations. In order to study this process, he developed materials that would seem to have no prior association with one another (or much of anything else): consonant-vowel-consonant (CVC) nonsense syllables: ZAK-CEG-KUF, and so on. Chapters 2 through 4 of his book provided his methods. Briefly, Ebbinghaus served as the only subject in all his experiments. He knew this was a danger on several grounds, but he addressed it directly. He created about 2300 CVC syllables, and he randomly arranged them into numerous lists. He would read them in time to a metronome to learn them, and he would measure the number of trials it took him to learn the list so that he could repeat the syllables correctly in order. This task is called serial learning (learning a series in correct order), and his primary measure was the number of trials (or the amount of time) it took to reach a criterion of 100% correct recall, in the proper order. Serial learning was a natural task, because it seems to be accomplished by each syllable being associated to the next, so recall of one syllable cues recall of the following one through a direct association (what Ebbinghaus referred to as the “invisible threads” linking the syllables).

Difficulty of learning a series of nonsense syllables was assessed by the number of trials (or time) needed to achieve a perfect recitation, but how should retention at a later time be measured? One idea would be to ask for recall of the series, but Ebbinghaus learned so many series that specifying one from a particular day and time would have been impossible. Besides, recall is an introspective and subjective; just because a person cannot recall an item or event does not mean that no trace of the event exists. Ebbinghaus’s ingenious solution to this problem was to have himself relearn the lists (he had a careful labeling system) and to measure the number of trials it took. The stronger the “invisible threads” that remained, binding list items together, the fewer trials it would take to relearn the list. So, the measure of retention was the savings in relearning, which could be a continuous measure. If he had originally taken 15 trials to learn the list, and a week later it took him only 5 trials, he would have “saved” 10 trials. He would have a savings score of 67% (that is (15 – 5)/15 x 100) = 67%). If the interval between learning and testing had been two weeks, and after this delay it took him 10 trials to learn the list, then he would have shown 33% savings. If a year had passed and it took him 15 trials to relearn the list, he would have shown no savings and thus complete forgetting of the list. The beauty of this method is that even if people believe they have totally forgotten the list, the savings method of retention may show some latent residue or traces of the original experience that could be measured in behavior. In this sense, Ebbinghaus designed a way to measure unconscious memories about a decade before Freud (1895) began writing about a (quite different) form of unconscious memories.

*The findings.* Most of his book consisted of his experimental findings. He worried that his measures might be too variable to be reliable, but he satisfied himself that this was not the case by comparing them to the findings of the physicist Joule, which were responsible for Joule's Law, and concluding they were in the same range. As noted above, he also replicated his experiments.

Ebbinghaus showed that the longer the list of syllables, the more trials it took to learn it. That is no surprise. However, he also showed that with only 7 syllables, he could recall them perfectly on a single trial (thereby discovering what was later called the span of immediate memory; Miller, 1956). However, for lists of 12 syllables, only 5 beyond the memory span, it took him an average of 16.6 trials to reach 100%. He increased the list lengths to 16, 24 and 36 syllables, and it took him averages of about 30, 44 and 55 repetitions to remember the series correctly. Keep in mind that he memorized many series of each list length many times, to gain a stable average.

In another heroic experiment, he asked how the number of repetitions of a series of 16 syllables learned on one day would affect retention 24 hours later. He repeated series of 8, 16, 24, 32, 42, 53, or 64 times and measured savings in relearning them the next day. Except for the extreme cases where he needed essentially no practice the next day, he discovered an interesting function: Every three trials on Day 1 led to a savings of one trial in relearning the series on Day 2. (Keep in mind that he was actually learning many series on the first day and relearned many series on the second day, of varying length).

Perhaps the most famous experiment was reported in Chapter 7, because it reports the forgetting curve Ebbinghaus discovered, which appears in nearly every textbook of general psychology, cognitive psychology or human memory. Briefly, he learned lists to criterion and then relearned them after varying amounts of time. Before reporting the experiment, he sketched out what functions forgetting might plausibly follow, but the one he obtained declined rapidly at first and then became more level, descending downwards. He fitted a logarithmic equation to it, and although today we know a power function is a slightly better fit (Wixted & Carpenter, 2007), Ebbinghaus was close and still has his defenders (Rubin & Wenzel, 1996).

In one of the last chapters, Ebbinghaus produced another major achievement. In brief, he developed two theories of how associations might operate to produce recall. He then developed an ingenious experiment to decide between them, using the *method of derived lists*. One idea is that associations are only formed directly from one to another. If A-B-C-D-E-F-G … stand for nonsense syllables, then recalling A leads to B, B to C and so on. However, his second theory claimed that perhaps there are also remote associations, so that learning of A leads to a strong association to B, a weaker one to C, and a weaker one still to D. How to test for the existence of remote associations? Ebbinghaus learned a list as above (A-B-C…) and then developed what he called derived lists. An example would be learning A-C-E-G-B-D-F, a list derived by skipping the direct associate. Would this list be learned faster than a control list? Also, would a list like A-D-G-B-E (skipping two associative links) be learned better than control lists but less well than lists skipping one link? Indeed, his experiment provided evidence supporting both predictions, and thus he found evidence for the existence of remote associations in list learning (see Slamecka, 1985 for more on this issue). This derived list experiment was the first one in all of psychology that involved competitive hypothesis testing, which is supposed to be one hallmark of scientific methods. In his *Principles of Psychology*, William James wrote, "Dr. Ebbinghaus's attempt is as successful as it is original, in bringing two views, which seem at first sight inaccessible to proof, to a direct practical test, and giving the victory to one of them" (1890, p. 677).

Ebbinghaus discovered many other properties of memory, and he also made other notable methodological advances, but space is short. Once again, every discovery that Ebbinghaus made has stood the test of time. He developed a methodologically sophisticated, rigorous, method of studying memory. Many later researchers, including those today, work within the tradition that is his legacy. Yet other traditions exist, and the one we consider next was quite different from that of Ebbinghaus and his followers.

**Sir Frederic Bartlett (1886-1969)**

In 1922 Sir Frederic Charles Bartlett became Cambridge University's first professor of experimental psychology. During the thirty years in which he directed its Psychological Laboratory, he trained the first generation of British psychologists, many of whom went on to become quite influential in their own right (Roediger, 2000). Distinguishing him from Ebbinghaus was a style that might be called anthropological, attributable to his mentor, W.H.R. Rivers (Whittle, 2000). Bartlett did not work in the careful tradition of laboratory research, and he was interested in how people remember in daily life, not in the lab. In 1898, Rivers had led an expedition to conduct psychophysical research among the Torres Strait islanders, an indigenous people inhabiting the islands stretching between Australia and Papua New Guinea. He attempted, unsuccessfully, to demonstrate a then widely held belief that "savages" had greater sensory acuity than Europeans. Contrary to his hypothesis, it turned out that Torres Strait Islanders and Europeans have comparable psychophysical characteristics, but the time Rivers spent among the islanders convinced him that the apparent differences between those people and his own had to do not with evolutionary (i.e. biological) differences, but with the diffusion of culture.

Bartlett was not on this trip, but he became influenced with Rivers' ideas upon the latter's return. How cultural frames transform ideas as they are transmitted between people became a dominating concern of Bartlett's program of research. Ebbinghaus was interested in accurate remembering, and he never much discussed errors and what they might show. Bartlett was interested in the common errors people made in transmitting information from one person to another, or even when the same person repeatedly recalls a story or event. He came to believe transmission of memories changes them and reshapes them. Remembering was reconstructive rather than reproductive; that is, rather than memories being stored in some static form (the memory trace), bits and pieces are stored and from those pieces a story of the event is reconstructed. This reconstructive vision of memory, promulgated later by Hebb (1949), Neisser (1967) and others, differed quite radically from the dominant storehouse metaphors of memory and mind (Roediger, 1980).

This early cross-fertilization between psychological and anthropological concerns may partially explain many of the peculiarities of Bartlett's methods, particularly vis-à-vis Ebbinghaus. Bartlett was concerned with *meaning*, and what would later be called ecological validity, of studying remembering as it is used in life, not in the lab. Thus, he used naturalistic study materials and tasks, having participants recall stories or pictures, rather than nonsense syllables. He wanted his tasks to be reasonably similar to tasks his participants might perform during their normal lives, in the real world. He also showed a preference for illustrative case studies – in some cases nearly anecdotes – over formal statistical analyses. Perhaps the strongest influence from anthropology, however, was found in his recognition of the role played by social frames, culture, and interpersonal interactions on remembering. Indeed, even after administrative restructuring at Cambridge moved the Psychological Laboratory into the biology faculty, Bartlett acknowledged that the Torres Straits expedition had left a legacy on Cambridge psychology, which would thereafter always be "human as well as scientific" (Whittle, 2000, p.32).

**Bartlett's methods.** Bartlett's research covered a broad territory, but it is his 1932 book *Remembering: A Study in Experimental and Social Psychology* that future generations of memory researchers have appropriated most enthusiastically. Many of the book's insights were seminal in what would later be known as the "cognitive revolution," even though that revolution lay 30 years in the future. Each of the book's first eight chapters focused on a different method of probing the perception, imaging, and remembering of his Cambridge undergraduates, but the general principle behind each method was the same. Bartlett might give participants a short story to read. He would then ask them to repeat it back to him at a later time. This recall might have been half an hour later, or much later - for some participants the test could come several months or even years later. He would then closely examine the memory protocol produced by a participant and point out interesting alterations, as well as how the story recalled changed over time.

To contemporary eyes, Bartlett's methods appear exceedingly casual. He rarely gave detailed descriptions of his instructions prior to a task, explaining, "It is not necessary to give the questions in detail, particularly as I did not hesitate to adapt them or to supplement them in accordance with what I judged to be the psychological needs of the moment" (Bartlett, 1932, p.49). His analyses were likewise informal. In several chapters, he simply provided the transcripts of several memory protocols, and pointed out the changes the participant had made over the successive recall sessions. There was no attempt to measure the recall protocols and to aggregate the data. If Ebbinghaus had still been living, he might have despaired at how unscientific the study of remembering had become in the 47 years since he published *On Memory.*

Scandalous as they might appear, Bartlett had his reasons for his methodological choices. He framed his research program as a correction to what he viewed as Ebbinghaus' legacy of exceedingly artificial memory research. Ebbinghaus had mostly rejected naturalistic study materials in his experiments, such as stories, prose, life-like pictures, etc. He believed that with such complex material, any two participants would likely bring to the task entirely different networks of associations.[1] Still, different personal histories could thus prove to be a fatal confound for Ebbinghaus. The experimenter would never know why a participant remembered any particular item, and any conclusion would rest on shaky grounds if trying to attribute an effect to any particular experimental manipulation. Ebbinghaus proposed to resolve this problem by using study materials that would be equally meaningless to everyone. In doing so, he claimed, he could test "pure" memory, apart from the influence of individual life experiences. All well and good, Bartlett argued, except that people tend to impose meaning on even the most apparently meaningless materials. He cited the old story of a geologist, a naturalist, and an artist who walk through a landscape together, each of them bringing a unique set of expertise and interests to bear. They will each interpret the "neutral" stimuli according to those frames, and in doing so impose meaning on various salient characteristics. It would be functionally impossible to remove meaning. In fact, researchers eventually began studying the "meaningfulness" of nonsense syllables. For example, people find ZAM more meaningful and more easily remembered than QYM (Glaze, 1928). What researchers in the Ebbinghaus tradition studied,

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[1] In one exception, Ebbinghaus memorized Byron's poem Don Juan and estimated that learning poetry took only about 10% of the effort of remembering nonsense syllables

according to Bartlett, was merely the acquisition of somewhat strange and unnatural skills, or habits. Human memory, on the contrary, relies on meaning.

**Effort after meaning.** Meaning was a crucial element of Bartlett's theory of memory. For him, meaning did not "reside" in the stimulus; meaning was actively constructed as people try to form links between a stimulus and the cognitive frames and attitudes they bring to a task. An ambiguous picture might be interpreted as a "bird;" subsequent attempts to reproduce the picture would be more "birdlike" than the original image (Carmichael, Hogan & Walters, 1932). This attempt to connect a stimulus to existing frames of knowledge and memory, and the use of such frames in re-constructing a memory, would be what Bartlett called the *effort after meaning*. The effort after meaning is the "attempt to connect something that is given with something other than itself" (Bartlett, 1932, p. 227). This active striving to create meaning extended all the way from simple perception to the way people remember stories and pictures. Perceiving an object required participants to actively fit a sometimes-ambiguous stimulus into a pre-existing frame, or scheme in memory. Thus, perception itself was neither merely a passive representation of something in the external world, nor was it a straightforward, "data-driven" representation. If the effort after meaning – the attempt to comprehend the world around us – was a critical component of even relatively low-level perception, it was all the more so in a higher order cognitive task, such as remembering. As a contemporary demonstration of Bartlett's point, Zaromb and Roediger (2009) showed that requiring students to make an effort after meaning to resolve an ambiguous sentence improved their later retention of an experience, and later research showed that they were unaware of the effect (Zaromb, Karpicke & Roediger, 2010).

The idea that people often impose a rule of arrangement by which they make sense of some matter may be traced back to Alfred Binet's[2] (1900) discussion, in his book on suggestibility, of the *idée directrice*, the "guiding idea." A general rule is easier to remember than a variety of specific details, and the rule may be used to reconstruct details as necessary. Bartlett gives a simple example of a series of faces that he showed to his participants. He later asked the participants several questions, such as which direction the fourth face in the series was pointing, etc. One participant suggested that she noticed a progression, in which the faces early on in the series faced leftward, and the final faces faced rightward; intermediate faces in the series demonstrated a gradual rotation between these two extremes. This idea of a rotational progression became the participant's *idée directrice*, and when she "remembered" which direction the faces were pointing, she used this scheme to construct her responses. The faces did not, in fact, follow the rule that the participant believed she had discovered. Nevertheless, Bartlett felt his point made; such rules were useful because they were much easier to remember, and relevant details could normally be inferred as required. This participant's apparent rule offered a simple example of use of a guiding idea in reconstructive memory. Bartlett extended this general principle to more complex schemes, such as social stereotypes, or cultural standards concerning what constitutes a "good" story.

Probably his best-known studies involved what he called the *method of repeated reproduction* and the *method of serial reproduction*. Both followed similar procedures. In the method of repeated reproduction, a single individual would read a story or see a picture, and make several attempts, over a span of time, to recall the material. In the method of serial reproduction, one person would read the story or see the picture, and would recall it for a second

[2] Alfred Binet is better known for having created the first IQ tests, in order to identify which French school children were falling behind and in need of remedial education.

person, who recalled it for a third, and so on. Recall could thus be distributed across time within the same individual, or across acts of communication between individuals. Both methods demonstrated similar outcomes. When the material used was a story containing many culturally unfamiliar elements – for example, the famous *War of the Ghosts*, a Native American tale from the Pacific Northwest – each repetition would show characteristic distortions. The memory protocols, on average, became much shorter, as details that were not essential to the plot were forgotten. Participants introduced causal connections between apparently disconnected elements of the story, making it more "rational." Supernatural elements dropped out. When the protagonist of the story dies and "something black comes out of his mouth," this was often remembered as "his soul left his mouth;" Bartlett pointed out that once people believed an element symbolized something, they normally remembered the symbolized referent, rather than the symbolic "vehicle." Bartlett's Cambridge undergraduates also tended to remember culturally unfamiliar elements such as seal hunting or paddling canoes as more familiar activities, such as fishing or rowing boats. This was an example of a special type of effort after meaning with social origins, in which strange material is remembered in such a way that it becomes culturally intelligible. Bartlett termed the process *conventionalization*.

In analyzing his participants' memory protocols, Bartlett concluded that humans rarely remember accurately. This is particularly the case for the sort of complex narrative material people typically remember in the course of ordinary life. Rather, remembering is an active reconstruction, which arises in a specific social and environmental context. Importantly, the internal context, or psychological "setting," matters as well. Bartlett characterized this dynamical, organized psychological setting, or *schema*, as an accumulated mass of past experiences and activities. "Schema" is a famously difficult concept to define precisely (e.g.

Broadbent, 1970; Zangwill, 1972). At its simplest, a schema might be something like Binet's *idée directrice*, in that it is a sort of rule for how something in the world should be, which can be used to re-construct the details of a memory. When Bartlett described a participant beginning an act of recall by experiencing an attitude, or an emotional orientation toward the material, and then re-constructing the memory to justify that attitude, the attitude is providing a sort of schema to guide remembering. Bartlett emphasized that schemata are dynamic and constantly updating. Because schemata develop during the course of meaningful activities, they represent the framework against which stimuli are matched, and they shape acts of remembering. Schema-driven re-constructions cause material to become more subjectively meaningful, and more conventionalized, as it is recalled multiple times. This last point is important, in that, as implied in the example about hunting seals and fishing, schemata tend to be shared by members of the same cultural group.

One of Bartlett's greatest contributions to the study of remembering was in reframing the object of study from *memory* as a faculty to *remembering* as an activity, from structure to function. This activity was meaningful and adaptive. He shifted the theory of memory from the reproduction of "traces" to schema-driven reconstructions. For him, remembering and imagining were tightly related processes, a perspective that has been resurrected in recent years (Szpunar, Watson & McDermott, 2007; Szpunar, 2010). He showed that shared schemata lead members of the same groups to reconstruct memories in reliably similar ways, such that they are more rational and conventional by the group's standards. This insight into the selective pressures toward rationalization and conventionalization represented the beginnings of a cultural theory of memory, which Bartlett seems to have originated, then more or less abandoned (Douglas, 2000).

Bartlett's book was published in 1932, but it was not until later in the 1960s, when Ulric Neisser picked up Bartlett's themes in his 1967 book, *Cognitive Psychology*, that Bartlett's ideas gained traction and began to guide research, both in a qualitative tradition but also in the more experimental and quantitative tradition of modern cognitive psychology.

**The Verbal Learning Tradition**

This tradition of research follows in Ebbinghaus's footsteps. The hallmark is careful, compulsive, experimentation within a psychological laboratory. This tradition dominated memory research during the first half of the 20th century, and like most topics of this chapter, it is impossible to do it justice in a few paragraphs. The tradition lasted strongly into the 1970s, and it is easy to find its residue today in modern research. Ebbinghaus focused on serial recall and the method of savings, and he discounted measures of recall and recognition as introspective. However, other researchers quickly began to develop these other measures.

In 1895, in pioneering woman named Mary Calkins (1863-1930) developed what is now called the method of paired-associate learning. Calkins had studied at Harvard under William James and Hugo Munsterberg, and from 1894 to 1898 she published pioneering experiments with a new method, which she much later (1930) called the *right-associates method* when she wrote her autobiography. At the time, she gave it no name, but Thorndike (1905) called it the paired associate method and the name stuck (Madigan & O'Hara, 1992). Briefly, she showed a series of colors paired with numerals, such as a patch of blue paired with 47. On a later test when subjects were given the colors, they were supposed to respond with the correct number. Thus, given the blue patch on the test, to recall 47. She showed that bright colors were easier to associate with numbers than duller colors, but more importantly, she showed that frequency of presentation of the pair greatly affected recall, and so did its recency. Madigan and O'Hara

(1992) discussed Calkins findings a hundred years later, and they reported that she reported several important findings that were "discovered" by others much later. Today, paired associates learning is one of the main tools used by memory researchers.

Before we leave Calkins, we should note that she was a remarkable scholar. Harvard did not admit women, but through intercession of several people, the president of Harvard, Charles Eliot, permitted her to take classes so long as she was not registered; Eliot believed that men and women should never be educated together. Calkins' paired-associate experiments and findings formed the basis of her doctoral dissertation. The all-male faculty of the Department of Philosophy and Psychology voted unanimously that she should be awarded a PhD for her work. She had fulfilled all the requirements. Yet the Harvard president and board refused and appeals on her behalf fell on deaf ears. She was denied a PhD from Harvard solely based on her gender. William James was horrified at the outcome, but he was unable to change it. He wrote that her performance was "much the most brilliant examination for the Ph.D. that we have had at Harvard" (Scarborough & Furumoto, 1987, p.46). Despite this setback due to discrimination, Calkins went on to produce great research in psychology and wrote papers on the concept of the self in philosophy. She became the first woman president of the American Psychological Association in 1905 and of the American Philosophical Association in 1918, a remarkable testimony to her abilities.

We cannot trace the history of the 60-70 year verbal learning movement in a few pages, so we will just note a few studies and trends. Jenkins and Dallenbach (1924) were the first to study the effects of sleep on memory. They had subjects learn many lists of ten nonsense syllables in the lab either at night or in the morning. When learning at night, subjects were awakened after 1, 2, 4, or 8 hours and asked to recall the syllables. During the day, they were asked to come back to the lab at a specified time that corresponded to these intervals. Each list was tested only once. The issue was whether forgetting occurred more rapidly during sleep or waking. The findings were decisive and have been often replicated: Forgetting is greater when people are awake during the retention interval rather than asleep. This outcome may indicate that less interference occurs during sleep, that sleep helps to consolidate memories, or both – a debate that continues even today.

Why does forgetting occur? One idea is called decay theory (Thorndike, 1914) and was based on the simple fact of the Ebbinghaus forgetting curve. The idea is that traces of memories are formed in the brain, and then they begin to decay as a function of time (the forgetting curve). This was the reigning theory of forgetting for years, but McGeoch (1932) mounted a challenge from which decay theory never recovered. One prong of his argument concerned the results just discussed by Jenkins and Dallenbach (1924). They had subjects learn a list perfectly and then be tested (for example) four hours later. He argued that if decay theory were true and if forgetting just occurred as a function of time, then there should be equal forgetting after four hours no matter whether subjects were awake or asleep. Yet a large difference was obtained, favoring sleep. Another prong in his argument is that decay theory seems to assign a causal role to time, as if "time causes forgetting." Yet he pointed out that time causes nothing directly; it is processes that occur over time. If you leave your bicycle out in the rain day after day and it rusts, you would not say that "time caused rust." Rather, processes of oxidation occurring over time caused the bike to rust. McGeoch (1932) argued that the main cause of forgetting was interference, in particular, what is called retroactive interference.

Researchers distinguished between proactive and retroactive interference. For example, suppose subjects learn one list of nonsense syllables perfectly. Then one group, which we will call RI, for retroactive interference, learns two more lists of nonsense syllables, again to 100% criterion. A control group (C) is kept busy doing other tasks for the same amount of time, but none related to learning nonsense words. Then later both groups are asked to recall and then relearn List 1. The RI group recalls much less than the C group, and this is the result of retroactive interference from learning the two intervening lists.

Now imagine another situation that is rather similar. A PI (proactive interference) group learns three lists of nonsense syllables to the criterion of 100% each time. A control group (C) does other complex tasks for a while, but then learns one list to a 100% criterion. Now both groups are asked to recall the most recently learned list. If the final test occurs immediately after learning, the two groups recall at about the same level, and nearly perfectly. After all, they both just learned the list. However, if there is a delay of, say, 24 hours between learning that last list and the test, the PI group does much worse. Proactive interference exerts itself increasingly over time (Underwood, 1957).

One of the great achievements of the verbal learning tradition was the interference theory of forgetting (e.g., Underwood, 1957; Barnes & Underwood, 1959; Postman, 1963). McGeoch (1932) argued that retroactive interference was the cause of most forgetting and he gave short shrift to proactive interference. The field accepted that claim for 25 years and the hunt was on to identify causes of RI. A new paradigm was also developed to study the issue, using Calkins' method of paired associates, and it was named the A-B, A-D interference paradigm. Briefly, subjects would learn a list of (say) 20 paired associates, often pairs of unrelated words such as *chair-umbrella* (A-B). In the interference condition, subjects would then learn another list with the same A terms but new B terms. So, for example, they would have to learn *chair-penguin*. Then, after a delay, the subject would be given A-??? and asked to recall the word associated with it in the *first* list (*umbrella*, in this example). Two control conditions were used. In one, subjects learn A-B pairs and then were distracted with unrelated tasks (e.g., a puzzle) for a period of time, and later were asked to recall the list. This control is often called one for assessing nonspecific interference (from the puzzle). Not surprisingly, this condition shows much less forgetting or interference than when participants learned an A-D list after an A-B list (with item-specific interference). More interesting is the control group that receives an A-B, C-D task. That is, they learn the same A-B pairs as the other groups, but now they learn another list of unrelated pairs denoted C-D (e.g., *bullet-penguin*). They show more interference than the control group with just general tasks, but the first condition, with item-specific RI (having to learn both *umbrella* and *penguin* to chair) creates the most retroactive interference in recalling *umbrella* when given *chair*. This kind of item-specific RI in the A-B, A-D paradigm is what interference theorists sought to explain.

Two theories were developed. One theory argued that interference was caused by *response competition*. That is, at the test when the subject is given the A term (*chair*), both *penguin* and *umbrella* may compete in the subjects' minds as responses. One version of the theory stated that whichever response came to mind first would tend to drive out the other one, hence producing retroactive interference if the wrong one came to mind. Another theory stated that instead of (or in addition to) response competition, another factor called *unlearning* was at work. That is, as subjects in the A-B, A-D paradigm learned the A-D pair, the A-B associative bond became weaker; it was unlearned. These two factors together, unlearning and response competition, are called two-factor interference theory (Postman & Underwood, 1973).

We have sketched in these ideas with a broad brush, but thousands of subjects participated in hundreds of experiments from the 1940s to the early 1970s debating these topics.

Crowder (1976) provides a great summary of the debates just after this tradition of research began to exhaust itself. For the hardy aficionado, the paper by Postman and Underwood (1973) recounts the problems and prospects for interference theory quite thoroughly.

Interference theory was criticized by various researchers outside the verbal learning tradition as empty and sterile. For example, Neisser (1982, p. 9) argued that “the experiments of interference theorists seem like empty exercises to most of us. Were they ever anything else?” We would answer *yes*. In the same article, Neisser extolled the work of Loftus and Palmer (1974) in studying how misinformation affected eyewitness memory as new and exciting, and it was. However, the paradigm they used and that was used in later studies (e.g. Loftus, Miller & Burns, 1978) was a classic retroactive interference paradigm, just with different materials (Roediger, 1991).

We have surfed lightly over a compendious literature in the verbal learning tradition. Fortunately, two books from the 1970s capture the tradition and provide great sources for a huge number of experiments on many topics of this era (Hall, 1971; Kausler, 1974). During the late 1960s through the 1970s, the tradition of memory research morphed into a different form, casting many of the issues from the verbal learning tradition into a new form, although many verbal learning interests were dropped altogether.

## Organization and Memory

Miller’s (1956) paper introduced the idea of recoding, with the insight that often remembering is better if someone does not remember information the way it comes from the outside world, but instead recodes it into a form that is easier to remember. This idea is the key insight that lies behind many techniques used today to improve learning and memory for a body of information, including all mnemonic devices. For example, ask someone to remember this series of numbers after hearing it once: 1 4 9 1 6 2 5 3 6 4 9 6 4 8 1. Nearly everyone would struggle; people can recall roughly 7 digits, but not 15. Yet give them a scheme for remembering these numbers – they are the squares of the numbers 1 to 9, in order – and a person can recode the digits so they could be easily remembered an hour later. This case represents something of a gimmick, but it also represents how effective remembering often occurs via recoding.

In the 1950s, Bousfield (1953) showed that words that belonged common categories (types of furniture, sports, reptiles) are better remembered than unrelated words. Further, when the words from the categories were presented randomly, subjects grouped them into categories. In Miller's terms, subjects recoded the words into their meaningful categories to help remembering. Bousfield used a task called free recall, which was unlike the serial recall of Ebbinghaus or the paired associate task that dominated research in the verbal learning tradition. The task is the essence of simplicity: Subjects see or hear a list of words and then they recall those words in any order. The task soon became popular in the study of how learning develops over trials.

Tulving (1962) studied learning of random words over many trials. That is, subjects would get unrelated words in random order, recall them, have the words presented again in a new random order, recall them, and so. An orderly learning curve results, when recall is averaged over subjects. But why do learning curves go up in this situation? Tulving hypothesized that, even though no organization was built into the list, subjects find their own idiosyncratic organizational scheme in order to memorize the list. Tulving examined the order in which subjects recalled the list. He discovered that even though the words were presented randomly, they tended to be recalled in the same order over trials and this tendency increased with the number of study/test trials. The idea is that subjects formed their own scheme to remember the words and kept developing it over trials. Tulving called this process *subjective organization*, as opposed to the more objective organization that Bousfield had built into his list in the form of common categories. People try to create their own categories, even if the materials provides them no obvious clues.

The 1960s saw numerous studies of how organization improves remembering. Mandler and Pearlstone (1966; Mandler, 1967) developed a technique to uncover the organization that people used. They gave subjects 52 words, on cards, and asked them to sort the cards into piles of cards that belonged together. Even though no obvious organization was built into the list, subjects could do this task after a few trials (they had to sort the words into the same piles twice in a row when given the cards randomly). Mandler showed that subjects tended to sort the cards into 4-5 piles. Interestingly, the number of trials they took to sort the cards – that is, the number of repetitions – did not matter in later recall. It was the organization that mattered.

Another landmark paper on organization and memory was published by Bower, Clark, Lesgold and Winzenz (1969). They presented subjects with a large number of terms (e.g., minerals) that were either presented according to an organizational scheme, or without an organizational scheme. In one condition, participants saw words arranged into hierarchically nested category trees; at the top would be a superordinate category word such as “mineral;” beneath would be subordinate category words, e.g. “metal,” and “stone.” These categories would be further refined, e.g. under “metal” would be “rare,” “common,” and “alloys.” Finally, at the fourth level would be exemplars; under “rare” would be “platinum,” “silver,” “gold,” and under “common” would be “aluminum,” “copper,” “iron”. All these categorically nested terms were arranged visually into a tree, emphasizing their hierarchical, categorical relations. A control group saw the same words, presented in visually identical formations, but the words were randomly arranged, and their visual arrangement did not imply any obvious conceptual organization. For the controls subjects, even though they were learning the same items, a hierarchical category scheme by which they might effectively organize the material was absent. Even though both groups studied the words for the same amount of time, the group that studied terms in their appropriate organization recalled approximately twice as many words as did the control group.

All these studies and many more clearly show the powerful impact that organization has on successful remembering (Tulving, 1966, Crowder, 1976, Chapter 10). This line of work would seem to have much in common with Bartlett's idea of schema, and it does. The researchers in the 1960s were working in the laboratory tradition of Ebbinghaus, but the interest in the powerful effects of organization on memory, in hindsight, reveals a merging of the traditions. Schemas represent one form of organization.

**The Information Processing Tradition and the Cognitive "Revolution"**

We have just covered the verbal learning tradition, the end of which overlapped with the beginnings of the cognitive revolution. We should mention that the verbal learning tradition was not the main tradition in the study of learning and memory even during its heyday. Rather, the great debates and controversies from the 1920s through the 1960s revolved around studies of learning and retention in animals – pigeons, rats, cats, dogs and others (although primarily the first two). All psychology students in the 1940s and 1950s learned about the ideas of Edwin Guthrie, Clark Hull, Edward Tolman, B.F. Skinner, Kenneth Spence and many others. In the 1950s on to the early 1960s, a confluence of forces opened up experimental psychology to new ideas, new methodologies, and whole new arenas of study. Much of the verbal learning field morphed into cognitive psychology.

The learning theorists in the Hull-Spence tradition had attempted to explain all learning - human and non-human - in terms of stimulus-response (S-R) contingencies, shaped and conditioned by experience within particular environmental contexts. (Skinner's approach was different). By the 1960s, however, it had become apparent that this endeavor rested on tenuous assumptions. For humans in particular, responses to environmental stimuli seemed to be mediated by rather complex intervening processes. To be sure, some behaviorists had already conceded the need for theoretical chains in the "black box" between stimulus and response. In particular, Tolman, who was more of a cognitive behaviorist, introduced the idea that rats develop "cognitive maps" as they learned to navigate from the start box in a maze to their reward in the goal box (Tolman, 1948). Hull also proposed mediating processes in his theories, but more as unobservable S-R reactions (Hull, 1952), an approach he called neobehaviorism. This period of psychology (roughly 1920 to 1960), was the time when behaviorism dominated in North American psychology.

In the 1960s, several forces came together that ushered in a new age. To mention a few, ideas from electrical engineering flowed into psychology. Just as an engineer could map out how electricity flows through a house or city, so psychologists hoped to map the flow of information through the mind using a similar technique, in what came to be known as the information processing model. These were sometimes called (seriously or derisively) as "box and arrow" models, because this is how the ideas were represented graphically, as in Figure 1 below. In addition, psychologists, particularly in England, began to study the process of attention and to try to solve mysteries of how we can divide our attention or how we can selectively attend to one signal in a noisy array and ignore the others. Attended information is generally remembered, whereas unattended information is not (e.g., Moray, 1959). George Miller and others brought information theory from engineering to psychology, and his 1956 paper indicated that the principles that governed memory seemed different from those that governed sensing and perceiving. Noam Chomsky (1957) wrote about syntactic structures that underlie language and were believed to be universal. Psychologists interested in language developed the field of psycholinguistics (e.g. Brown, 1958a). Further, digital computers were being developed, and psychologists were interested in whether human memory might be modeled on the basis of memory as it is instantiated in computers (e.g., Feigenbaum & Simon, 1962; Feigenbaum, 1970). All these trends and more merged, so that human experimental psychology (as it was known) gradually became cognitive psychology. A landmark publication that helped to cement the cognitive revolution occurred in 1967, with the publication of Ulric Neisser's book, *Cognitive Psychology*. It gave the field its name. The book was inspired by Bartlett's constructive ideas – and the idea that perceiving was constructive and remembering was reconstructive – and also emphasized hard-headed empirical research. We next consider a few of the trends just mentioned in more detail.

**Information Theory.** Memory might be roughly defined as the retention and use of previously learned information. But what is information? Claude Shannon, an engineer at Bell Labs, who is credited as the founder of information theory, developed an influential operational definition (Shannon, 1948). During World War II, Shannon was working on the communications problem of how to transmit an intelligible signal across a noisy channel. In the process, he developed a general theory of information, and a way to quantify it. For Shannon, the information in a signal is a function of the amount of uncertainty it reduces. Given a specific range of possibilities, a particular outcome could carry a lot of information if it were very surprising, or little information if it were highly expected (i.e. if it were redundant). Information could be calculated and measured in quantities that he named *bits*. In a coin flip, there are two possible states; knowing how the coin landed, heads up or tails up, conveys one bit of information, because it resolves that particular binary set of possibilities. Using these measurements, an engineer could measure the capacity of any particular information channel.

The first psychologists in the information-processing paradigm enthusiastically co-opted Shannon's concept of a limited-capacity channel and used it as a lens for studying human memory (Broadbent, 1958; Cherry, 1953. Psychophysicists had been doing this sort of work for some time. A sound, weight, light, etc. could be the source of a signal at one end of the channel, and the subject's perception represented the receiver at the other end. An experimenter might have a participant try to distinguish between two, three, five, or ten tones. If the participant could successfully and accurately distinguish four but not eight tones, the channel could be said to have a capacity limit, characterized by the number of bits corresponding to a four-tone maximum – that is two bits of information. If the person could distinguish eight tones, that would be three bits. This is the correct range for sensory channels when only one dimension of a stimulus, say, pitch of a tone, is varied. For most dimensions, people can distinguish from around 5-7 stimuli varying on a single dimension (or 7 + or – 2).

In his influential 1956 article, "The magical number seven, plus or minus two," George Miller at Harvard University's newly created Center for Cognitive Studies discussed the channel capacities of various sensory channels, showing a common limit. He wondered if immediate memory would show the same kind of limited channel capacity that could be defined precisely in information theoretic terms. He performed experiments with binary digits (series of zeroes and ones, decimial digits (0-9), letters of the alphabet (26), and even one-syllable English words, from a pool of 1000 words. If there is a "channel capacity" for human memory in terms of the amount of information (measured in bits) that is transmitted, then people should be able to remember many fewer words in order than decimal digits. In turn, they should remember fewer decimal digits than binary digits, again if the channel capacity is fixed. However, Miller reviewed experiments showing that this is not at all what occurs from immediate memory experiments with different sets of stimuli. What he found is that people generally remember 7 items from a set, and it does not too much matter whether they are binary digits or letters or words. "Channel capacity as measured in bits" did not seem to apply to human memory.

Miller (1956) argued that for memory, people remember chunks of information or items, although he admitted that it is hard to define a chunk. For example, people can remember about 7 letters presented one at a time, but if letters are chunked into single syllable words of 5 letters each, the people can easily remember 7 words and hence 35 letters. This grouping, or organizing, Miller stated, arises from the process of *recoding*, another concept from information theory. In recoding, a processor can increase the number of bits per chunk by designing a symbol that efficiently stands for the lower order information and operating on that symbol rather than the original information. In terms of the example just used, a person can remember the 7 words and not 35 letters, although of course the 35 letters are remembered and in the correct order. Miller (1956) further described how language is an effective recoding device to chunk events we wish to remember, and he speculated that forming mental images was another good recoding technique.

**Computing.** Another important technological development during World War II was the advent of computing. A whole new lexicon and conceptual ecology arose, which cognitive scientists could appropriate – encoding, search processes, storage, input, output, "self-addressable stores," etc. Such was the exuberance at these new models that Herbert Simon, recognized as one of the founders of the cognitive revolution, could declare in 1956 that by 1967, all psychological theories would be written as computer programs (Leahey, 2003, p. 430.). Most importantly for the new field of cognitive psychology and the study of human memory, the computer metaphor provided a principled conceptual division between the hardware (the brain) and the software (the mind). Although any particular program undoubtedly needs some sort of material substrate on which to run, the program itself may be represented in terms of symbols and logical operations. Newell and Simon (1976) proposed that the mind is a symbol system, and cognitive processes are the mind's various programs being run.

Later, David Marr (1982) would formalize this symbol-processing model of cognition in his influential three-level scheme. At the highest level of abstraction is the *cognitive or computational level*; this is the task a system is to perform, perhaps remembering the name of an actor in a film. The lower *algorithmic level* includes the specific processes required to accomplish this high level computational task. Such algorithms might involve matching the percept of the face to the image of the face in memory, and activating associated memory traces, one of which may be the actor's name, which may then be retrieved and uttered. Particular steps in a cognitive task, then, involved discrete operations, which a researcher could specify and test, and ultimately schematize in the form of a flow chart, another tool borrowed from computer science (Sternberg, 1966, 1969). Finally, at the lowest *implementation level* analysis, researchers could specify the particular pattern of neural activity needed to carry out this series of tasks. While recognizing that the neurological implementation was interesting and worthy of research (by other researchers), these early cognitive psychologists asserted that detailed knowledge of implementation was superfluous to an understanding of the computational and algorithmic levels of cognition (Murdock, 1974, p.14). McGeogh (1932) had advanced a similar position much earlier when he said that the serial-position curve would not vanish if someone deciphered the RNA codes of memory (Murdock, 1974, p.6). Just as a computer program could run on different types of computer, as long as the logical relations between symbols were maintained, a cognitive act like remembering represented its own level of analysis, regardless of how the brain actually implemented the process.

Memory researchers operating in the information-processing tradition faced a number of tasks. They needed to characterize the operations involved in encoding, storage, and retrieval. They attempted to determine whether they could categorize these operations into relatively discrete systems (or modules and stages). These ideas of symbol systems pushed cognition away from concrete operations and into the idea that all thought was symbolic. Images, for example, were thought to be something like a mirage, of no explanatory value (just as behaviorists had claimed). In turns out, however, that imagery and memory are intricately linked.

**Memory Models**

In the late 1950s and early 1960s, psychologists began to argue that "memory" was not of one kind, but came in at least two types: short-term and long-term (e.g., Peterson & Peterson, 1959). In the 1960s, various proposals were put forward, with different sorts of evidence, for two different stores in memory (Waugh & Norman, 1965; Glanzer & Cunitz, 1966). Atkinson and Shiffrin (1969, 1971) proposed the most complete system of this sort. Murdock (1974) dubbed all these various models the "modal model" of memory at the time, because they all shared common characteristics of proposing short and long term stores of memory. We will consider Atkinson and Shiffrin's theory in more detail to give a flavor of the idea, which still guides thinking today on many issues.

Atkinson and Shiffrin's (1969) model of memory synthesized much of the early memory research in the information processing tradition. Like many models in the information processing tradition, Atkinson and Shiffrin's modal model of memory was agnostic about neurological implementation. They suggested that the cognitive processes they described could very well have been accomplished by a variety of different configurations of neural systems. Shiffrin and Atkinson (1969) described the structure and operation of the system by considering three components of information flow: sensory registers, a short-term store, and a long-term store, as represented in Figure 1. Information would be recoded as it was transferred from one store to the next; this recoding was necessary because each of the three components of memory operated on its own "format."

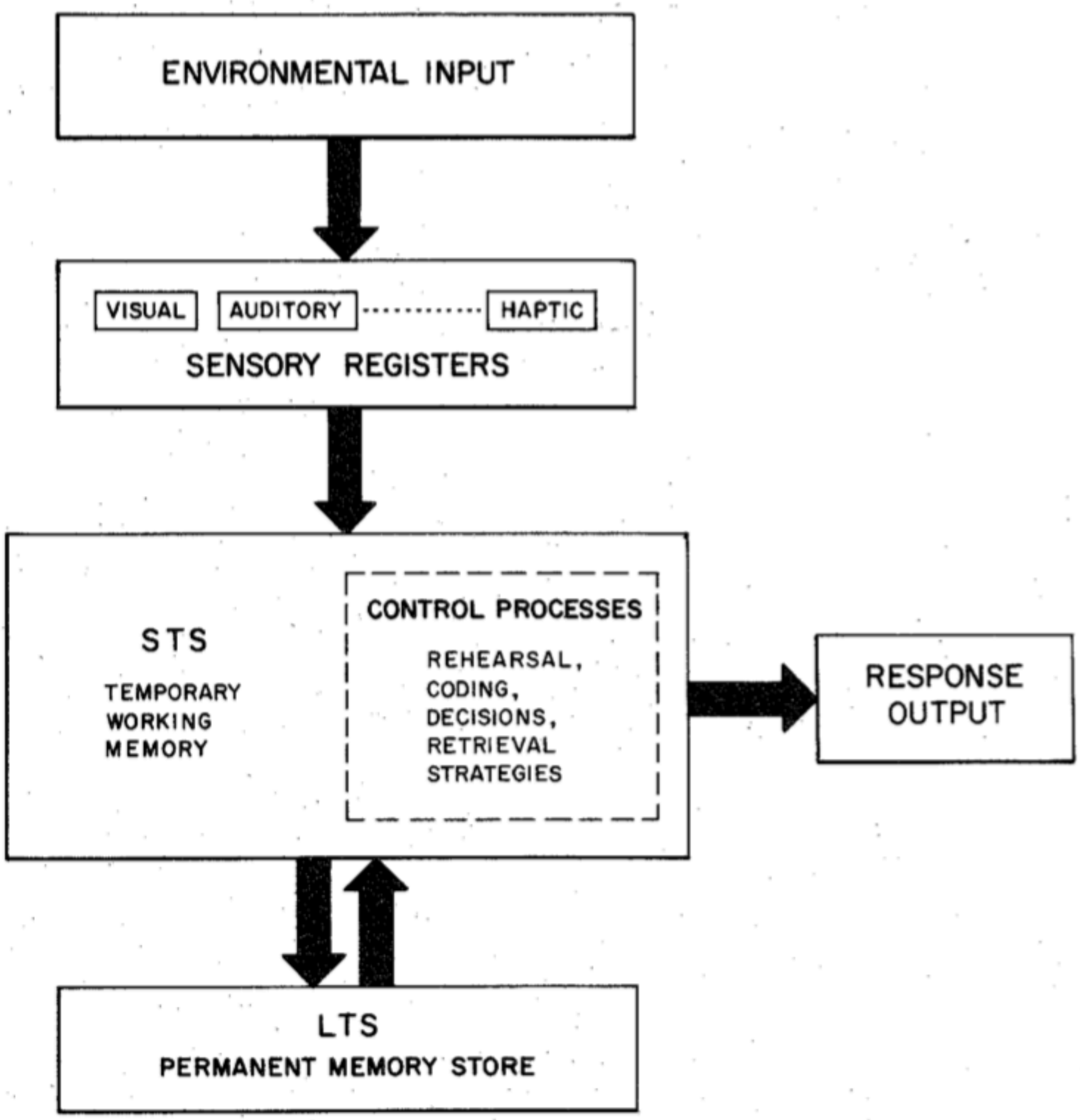


*Figure 1.* Shiffrin and Atkinson's memory systems, a paradigmatic "box and arrow" model.

***Sensory register***. When energy from the outside world affected an organism's senses, it would be coded and pass into a sensory register associated with the particular sensory modality. This first stage of memory was a more or less full, literal representation of, say, the retinal (or visual) image. Sperling (1960) performed now-classic experiments examining the qualities of this store. He flashed an array of three rows of three letters into a subject's eyes very rapidly and then varied the time between presentation of the array and a tone which told participants which line to report. He was interested in measuring the rate of decay of information in the visual store. Without going into details, he showed that his subjects had access to nearly the whole array when given an immediate test, but that within half a second, the detailed information was gone. The visual store or sensory register faded rapidly. The sensory register was pre-attentive, in the sense that unless attention was paid to part of it, the information would be lost. A similar store was postulated for audition (Crowder & Morton, 1969) and then later for other senses. Unless information from a sensory register were selected and recoded into the short-term store, it would be quickly lost.

***Short-term store.*** Attending selectively to information in the sensory register could transfer it into the short-term store, where it might enter conscious awareness. Much of the early experimental research on memory was on what Atkinson and Shiffrin would term the short-term store, due to its relative accessibility to laboratory experimentation (Murdock, 1974). Miller's (1956) work, discussed above, concerned capacity limits of the short-term store. We will not review the extensive body of research on the short-term store, also referred to as short term memory and later as part of working memory (for an overview, see Baddeley, 2003), but we will mention some of its traits as are relevant to its place in a modal model of memory.

According to the model, attention may selectively transfer some information from the sensory register into the short-term store. This transfer involved recoding. Whereas information in the sensory register is a more or less literal coding of the input from the sensory modality, the "raw" sight or sound, information in the short-term store initially was thought to be represented acoustically; it could be perceived phenomenologically as a sort of "inner voice" (Baddeley, 1966). An individual could maintain information in the short-term store by rehearsing it or mentally saying it over and over. The role of rehearsal in maintaining information in short-term store was demonstrated experimentally. When given a long string of items to remember, people's free recall tends to produce the U-shaped serial position curve, with items at the beginning and end of the series well retained, and items in the middle poorly retained. The recency effect, where items toward the end of the list are remembered better than items in the middle, was hypothesized to occur because those items were still retained in the short-term store via rehearsal. Postman and Phillips (1965) and Glanzer and Cunitz (1966) tested this hypothesis by giving participants a list of items to remember, and then either gave them an arithmetic task or no task. The arithmetic task served to occupy attention so that no items could be rehearsed in short-term store. When participants had no subsequent task, they showed the usual U-shaped serial position curve. Participants whose attention had been diverted for 20-30 seconds, on the other hand, showed a primacy effect, because those early items had presumably been transferred into long-term memory, but no recency effect.

Similarly, Peterson and Peterson (1959) developed a method for testing the duration of information in the short-term store, without rehearsal. They gave participants three letter strings called trigrams (e.g., BXG) to remember, and then gave participants a challenging task counting backwards by 3s from a specified number (e.g., 393) to prevent rehearsal. By varying how long they allowed participants to count backwards, they could vary the retention interval during which participants had to hold the trigrams in short-term store. Brown (1958b) had developed a similar procedure, so the task is known as the Brown-Peterson task. In doing so, they were able to measure the duration of information in short-term store if it is not rehearsed: their estimate was about 15 seconds, although later research complicated this simple story. This duration, though limited, was considerably longer than the fractions of a second Sperling had found for the sensory register's trace duration.

Retrieval from the short-term store also had special characteristics. That is, if, say, a string were maintained in short-term store, how would an individual retrieve it? For example, if you were given the numbers 7623759 and you were asked if a particular character (e.g., 3) was in the set, how might you search short-term memory? Consider two possible strategies: serial and parallel. A serial search involves examining each digit one at a time until the digit is "found;" once found, the person would push a key meaning *yes*, *it is in the list*. If the list is exhausted and the digit (say, 1) was not found, then the subject would push a different key indicating *no*. If retrieval is serial, the time to answer should increase linearly with the length of the string, because the participant has, on average, to process more characters to get to the right one. On the other hand, the search process in retrieval could occur in parallel, that is, all the letters would be searched at the same time. The simplest prediction from a parallel search is that as the string length increases from (say) 3 to 7, there would be no increase in retrieval time to find the 3 if it were there. Sternberg (1966) proposed this logic, and he obtained results showing that retrieval time does increase with string length, suggesting that search during retrieval is serial and not parallel. Further, he even proposed (based on data) that the search was exhaustive, which means that even if 3 were found early in the set, the person continued to search all the elements in the set. We cannot take the space to describe how Sternberg reached this counterintuitive conclusion (see Sternberg [1969] for a good treatment), but his experiments began a long series of debates on how short-term store was accessed. Sternberg (2016) provides an update to his research on high-speed scanning in short-term memory.

***Long-term store.*** Obviously, humans can retain some information for very long periods, even after it has left conscious awareness. Information transferred into the long-term store may be maintained until test. Atkinson and Shiffrin (1968), drawing from the computer hard-drive model, suggested that the long-term store operated off of a "self-addressable memory system." When a person attempts to transfer information from the short-term store into the long-term store, a potential problem arises: the more information a person acquires, the more difficult it becomes to find any particular item. Such a difficulty can be overcome by using an organizational schema in which different clusters of information that are likely to be retrieved together are stored together (Bower, 1967). When new information is learned, it is stored, according to its various components, with prior knowledge that is associated with those components. Any particular piece of memorized information, then, occupies a certain "location" in the long-term store, which is determined by the individual's organizational schema. Whereas the sensory register and short-term store had relatively limited capacity, the capacity of the long-term store was postulated to be unlimited; there are no known capacity limits for long-term memory. An item is effectively memorized, that is, memorized in a way that is useful for future purposes, may be found effectively in the future if the right cue is given. If an item (or fact or event) is placed in the organizational schema is such a way that future searches are unlikely to discover it, it may be forgotten (even if it is "there"), much like a library book that has been placed on the wrong shelf will be hard to find. Such an emphasis on location and searchability, Atkinson and Shiffrin note, helps explain the availability/accessibility distinction (Tulving & Pearlstone, 1966), which points to the strange fact that information encoded in the long-term store may be there more or less permanently, but memory failures nonetheless still occur.

**The Atkinson-Shiffrin model, evaluated.** This new model of memory represented a paradigmatic achievement of the information-processing tradition. In specifying the qualitatively different but interacting structures in which humans encoded, stored, and retrieved information, these researchers patterned human memory after a von Neumann architecture for digital computers (von Neumann, 1958). In doing so, they prioritized several key perspectives. First, they described memory in terms of its structures and operations. Second, because of the guiding computer metaphor, they tended to focus on reproductive memory, rather than reconstructive memory (Murdock, 1974, p.5). When a computer stores information, it does so literally; the information is coded into the hard-drive, and when it is retrieved, it is simply reinstantiated. As such, these information-processing theorists operated much more in the Ebbinghaus intellectual lineage than the Bartlett lineage, although to be sure, Ebbinghaus would have found the multiple stores language unusual. In addition, the Bartlett lineage, which emphasized cultural influences and reconstructive memory, continued concurrently with the information-processing paradigm. In the chapter on memory in Neisser's (1967) seminal textbook on cognitive psychology, he emphasized that remembering is an activity, and that it occurs via schema-driven reconstructions, which are shaped by culture; Neisser was rather critical of the "reappearance hypothesis" on which the computer model of encoding, storage, and retrieval depended – that is, the memories are retrieved in some pristine form in the exact way they have been stored. Additionally, the storage model is entirely self-contained within the head of the (ideal) individual, except for the input and output of information from and to the environment. This methodological solipsism (Fodor, 1991) will be addressed below in the section on social remembering. For a retrospective look at the modal model, see Healy and McNamara (1996). As we write, a special section of

*Memory & Cognition* is being developed to provide reflections on the Atkinson-Shiffrin model after 50 years.

**Processing approaches to memory.** Proponents of the box-and-arrow models of memory grounded their arguments in terms of storage characteristics, with differences in trace duration, capacity, format, storage and retrieval providing evidence for qualitatively different stores. However, using something like trace duration to define different systems ran the risk, so Craik and Lockhart (1972) suggested, of circular argument. While recognizing that the dismissively termed “boxes and arrows” approach to memory systems indeed seemed to make theorizing and experimentation more scientifically tractable, they expressed concerns that the number of stores seemed to be multiplying (also see Morton, 1970; Sperling, 1970; Roediger, 1993). A more parsimonious tact, they suggested, would be to focus on encoding operations, rather than positing various types of store for each new dissociation someone discovered. They began the processing approach to memory, with their specific variant called the levels of processing approach (Craik & Lockhart, 1972). Briefly, the operations performed on information coming in from the outside world determines its mnemonic fate.

The levels of processing approach in memory derived in part from Anne Treisman’s (1964) stages of perception. At preliminary stages of perceptual processing, the perceptual system processes physical features such as lines, shapes, hue, brightness, loudness, pitch, etc. Successive stages use information from earlier stages to construct more abstracted representations such as shapes, and finally objects are matched with stored conceptual knowledge to create recognizable percepts. The stages of processing thus proceed in a continuum from low-level perceptual characteristics to high level, meaningful representations. Any particular stimulus from the outside world may be processed to different levels, depending on whether it is held in focal attention or not. Memory for an item, according to the unitary model, is a side effect of the depth of perceptual processing. A trace is remembered better if processed conceptually, because by the time a particular item reaches that stage, it has undergone more processing, and may additionally have been integrated with pre-existing knowledge (Craik & Tulving, 1975). On the other hand, a trace that is processed only, say, phonetically or orthographically, and not in terms of meaning, has not undergone such deep processing, and is thus transitory. Such a framework could explain the different outcomes nominally explained by the multiple stores model. It was not that information in the short-term store was formatted acoustically; it was that acoustic information had attained a lower level of processing and so was more rapidly forgotten. It was not that information in the long-term store was semantically encoded, but that if information were encoded semantically, it had attained a deeper level of processing and so was more permanent. One could, Craik and Lockhart suggested, draw boxes around particular points within this continuum, but the boxes or "stores" concept did not add much to the analysis. A levels of processing approach changed the emphasis of memory research from memory *structures* to memory *processes*.

Experimental examinations of the levels of processing account typically used some version of an orienting paradigm developed that had been used over the years for various purposes but was refined by Craik and Tulving (1975). Their version is now known as "the levels of processing paradigm." In this paradigm, subjects usually are not told they were in a memory experiment; rather, they were simply given a task to do and a list of words to perform it on. Such a task is called incidental learning (Postman, 1964), as opposed to intentional learning, where subjects are instructed to remember. Craik and Tulving (1975) asked subjects to answer one of three types of question about words, such as EAGLE. Is it in upper case letters? Does it rhyme with legal? Is it a type of bird? Half the time the answer was *yes*, as in the example, but half the time the answer was *no*. The idea was that the questions should direct subjects to process the words to either a shallow, graphemic level of processing (focusing on the case of the letters), to a somewhat deeper phonemic level (focusing on sound in the rhyme question), to a meaningful or semantic level. Thus, the subjects study exactly the same materials for exactly the same amount of time; all that differs is the type (or level) or processing. Craik and Tulving reported ten experiments showing (and replicating) that this manipulation has a dramatic effect on recognizing the words later, with semantic processing better than phonemic, and phonemic better than graphemic. The outcome emphasized that what one remembers is less about the qualities of the material per se, and more about how one encodes it. Semantic encoding was better than the shallower forms of encoding.

Although the levels of processing account proved to be a highly popular alternative to the two-store model, it was also criticized and amended. In an important extension, Morris, Bransford, and Franks (1977) showed that if semantic encoding usually leads to superior memory, it is only because typical memory tests tend to require semantic or conceptual information. If the test offers phonetic cues, ones that emphasized the sound quality of words to be remembered, then words that received "lower" level phonetic encoding are recalled better than those semantically encoded. Morris, et al. criticized the notion of a single dimension from shallow to deep processing, and they proposed instead a transfer-appropriate processing approach that is similar to an idea called the encoding specificity principle (Tulving & Thomson, 1973) to be discussed in the next section of the chapter. Another problem is that critics argued that the levels of processing theory is circular, because there is no real measure of "depth of processing" except how good recall is (Nelson, 1977). Given the findings of transfer-appropriate processing, a serial chain of processing from shallow to deep seemed simplistic. Another problem for the standard levels-of-processing theory is that it occurs both under incidental and intentional learning instructions. If subjects are told they will need to recall words later, they process them meaningfully and recall is often as good as when they are given deep, semantic orienting tasks. So, why should the levels of processing effect occur under intentional learning instructions? Selective summaries of the levels of processing literature appear in papers by Lockhart and Craik (1990) and Craik (2002).

The undeniable value of the processing approach was to encourage memory researchers to think about the operations of remembering. Kolers (1973; Kolers & Roediger, 1984) discussed remembering in terms of operations. For example, Kolers (1973) measured memory indirectly by using speed of reading a sentence or a passage. If a person read the sentence (out loud) faster after having read it once, that reflected prior memory for the sentence (a form of the savings paradigm used by Ebbinghaus). Kolers and Perkins (1975) showed that operations used in various rotations of text were retained as part and parcel of memory. For example, imagine one group of subjects reading a sentence that is printed left to right, but with every letter upside down. Another group reads the same sentence right side up (but other sentences upside down). Later, both groups read the same target sentence upside down. The subjects who had previously read the sentence using those same cognitive operations read it faster than those who had read it in normal text. Kolers (1976) showed that the operations used in reading specific pages were still reinstated in reading the passages a year later; reading pages from a year previously was faster than reading comparable new pages. Kolers called his position a procedural approach to remembering, and it is similar in some ways to transfer appropriate processing (see Kolers & Roediger, 1984). Craik and Lockhart (1972) argued that encoding operations determined later remembering, but later writers emphasized that processes during retrieval were equally important, if not more so (e.g., Tulving, 1979).

## From the 1970s to the Present

We have painted the story of the psychological study of human memory with a broad brush from 1885 to the 1970s. The remainder of the chapter is about the last 50 years. Recent history is the hardest to write, because our own enthusiasms for various issues and types of research may intrude. That is doubtless true here. The field has broadened over the years, and no single stream of thought (such as the information processing tradition) can orient our story. Thus, we have selected several strains of research to cover. By reporting on each discretely, we do not mean that researchers working in one tradition do not know about and are not influenced by work in the other traditions. Often the same researchers work across these traditions, using the various methods employed. In fact, borrowing methods from one field to investigate a topic in a related field is a common tactic in science.

We have one proviso: We are omitting perhaps the main trend in the study of human memory since 1970, the cognitive neuroscience of memory. We continue to cover behavioral approaches to the study of memory. An entirely new chapter, at least, would be needed to cover the approaches of cognitive neuropsychology (studies of brain-damaged patients) and studies using various brain-imaging techniques collectively referred to as cognitive neuroscience of memory. Despite this omission, the traditions we cover are all important ones, central to the study of human memory. We refer to them as: Working memory; Episodic memory; Autobiographical memory; Implicit memory; and Social memory (or remembering). We then end the chapter by considering the varieties of memory and applied aspects of remembering.

### Working memory

The term working memory was coined by Baddeley and Hitch (1974). The idea behind working memory is that the mind has a temporary store that holds both verbal and visual information in consciousness while the information is used for higher forms of processing. This differs from the idea of short-term memory or the short-term. If someone reads you a 7-digit phone number, you can repeat it back from your short-term store without much trouble. However, if you multiply 46 x 52 without paper, you rely on working memory to perform operations, store intermediate products, and eventually come to the answer. Thus, working memory involves short-term retention, but it implies more: the ability to work with the information in the short-term store (Cowan, 2008). One requirement for successful working memory is attentional control, the ability to focus and maintain attention on the task. The depiction of working memory in this paragraph deviates somewhat from the original Baddeley and Hitch (1974) view to reflect more recent developments.

Baddeley and Hitch (1974) focused on how working memory is used in understanding speech, via the phonological loop, as they called it. That is, to understand speech, we need to preserve the phonemes in language from early in a sentence to be able to comprehend those coming later. They also argued for a similar ability in understanding visual representations (like forming images or following directions), which they called the visuospatial sketchpad.

The concept of working memory became an important research area over the years, with numerous models of the basic processes (e.g., Miyake & Shah, 1999). As with other topics, we can only give the flavor of some of the vast research on working memory in this section. One important development in the study of working memory was the discovery of stable individual differences. Daneman and Carpenter (1980) developed the first task to measure individual differences in working memory, the first complex span task. Complex span tasks are distinguished from simple span tasks, in that they have both a short-term and long-term component, although even the simple span task may involve a long-term component (Watkins, 1977). We will illustrate complex span tasks with the operation span task (Unsworth. Recall that digit span for adults is usually 7; that is, people can remember 7 digits in a row. That is called simple span. The complex span task known as operation span involves remembering digits in a row while at the same time being faced with a competing task. For example, the subject might receive alternating trials of digits and equations; they need to remember the digits in order while at the same time deciding whether or not the equations are correct. Imagine seeing 64, then on the next screen 9 + 3 = 27, then on the next screen 21, then 7 + 6 = 13, and so on. When the experimenter stops the trial, the subject's task is to recall 64, 21 and so on (i.e., to recall the two-digit numbers). The number of digits that can be recalled is the measure of operation span.

The hallmark of a complex span task is to remember some target information in the face of another, distracting task. Such tasks take concentration (or attentional control), and the measure of working memory capacity on the operation span is relatively stable across people (that is, there is good test-retest reliability). Also, Engle and his collaborators have developed various span tasks, and people's correlation across tasks is high (e.g. Unsworth & Engle, 2007). This outcome shows that working memory capacity reflects a fundamental individual difference among people that can be reflected in several tasks. Indeed, studies have shown that it is correlated with many other cognitive tasks, such as reading comprehension, performance on SAT tests, among others. Working memory capacity is related to fluid intelligence (although not exactly the same). In addition, it increases across childhood (Kail, 2007) and declines sharply in older adults, even ones without signs of dementia (McCabe, Roediger, McDaniel, Balota & Hambrick, 2010).

We have barely scratched the surface here. Both cognitive psychologists and cognitive neuroscientists study working memory and its neural underpinnings. Some reviews of the cognitive approach can be found in Baddeley (1986, 2003; see also Conway, Kane & Engle, 2003).

**Episodic memory**

Endel Tulving coined the term episodic memory in 1972 to refer to our remembering of events at a particular time and place. If I ask you to recall events that occurred to you during the past week, that would be an example of recollection from episodic memory. Tulving argued that the study of human memory in laboratory settings using word lists can be used as a proxy for remembering outside the lab: "Words to the memory researcher are what fruit flies are to the geneticist: a convenient medium through which the phenomena and processes of interest can be explored and elucidated….Words are of no more intrinsic interest to the student of memory than *Drosophila* are to a scientist probing the mechanisms of heredity" (Tulving, 1983, p. 146). The assumption is that the principles that emerge from laboratory studies will have direct relevance to memory outside the lab.

Defined this way, the study of episodic memory continues to employ many of the research techniques from the verbal learning tradition, although many were re-purposed to ask new questions. Dominant tasks in this tradition are free recall, paired-associate recall and variants on these tasks, as well as various types of recognition memory tasks. The number of research questions addressed using these methods are many, and no summary here would do justice to the plethora of research. We content ourselves with one example.

Tulving and Pearlstone (1966) began the formal study of the power of retrieval cues in human memory, and they revived a distinction between learning and performance. Psychologists would like to know the answer to the question of "what has been learned?" but they often must content themselves with seeing performance and trying to infer learning. The same is true about the distinction of what information is stored in the cognitive system and what can be retrieved. We would like to know the former, but we can only measure and assess the latter.

Tulving and Pearlstone had subjects learn lists of words belonging to various categories, as discussed previously in work by Bousfield (1953). They then gave one group of subjects a free recall test, giving them a blank sheet of paper and the task of recalling as many words as possible. One of their lists was 48 words long and had 2 words in each of 24 categories. The subjects recalled 10.5 words, on average, in the free recall condition. Is this all they had learned and stored? Did the other words leave no trace in the memory system? To help answer these questions, they also employed a cued recall condition in which subjects were prompted to recall by being given the 24 category names. Now subjects recalled 20.5 of the 48 words, nearly twice as many. Thus, the traces of at least this many words were represented in memory, and of course this could still be an underestimate of what was learned. More powerful retrieval cues (e.g., the category name and the first two letters of words) might produce even greater recall. The authors showed that the outcome of enhanced recall from providing cues could not be due to mere guessing from the category name.

Tulving and Pearlstone (1966) distinguished between the information *available* in memory (what has been learned and stored) and information that is *accessible* under a particular set of retrieval conditions. Psychologists (and for that matter, neuroscientists) would like to know what information experience has left available in the system, but they never can. All their methods permit them to know is what information is accessible under a particular set of circumstances. Everyone reading this chapter has had the experience of forgetting a name or a fact on a test, only to remember it again later (a situation demonstrated experimentally by Brown, 1923). One possibility is that a recognition test could measure information available in the memory store. After all, if a subject studied the word *caterpillar* in a list of words, what better cue could there be on the test than *caterpillar*? That sounds plausible, but under some circumstances, a recall test (with a different word used as a cue) can retrieve the experience of studying a word better than the actual word itself (Tulving & Thomson, 1973).

In the late 1960s and early 1970s, Tulving (and others) conducted a thorough series of experiments to elucidate the issue of how and when retrieval cues operate effectively. Based on a wealth of experimental evidence (see Tulving, 1983, Chapters 9-14), he put forth the encoding specificity principle as guiding the effectiveness of retrieval cues: A retrieval cue is effective to the extent that information in the cue matches (or overlaps or reinstates) the conditions of original encoding. That is, to use a simple example, if a subject encodes *bank* in the category of financial institutions in a long list of words, the cue *financial institutions* is likely to cue retrieval of *bank*. Yet, having studied the same list, receiving the cue "the side of a river" will not cue the word *bank*, even though a river bank is the side of a river. The information in the retrieval cue "a side of a river" does not match the context or meaning in which *bank* was studied. In short, any word or any experience can be coded in multiple ways depending on the context of the event and the rememberer's knowledge. To be effective, a retrieval cue must overlap with the way the event was encoded. If this principle seems like a familiar idea, that is because it is similar to the transfer-appropriate processing approach discussed previously (Morris et al., 1977). The encoding specificity principle preceded it in time, but the core ideas are similar.

The episodic memory tradition has created dozens of paradigms and issues in the study of human memory and answered numerous questions. It continues to be fruitful today. The hallmarks are a) tight experimental control; b) usually simple materials such as lists of words or pictures, or word pairs, although sentences and paragraphs are sometimes used; c) relatively short retention intervals between study and test (often within a one-hour experimental session), and d) paradigms such as free recall, cued recall, recognition, and paired-associate learning. For a review of the wealth of knowledge that has been achieved, recent textbooks are a good source (e.g., Baddeley, Eysenck & Anderson, 2014; Radvansky, 2010).

Tulving (1972, 1983) assumed the episodic memory in the lab uncovers similar principles to memory outside the lab, often called autobiographical memory. However, this assumption can be questioned. For example, McDermott, Szpunar and Christ (2009) conducted a meta-analysis on brain-imaging studies of episodic memory with word lists and other tasks reflecting memory outside the lab. They showed that the neural areas that were activated in the two types of tasks are practically nonoverlapping. Now we consider these other sorts of tasks, ones thought to reflect autobiographical memory outside the lab.

**Autobiographical Memory**

In 1986 David Rubin of Duke University edited the first cognitive psychological book on autobiographical memory, titled, appropriately, *Autobiographical Memory*. This volume inaugurated a sustained inquiry into people's memory for their lives. These memories were of a different sort than those normally studied by experimental psychologists. Research in the Ebbinghaus tradition required that memory performance be related back to a known stimulus (usually a word); with autobiographical memories, there was usually no way for the researcher to go back and examine the event being remembered, that is, to check the "verifiability" of a memory (Rubin, 1986, p. 4). From the start, then, autobiographical memory research tended to focus on the internal structure of memories from across the lifespan, rather than their accuracy (although see Linton, 1975, 1978). Work on autobiographical memory also departed from typical laboratory concerns by including phenomenological reports as data, incorporating developmental and lifespan perspectives, and interacting with fields outside of psychology such as literature and history (Rubin, 1986).

**Reminiscence bump.** One early finding was that autobiographical memories did not follow the standard forgetting curve (Rubin, 1982; Rubin & Schulkind, 1997; Rubin, Wetzler, & Nebes, 1986). This discovery was made using the Crovitz technique, named after one of its inventors; in this task, participants are given a series of words, and for each word described the first memory that comes to mind (Crovitz & Schiffman, 1974; Galton, 1879, used an earlier version of the technique, but his was more for free associations rather than to elicit personal memories). After remembering an event from their lives, participants rated the memory on several characteristics, such as how old they had been at the time of the event, as well as various phenomenological qualities such as the sense of reliving, vividness, emotional valence, etc. Participants repeated this task for many different words. Researchers can then plot the frequency of memories produced from each (self-reported) age of the person. Rather than a smooth forgetting curve, with memories decreasing in accessibility logarithmically as one proceeded further into the past, Rubin and colleagues discovered a "bump." When testing people in their 50 and 60s, memories from people's teens and twenties were disproportionately accessible relative to memories from other ages. Similarly, if asked to list their most important or most vivid memories, people tended to select memories from this bump period (Fitzgerald, 1988). Subsequent research on the reminiscence bump offered several mutually compatible explanations for why it might occur: maturational-biological accounts (Cerella, 1985; Janssen, Kristo, Rouw, & Murre, 2015), identity accounts (Robinson 1992; Fitzgerald, 1996; Conway & Holmes, 2004), and cognitive accounts (Shrauf & Rubin, 1998; Rubin, Rahhal, & Poon, 1998). There is some evidence that the age ranges for which the reminiscence bump appears may vary depending on the type of cue used (Koppel & Rubin, 2016; Koppel & Berntsen, 2016).

**Sociocultural construction.** Telling autobiographical stories is in many aspects a cultural skill. Research on the development of autobiographical memory – how children learn to remember their own lives – draws heavily on a Vygotskian sociocultural framework. Lev Vygotsky was a contemporary of Bartlett's working in the Soviet Union. His sociocultural psychology emphasized that complex, higher order cognitive skills begin as social interactions between, typically, a child and an adult (Wertsch, 1985). The more expert adult structures problems in such a way that the child may contribute to a joint task which the child would be unable to accomplish alone. For example, children are initially unable to organize their memories into stories with a well-structured narrative. A parent might ask the child for such structurally important information as the setting of a memory, the characters, their motivations, etc. By strategically eliciting these elements of an effective narrative, the adult provides *cognitive scaffolding* (Wood, Bruner, & Ross, 1976). That is, the parent assists the child in learning how to use a valued cultural tool – narrative – to mediate his or her remembering (Nelson, 1996). Eventually, the child is able to use this cultural tool independently; the tool has been *internalized*. Detailed developmental studies have shown that mothers' scaffolding style strongly impacts children's later autobiographical remembering (Fivush, Haden, & Reese, 1996; Nelson & Fivush, 2000). Additionally, as would be expected within a sociocultural framework, there are significant cultural variations in maternal scaffolding styles and autobiographical memory (Choi, 1992; Mullen & Yi, 1995; Wang, Leichtman, & Davies, 2000).

**Memory and the self**. In addition to basic narratives, adult autobiographical memory develops much more complex organizational structures. Conway and Pleydell-Pearce's (2000) Self-Memory System (SMS) provided an influential model for how three constructs - the goals of the "working" self, abstract self-knowledge, also referred to as the conceptual self, and autobiographical memory - could mutually shape one another. In the SMS, the goals of the working self act to select different elements within the autobiographical memory base. Personal memories that are relevant to current goals will become more accessible, and those irrelevant to these goals will be forgotten.

**Life Scripts.** The conceptual self incorporates abstract autobiographical knowledge structures, an important class of which are life stories or scripts (Berntsen & Rubin, 2004; Rubin & Berntsen, 2003). The principle underlying life scripts was drawn from Schank and Abelson's (1977) more general script concept, which concerns cultural knowledge for normative sequences of events. Life scripts are cultural schemata for how a typical life should unfold in a particular culture and for people of a particular social class. A script is a temporally ordered sequence of events, composed of slots into which specific events may be inserted. Life scripts offer another explanation as to why the reminiscence bump occurs; a majority of life script events occur during the bump period. The concept of script is of course similar to Bartlett's (1932) concept of schema.

**Flashbulb memories.** At times, autobiographical memories can intersect with public events of great consequence. A curious phenomenon initially examined by Brown and Kulik (1977) is the *flashbulb memory*, which they defined as memory for the circumstances in which one learned of a major public event. According to Brown and Kulik, most people who experienced a major public event, such as the assassination of JFK, seemed to remember extremely vivid details of the circumstances in which they received the news; these qualities of the flashbulb memory suggested a special mechanism. It was as if a camera's flashbulb had frozen the scene in memory, and given a "Now Print!" command (Livingston, 1967). Interestingly, flashbulb memories also tended to be community specific; African Americans had flashbulb memories for the circumstances in which they learned of the deaths of Martin Luther King, Jr. and Malcolm X, but European Americans did not.

Subsequent research on flashbulb memories has eroded the hypothesis that flashbulb memories are a qualitatively, perhaps even physiologically, special sort of memory. For instance, although people continue to demonstrate high confidence in their flashbulb memories, the memories themselves are not any more consistent over time than ordinary memories (Talarico & Rubin, 2003). Indeed, Hirst et al.'s (2015) ten-year study of flashbulb memories for the events of September 11, 2001 showed that consistency dropped precipitously over the first year for both flashbulb memories and memory for the facts of the story, and leveled off after that. Despite this, people remained highly confident in their "flashbulb memories" across the ten years of the study. Rather than resulting from a special mechanism, as Brown and Kulik posited, flashbulb memories seem to be important in that they concern events for which there is a public "moral duty" to remember (Echterhoff & Hirst, 2006).

**Implicit memory**

This entire chapter has been about the conscious experience of remembering. Some event happens in our past, and we bring it back to mind later (or we fail to do so, but we usually know when we fail). However, much of our learning is expressed in our behavior without our remembering the time and place that we learned the knowledge, as required for episodic recollection. Virtually all Americans know that George Washington was the first president of the

U.S. (Roediger & DeSoto, 2014), but they can probably not recall the episode of first learning this fact. Tulving (1972) referred to this type of knowledge as semantic memory, our general store of knowledge. However, another type of memory is revealed when we perform operations that we originally had to learn laboriously but that we now run off effortlessly, again without recalling time and places (episodic memory) or facts (semantic memory). You can tie your shoes, which was hard to learn at first, without much trouble, and you can multiply two three-digit numbers with only a bit more effort. These sorts of skilled performances reflect procedural memory, because they reflect our ability to execute many procedures we have learned (writing, riding a bicycle, tying shoes and so on).

Implicit memory reflects the power of prior experience to affect our current behavior without our awareness. This idea is a very old one in psychology (see Schacter, 1987), but it was only in the 1980s that psychologists (and neuroscientists) began to study such implicit expressions of knowledge. The initial observations were made on brain-damaged patients whose injuries had made them deeply amnesic; they seemed unable to learn and retain new information. For example, when given a list of words and then distracted for a few moments before asked to recall it, they might not be able to free recall any words or even recall that they had seen a list. They perform far below control subjects in free recall, and if the patients produce any words, they say they are just guessing.

Warrington and Weiskrantz (1968, 1970) performed some experiments similar to the one just outlined, but after studying the list, they gave both the patients and the control subjects word stems as cues. For example, if *chair* were on the list, they would get *cha*___ and be asked to fill it in with a word from the list. (Many other words begin with those three letters, so guessing is not a problem). Surprisingly, the amnesic patients performed just as well as control subjects, even though they said they were just guessing! This means that the words must have been stored in some way in the amnesics' brains, but the problem was one of accessing them consciously. The patients could produce the words, but not remember them. This phenomenon is today called priming or repetition priming – the words in the list "primed" their production on the later word-stem test, even though patients did not realize they had seen the words.

Some other researchers had trouble replicating the Warrington and Weiskrantz (1968, 1970) results, but the reasons became clear later: The key element is the type of instructions provided to subjects at the test (Graf, Squire & Mandler, 1984). If patient and control subjects are told to use the word stems like *cha*__ to remember words from the list, then the controls do much better than the amnesic patients. On the other hand, if the subjects are given fragments and just told to produce the first word that comes to mind, then the two groups perform equally. In addition, both groups do much better on words they recently saw than on fragments for control words not seen (e.g., saying "chair" to *cha*__ when chair had not been in the list).

The first type of test just described, where subjects are told to consciously remember the words, is now called an explicit memory test. Virtually this entire chapter to this point has been concerned with explicit memory, when people are asked to retrieve some experience. The other type of test, where the traces of past experience are demonstrated in behavior without instructions to consciously remember, is referred to as implicit memory. Graf and Schacter (1985) coined these terms as descriptive ones, not theoretical ones. That is, the distinction referred to different experimental operations and tests, not to different types of memory. However, explicit memory tests became theoretically associated with episodic memory, whereas implicit memory was reflecting more by priming of general knowledge or skills (sometimes referred to as implicit learning, as initiated by Reber, 1967). That is, priming seemed to reflect semantic or procedural memory processes. At first, the distinction between explicit and implicit memory seemed to apply only to differences (or dissociations) in performance by amnesic patients and by control subjects. However, this state of affairs soon changed.

In the early 1980s, several powerful demonstrations of differences between explicit and implicit memory were demonstrated in people whose brains were perfectly intact and functioning well, college students. For example, Jacoby and Dallas (1981) employed a levels-of-processing manipulation as we have discussed previously, where subjects answered questions about words requiring them to consult the case the word was written in (upper or lower), whether it rhymed with a word, or whether it belonged to a semantic category. After studying the list with these orienting tasks, one group of subjects was given a long test list of words and was told to judge whether each word had been studied or not; as usual, the levels-of-processing manipulation had a huge effect, such that encoding words in terms of meaning produced much better recognition than did encoding words in terms of their sound or their physical appearance. However, Jacoby and Dallas tested another set of subjects under different instructions. This test involved presenting exactly the same test words as for the other group, but now the words were presented for a fraction of a second and the subjects' task was simply to name the word from the brief flash. This is an implicit test, because there was no instruction to remember. Two outcomes were of interest. First, words that had been presented in the study list could be named better than words that had not been presented; this outcome reflects priming. The other finding was the big surprise: The levels-of-processing effect did not occur at all! Priming was equivalent whether words had been processed superficially (case or rhyme judgments) or more deeply (semantic judgments). Just as great differences could be found between amnesic and control subjects by using explicit and implicit tests, the same outcome could be obtained in all people.

In brief, a variable could be manipulated to greatly affect an explicit test and leave an implicit test unaffected (but still reflecting learning because priming occurred). Yet other experiments showed that a variable that often did not have much effect on explicit memory measures (such as modality of present of words, visual or auditory) could have a huge effect on priming on perceptual implicit tests like word stem completion or identifying words briefly presented (e.g., Jacoby & Dallas, 1981; Roediger & Blaxton, 1987). In fact, Jacoby (1983) even showed opposite patterns of result on the two types of test. In explicit memory tests, when a word is generated from a clue (*opposite of cold - ????*) it is generally remembered better than if subjects read the pair (*opposite of cold – hot*; Slamecka & Graf, 1978). Jacoby (1983) replicated this result, but he showed that the opposite pattern occurred on the perceptual task of identifying words from fast presentations. On, this task, having read the word produced more priming than having generated it, a finding replicated and extended by Blaxton (1989). Other variables, such as studying a mixed list of pictures and words, can produce the same effect. Pictures are better remembered than words on explicit tests including recognition memory of words (corresponding to pictures and words from the list). However, words produce more priming than pictures on verbal implicit tests (Weldon & Roediger, 1987; Rajaram & Roediger, 1993).

From 1980 to around 2000, the study of implicit memory boomed in cognitive psychology. The excitement was that the principles or (some would say) “laws” of memory seemed different for explicit and implicit tests. The main theories of the differences were in terms of different memory systems in the brain (e.g., Tulving, 1985; Squire, 1987) or in terms of different processes invoked and required by the different types of tasks (e.g., Roediger, Weldon & Challis, 1989). This debate was carried forward for some years, and still lingers in current theorizing (which generally provides an amalgamation of the two points of view). After 2000, speaking roughly, the study of priming on implicit memory tests was mostly carried forward by neuroscientists who sought the neural underpinnings of performance on different memory tasks. A review of implicit memory in normal human subjects during the heyday of priming research was provided by Roediger and McDermott (1993). A somewhat more recent review of the cognitive neuroscience of priming can be found in Schacter, Dobbins & Schnyer (2004).

**Social remembering**

Recently, a growing number of researchers have revived an old interest in social memory. Even though most research reviewed in this chapter has been about individuals remembering events alone, remembering as a social activity often occurs outside the lab and has interested researchers at least since Bartlett's (1932) discussions of it. Indeed, although contemporary discussions of Bartlett tend to reduce his contributions to the concepts of schemata and reconstructive memory, the entire second section of his book *Remembering* concerns how social group membership affects how people remember. Vygostky's sociocultural psychology, discussed above, further analyzed remembering as a socially mediated activity. Finally, many researchers have begun to draw on the work of the French sociologist, Maurice Halbwachs, a contemporary of Bartlett's. Halbwach's discussions of collective memory and types of social frames that people use when remembering (e.g., the characteristics of a good story or narrative) structures remembering in important ways, by suggesting frames of relevance and interest. The presence of other people motivates coherence in an activity that might otherwise ramble without purpose.[3] Furthermore, the people with whom one remembers are usually not random strangers; they are fellow members of the various social groups to which we belong, with whom we regularly interact. They present a dependable external scaffold to memory (Sterelny, 2010); their

[3] Halbwachs suggested that memory material in dreams might take on just such an unstructured quality because in dreaming, the dreamer is the only one in there, with no observer for whom the dreamer will shape the narrative.

perspectives and priorities strongly shape what is habitually remembered and forgotten. This dependable, long-term, external social structuring of memory is what Halbwachs called the *social frames of memory* (Halbwachs, 1925/1992). Because most remembering occurs supported by particular social frames, Halbwachs argued, memory is essentially a social, not an individual, phenomenon, even though it is undeniably individuals who do the remembering.

Experimental psychologists studying social remembering have adopted a variety of perspectives, and no methodological paradigm has yet come to dominate the field (Hirst, Yamashiro, & Coman, 2018). Some researchers have examined how remembering in collaboration with others differs from remembering alone (Rajaram & Pereira-Pasarin, 2010); some have examined how people may reshape one another's memories in conversation (Hirst & Echterhoff, 2012), and how such dyadic influences on memory can propagate through social networks to drive group-wide convergence onto shared memories (Lyons & Kashima, 2001; Roediger, Meade, Gallo, & Olson, 2014; Coman, Momennejad, Drach, & Geana, 2016); others have examined how remembering as a member of a social group impacts how the group's past is recalled (Putnam, Ross, Soter, & Roediger, 2018). We address briefly some of the major lines of research in this rapidly evolving field.

**Collaborative remembering**. One of the fundamental questions spurring a social approach to remembering is, how does remembering with other people differ from remembering alone? One experimental paradigm developed in the late 1990's, collaborative remembering, allows for a careful comparison of group with individual performance on memory tasks, and between individuals who are remembering as parts of groups and individuals who remember solo (Weldon & Bellinger, 1997; Rajaram & Pereira-Pasarin, 2010). Collaborative remembering experiments compare two types of groups: *collaborative groups*, in which three to four individuals help one another remember items they had all previously learned, and *nominal groups*, or groups of the same size where members undergo the same learning and recall tasks, but do so alone.

Reliably, groups do outperform individuals, and the collective recalls more than any individual within it, when counting non-redundant items. This is a product of aggregating several non-overlapping protocols spoken or written by different people who remember somewhat different events. On the other hand, in comparing individuals who had collaborated with individuals who had not, a counterintuitive finding arises. Individuals who had never collaborated remember significantly more items or events than individuals who had collaborated; this frequently replicated finding is termed *collaborative inhibition.* Collaborating to remember, it seems, is actually detrimental to individual recall, and likely arises from the fact that collaborators disrupt one another's retrieval strategies (Basden, Basden, Bryner, & Thomas, 1997).

**Conversational influences.** Another broad domain of research examines how speakers and listeners can reshape one another's memories in conversation (Hirst & Echterhoff, 2012). Remembering an event is frequently inseparable from communicating about it; people talk to one another about the past, their exciting or emotional experiences, and their knowledge (Harber & Cohen, 2005; Pasupathi, McLean, & Weeks, 2009). During such conversational remembering, recall is nearly always a selective retelling; rarely do people try to recall everything they can about a topic, instead tuning their message as is socially appropriate (Marsh, 2007). This selective recall presents opportunities for speakers and listeners to reshape one another's memories, making information frequently retrieved in conversation more accessible (Congleton & Rajaram, 2011; Blumen & Rajaram, 2008; Roediger, Zaromb, & Butler, 2009). Importantly, such selective recall also induces forgetting for silenced information (Cuc, Koppel, & Hirst, 2007; Stone, Coman, Brown, Koppel, & Hirst, 2012). Further, if one remember makes errors in recall, these will often be picked up and incorporated into the listener's memory for the event. Such transfer of false memories from one person to another has been called the social contagion of memory (Roediger, Meade, & Bergman, 2001; see too Meade & Roediger, 2002). Studies on conversational influences on memory typically bring pairs of individuals - conversational dyads – into the laboratory for an initial learning phase, followed by a social remembering phase in which the experimenter manipulates various characteristics of the interaction, and then a final individual free recall.

As a whole, this class of research has repeatedly shown that memory is highly sensitive to social influence. Some researchers have argued that, rather than being a "sin" of memory (Schacter, 2001), this malleability is adaptive, in that it allows people to converge with other members of their social groups onto shared ways of remembering the past (Fagin, Yamashiro, & Hirst, 2013). Such convergence occurs both via what is collectively remembered (Roediger, et al. 2009) and what is collectively forgotten (Hirst & Yamashiro, 2017). Susceptibility to social influences is a characteristic of human memory that allows people to form the collective memories that undergird stable social relations (Wertsch & Roediger, 2008; Hirst & Manier, 2008).

## Varieties of Memory

We have covered the history of research on memory in a long chapter. Although English provides a single noun – *memory* – we have seen the psychologists and neuroscientist distinguish among many types of memory by modifying the noun with some adjective (or noun) to refer to different types of memory. Among others, we have discussed short-term memory, long-term memory, episodic memory, semantic memory, autobiographical memory, flashbulb memory, implicit memory, social memory, and others.

And this listing is just the start. In a chapter published in 2007, Tulving asked “Are there 256 kinds of memory?” He had been keeping a list while reading the memory literature. Some of the terms are synonyms of one another, but not too many. So, for example, Tulving discussed iconic memory (a very brief visual representation that exists when you see something), fear memory, illusory memory and so on. We have obviously not covered many of these topics, and some (false or illusory memories) have a long history in psychology (Roediger, 1996).

In short, this chapter is at once quite long yet provides a woefully incomplete picture of the history of the field. Unfortunately, no book-length history of the field exists.

## Applied Memory Research

Before concluding, we need to consider one more topic: applied memory research. The preceding chapter may leave the impression that psychologists are not much interested in using their knowledge outside laboratory settings and theoretical debates, but that is not true.

One important application is in police investigations. For example, imagine you witnessed a robbery from some distance, but you did see the robber. You are an eyewitness to the crime. Later the police arrest a suspect and they ask you to come to the police station to view a lineup. So, you find yourself looking at six men who fit the general description you gave of the robber (white, about 6’2” tall, brown hair). You look at the lineup trying to pick one, but you also try to keep in mind that the lineup might not contain the robber at all. This is a difficult task. Making a mistake and picking an innocent person can create a miscarriage of justice by helping to convict him. On the other hand, failing to recognize the robber may set him free to rob again. Psychologists have worried about the accuracy and fallibility of eyewitness identification since

Munsterberg's (1908) book, *On the witness stand*. A recent review of research on eyewitness identification can be found in Wixted and Wells (2017).

Another problem in witness testimony is in the malleability of memory. We normally think we see a scene – say the robbery just mentioned – and it is frozen in our memories due to the high emotion. Even though emotional memories are often accurate, they (and all other memories) can be changed over time. Repeatedly telling a story can lead to changes over time, as the person may embellish slightly and then remember the embellishments as facts (Bartlett, 1932; Marsh, 2007). Another issue is when a witness may receive some misinformation from either a co-witness, a police officer or even a friend making helpful suggestions. Such misinformation can distort the witness's memory for the event. Elizabeth Loftus pioneered the study of what is called the misinformation effect in memory and explored the effects of misinformation in many ways (see Loftus, 2005, for a review). This research has been relevant in several arenas in which people are charged with crimes when the recollections that form the basis of the charge turn out to be false, ones due to errors implanted in memory of the witness (e.g., Loftus, 1993).

Research on human learning and memory has also been applied to education. In fact, the field of educational psychology is partly based on extensions of knowledge from cognitive psychology to education. Many cognitive psychologists in their own right have taken up the application of what they know to educational issues (e.g., see Dunlosky, Rawson, Marsh, Nathan & Willingham, 2013; Karpicke, 2012).

These selections represent just some examples of applied memory. Perfect and Lindsay (2014) edited a *Handbook of Applied Memory Research* that provides many more examples.

## Conclusion

As this chapter makes clear, psychologists have a long history of pondering learning and memory. The early attempts were to search for general laws or principles of learning, ones that would transcend not just particular tasks but species (pigeons, rats, and humans were thought by some scholars to learn in similar ways). The roughly 135-year history of the field shows that no general laws exist, although some principles do operate across situations (Roediger, 2008). Still, the field has made wonderful progress from its early beginnings in the 1880s, even if many problems and unresolved issues remain. The many traditions and approaches reviewed in this chapter should be seen as complementary, rather than competitive, leading to a rich tapestry in our understanding of the many mysteries of our memory.

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