CHAPTER 1

Cognitive Psychology
An Introduction

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What a piece of work is man. How noble in reason! How infinite in faculty! In form and moving how express and admirable! In action how like an angel! In apprehension, how like a god!
(Act 2, Scene 2, of Shakespeare’s Hamlet)

This text is about human memory and cognition, and specifically about the scientific study of human memory and cognition. For the moment, consider memory and cognition to be the mental events and knowledge we use when we recognize an object, remember a name, have an idea, understand a sentence, or solve a problem. In this text, we consider a broad range of subjects, from basic perception through complex decision making, from seemingly simple mental acts such as recognizing a letter of the alphabet to very complicated acts such as having a conversation. We ask questions such as “How do we read for meaning?” “How
do we memorize facts?" “What does it mean to forget something?” “How do we know that we don’t know something?” The unifying theme behind all this is one of the most fascinating and important questions of all time: How do people think?

Here we are interested in a scientific approach to memory and thought. This is cognitive psychology. One of the central features of modern cognitive psychology is its allegiance to objective, empirical methods of investigation. We are experimentalists, and this is the approach you will read about here. However, although we do present a lot of studies, we also try to make connections with your everyday experiences and how they are relevant to the issues being discussed.

Within the boundaries of science, cognitive psychology is asking a wide range of fascinating questions. There has been an explosion of interest in cognition both in and outside of psychology proper. Questions that were on the back burner for too long—such as “How do we read?” or “How do we use language?”—are now active areas of research. The pent-up interest in these questions, unleashed during the cognitive revolution of the late 1950s, has yielded tremendous progress. Furthermore, we now acknowledge, seek, and sometimes participate in the important contributions of disciplines such as linguistics, computer science, and the neurosciences. This interdisciplinary approach is called cognitive science, the scientific study of thought, language, and the brain—in short, the scientific study of the mind.

The most basic aim of this text is to tell you what has been discovered about human memory and cognition, and to share the insights those discoveries provide about human thought. Human memory—your memory, with its collection of mental processes—is the most highly sophisticated, flexible, and efficient computer available. How does it work? As amazing as electronic computers are, their abilities are primitive compared with what you do routinely in even a single minute of thinking. The need to understand ourselves is basic, and this includes an understanding of how our minds work.

Another aim of this text is to describe how cognitive psychology has made these discoveries. You’ll better appreciate this information if you also understand how research is done and how new knowledge is acquired. Few of you will become cognitive scientists, but presumably most of you are majoring in psychology or a related field. Because the cognitive approach influences many areas of psychology—indeed, cognitive psychology is at the core and is “the most prominent school” of thought in psychology (Robins, Gosling, & Craik, 1999)—your mastery of psychology as a whole will be enhanced by understanding cognitive psychology.

A final aim of this text is to illustrate the pervasiveness of cognitive psychology and its impact on fields outside of psychology. Cognitive science is a multidisciplinary field. This fusion and cross-pollination of ideas stems from the conviction that researchers in linguistics, artificial intelligence, the neurosciences, economics, and even anthropology can contribute important ideas to psychology and vice versa. Psychology has a long tradition of influencing educational practice, and the potential for cognitive psychology to continue this is obvious and important. Even fields as diverse as medicine, law, and business use findings from cognitive psychology—for example, a cognitive psychologist named Kahneman won the Nobel Prize in Economics in 2003 for his work on decision making. But it should
not be surprising that cognitive psychology is relevant to so many other fields. After all, what human activity doesn’t involve thought?

THINKING ABOUT THINKING

Let’s begin to develop a feel for our topic by considering three examples. For all three, you should read and answer the question, but more importantly try to be as aware as possible of the thoughts that cross your mind as you consider the question. The first question is easy:

1. How many hands did Aristotle have?

Here we are not particularly interested in the correct answer, “two.” We are more interested in the thoughts you had as you considered the question. Most students report a train of thoughts something like this: “Dumb question. Of course he had two hands. Wait a minute—why would a professor ask such an obvious question? Maybe Aristotle had only one hand. Nah, I would have heard of it if he had had only one hand—he must have had two.” An informal analysis will uncover some of the thoughts you had. This is tracked with the list in Table 1-1. Bear in mind that Table 1-1 illustrates the intuitive analysis and is not a full description of these processes.

<table>
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<tr>
<th>Processes</th>
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<td>Focus eyes on print</td>
<td>Visual perception, sensory memory: Chapter 3</td>
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<tr>
<td>Encode and recognize printed material</td>
<td>Pattern recognition, reading: Chapters 3 and 10</td>
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<tr>
<td><strong>Memory and retrieval</strong></td>
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<tr>
<td>Look up and identify words in memory</td>
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<tr>
<td>Retrieve word meanings</td>
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<td><strong>Comprehension</strong></td>
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<td>Combine word meanings to yield sentence meaning</td>
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<tr>
<td>Evaluate sentence meaning, consider alternative meanings</td>
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<td>Retrieve answer to question</td>
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<td>Determine reasonableness of question</td>
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<td><strong>Computational (Question 2)</strong></td>
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<td>Retrieve factual knowledge</td>
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<td>Procedural knowledge: Chapters 6, 11, and 12</td>
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First, perceptual processes were used for the written words of the question to focus your eyes on the printed line, then move your focus across the line bit by bit, registering the material into a memory system. Smoothly and rapidly, other processes took the material into memory to identify the letters and words. Of course, few college readers consciously attend to the nuts and bolts of perceiving and identifying words unless the vocabulary is unfamiliar or the print is bad. Yet your lack of awareness does not mean that these processes didn’t happen; ask any first-grade teacher about the difficulties children have identifying letters and putting them together into words.

We have encountered two important lessons already. First, mental processes can occur with little conscious awareness, especially if they are highly practiced, such as reading. Second, even though these processes can operate very quickly, they are complex. Their complexity makes it even more amazing how efficient, rapid, and seemingly automatic they are.

As you identified the words in the question, you were looking up their meanings and fitting them together to understand the question. Surely, you weren’t consciously aware of looking up the meaning of hands in a mental dictionary. But just as surely, you did find that entry, along with your general knowledge about the human body.

Now we are getting to the meat of the process. With little effort, we retrieve information from memory that Aristotle refers to a human being, a historical figure from the past. Many people know little about Aristotle beyond the fact that he was a Greek philosopher. Yet this seems to be enough, combined with what we know about people in general, to determine that he was probably just like everyone else: He had two hands.

At a final (for now) stage, people report thoughts about the reasonableness of the question. In general, people do not ask obvious questions, at least not of other adults. If they do, it is often for another reason—a trick question, maybe, or sarcasm. So, students report that for a time they decided that maybe the question wasn’t so obvious after all. In other words, they returned to memory to see whether there was some special knowledge about Aristotle that pertains to his hands. The next step is truly fascinating. Most students claim to think to themselves, “No, I would have known about it if he had had only one hand,” and decide that it was an obvious question after all. This lack-of-knowledge reasoning is fascinating because so much everyday reasoning is done without benefit of complete knowledge. In an interesting variation, if students are asked, “How many hands did Beethoven have?” their knowledge of Beethoven’s musical fame typically leads to the following inference: “Because he was a musician, he played the piano, and he could not possibly have been successful at it with only one hand; therefore he must have had two.” An occasional student goes even further with “Two, but he did go deaf before he died.”

Now that’s interesting! Someone found a connection between the disability implied by the question “How many hands?” and a related idea in memory, Beethoven’s deafness. Such an answer shows how people can also consider implications, inferences, and other unstated connections as they reason: A great deal of knowledge can be considered, and this illustrates the role of prior
knowledge in reasoning, where richer knowledge about Beethoven can lead to an inference.

One other thing to note from this example is that there are different cognitive processes that are all operating at the same time or similar times—perception, attention, memory, language comprehension, and so forth. These processes are also providing input and influencing one another. In essence, cognition is a complex and interactive thing, and it is going to take a lot of time and effort to tease it all apart and understand how it works.

2. What is 723 divided by 6?

This question uses your knowledge of arithmetic. Just as with the first question, many of your mental processes happened more or less automatically: identifying the digits, accessing knowledge of arithmetic procedures, and so on. Yet you may be aware of the steps in doing long division: Divide 6 into 7, subtract 6 from 7 to get the first remainder, bring down the 2, then divide 12 by 6, and so on. These steps are mentioned at the bottom of Table 1-1, “Computational,” which includes your knowledge of how to do long division. Cognitive psychology is also interested in your mental processing of arithmetic problems and knowledge you acquired in school, not just the kind of reasoning you used in the Aristotle question (see Chapter 12 for more on the cognitive psychology of arithmetic and math).

3. Does a robin have wings?

Most adults have little to say about their train of thought when answering this question. Many people insist, “I just knew the answer was yes.” The informal analysis for Question 1 showed how much of cognition occurs below awareness. The assertion that “I just knew it” is not useful, however certain you are that no other thoughts occurred. You had to read the words, find their meanings in memory, check the relevant facts, and make your decision as in the previous examples. Each of these steps is a mental act, the very substance of cognitive psychology. Furthermore, each step takes some amount of time to complete. Question 3 takes adults about one second to answer; the question “Does a robin have feet?” takes a little longer, around 1.2 or 1.3 seconds. Even small time differences can give us a wealth of information about cognition and memory. What is different for Question 3 is that most of the mental processes do not require much conscious activity; the question seems to be processed automatically. Because such automatic processes are so pervasive, we are particularly interested in understanding them.

Section Summary

- Cognitive psychology is the scientific study of human mental processes. This includes perceiving, remembering, using language, reasoning, and solving problems.
- Intuitive analysis of examples such as “How many hands did Aristotle have?” and “Does a robin have wings?” indicates that many mental processes occur automatically (very rapidly and below the level of conscious awareness).
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MEMORY AND COGNITION DEFINED

Now that you have an idea of the topics in the area of cognitive psychology, we need more formal definitions of the terms memory and cognition. Most of us have a good idea of what the term memory means, something like “being able to remember or recall some information” or “the act of recalling previously learned facts or events.” Note that both of these definitions are hopelessly circular; memory is “being able to remember” or “the act of recalling.” However, the definitions do point to several critical ideas.

First, the information recalled from memory is from the past. The past could be a childhood memory from years ago or something that happened only moments ago. Second, memory is a process of storing information or recovering it for current use. Note that retrieval includes both the conscious, intentional recalling to mind and the more automatic (or even unaware) retrieval of the earlier examples.

Finally, memory is also a place where all the knowledge of a lifetime is stored. This is evident in theories of cognition that rely on divisions such as short-term and long-term memory. Although there is some physical location in your brain for storage, “location” is often taken metaphorically; regardless of where it happens, there is some memory system that holds information. With the advent of neuroimaging, we are making progress in understanding where functions and processes occur in the brain. Chapter 2 introduces you to some of this new methodology.

A formal definition of memory captures these essential ingredients. Consider memory to be the mental processes of acquiring and retaining information for later retrieval and the mental storage system that enables these processes. Memory is demonstrated whenever the processes of retention and retrieval influence behavior or performance in some way, even if we are unaware of it. Furthermore, this definition includes retention not just across hours, weeks, or years, but even across very brief spans of time, in any situation in which the original event is no longer present. Note that memory refers to three kinds of mental activities: acquisition (also called learning or encoding), retention, and retrieval (Melton, 1963). Because all three are needed to demonstrate remembering, we include them in our broader definition.

The term cognition is a much richer term. In Neisser’s landmark book Cognitive Psychology (1967), he stated that cognition “refers to all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used . . . [including] such terms as sensation, perception, imagery, retention, recall, problem solving, and thinking” (p. 4). For the present, we use the following definition: Cognition is the collection of mental processes and activities used in perceiving, remembering, thinking, and understanding, as well as the act of using those processes.

Cognitive psychology is largely, though not exclusively, interested in what might be everyday, ordinary mental processes. These processes are entirely commonplace—not simple, by any means, but certainly routine. Our definition should not include only “normal” mental activities. Although cognitive psychology generally does not deal with psychologically “abnormal” states, such as schizophrenia, such “nonnormal” processes, although unusual or rare, may enrich our science.
Most cognitive research deals with the sense modalities of vision and hearing and focuses heavily on language. Some people have been bothered by the reliance on seemingly sterile experimental techniques and methods, techniques that ask simple questions that may yield overly simple-minded views about cognition. This reflects a concern that cognitive research lacks ecological validity, or generalizability to the real-world situations in which people think and act (e.g., Neisser, 1976). To some this criticism was sensible, but to many it was premature. Cognition is complex, even when using artificially simple tasks. At our current level of sophistication, we would be quickly overwhelmed if tasks were very complex or if we tried to investigate the full range of a behavior in all its detail and nuance. In the early stage of investigation it is reasonable for scientists to take an approach called reductionism, attempting to understand complex events by breaking them down into their components. An artificially simple situation can reveal an otherwise obscure process. Of course, scientists eventually put the pieces back together and deal with the larger event as a whole.

**Section Summary**

- Memory is composed of the mental processes of acquiring and retaining information for later use (encoding), the mental retention system (storage), and then using that information (retrieval).
- Cognition is the complex of mental processes and activities used in perceiving, remembering, and thinking and the act of using those processes.

**AN INTRODUCTORY HISTORY OF COGNITIVE PSYCHOLOGY**

Let’s now turn to cognitive psychology’s history and development (for an excellent history of cognitive psychology, see Mandler, 2007). Figure 1-1 summarizes the main patterns of influence that produced cognitive psychology and cognitive science, along with approximate dates.

To a remarkable extent, the bulk of the scientific work on memory and cognition is quite recent, although some elements, and many experimental tasks, appeared even in the earliest years of psychology. However, interest in memory and cognition—thinking—is as old as recorded history. Aristotle, born in 384 BC, considered the basic principles of memory and proposed a theory in his treatise *De Memoria* (Concerning Memory; Hothersall, 1984). Even a casual reading of ancient works such as Homer’s *Iliad* or *Odyssey* reveals that people have always wondered how the mind works and how to improve it (in Plato’s *Phaedrus*, Socrates fretted that the invention of written language would weaken reliance on memory and understanding, just as modern parents worry about television and computers). Philosophers of every age have considered the nature of thought. Descartes even decided that the proof of human existence is our awareness of our own thought: *Cogito ergo sum*, “I think, therefore I am” (Descartes, 1637, p. 52).

The critical events at the founding of psychology, in the mid- to late 1800s, converged most strongly on one man, Wilhelm Wundt, and on one place, Leipzig,
Germany. In 1879, Wundt established the first laboratory for psychological experiments, at the University of Leipzig, although several people had already been doing psychological research (e.g., Weber's and Fechner's work in psychophysics, Helmholtz's studies of the speed of neural impulses, and Broca's and Wernicke's identification of linguistic brain regions). A laboratory was even established by American psychologist William James in 1875, although apparently it was used more for classroom demonstrations than for genuine experiments. Still, the consensus is that 1879 is the beginning of the discipline of psychology, separate from philosophy and physiology.
Anticipations of Psychology

Aristotle, for two reasons, is one of the first historical figures to advocate an empirically based, natural science approach. Although he was certainly not the only great thinker to insist on observation as the basis for all science, he was the first to express this—a position known as empiricism. Second, Aristotle’s inquiry into the nature of thought led him to a reasonably objective explanation of how learning and memory take place. The basic principles of association he identified have figured prominently in many psychological theories. Equally important was Aristotle’s insistence that the mind is a “blank slate” at birth, a tabula rasa, or clean sheet of paper (Watson, 1968). The idea is that experience, rather than inborn factors, “writes” a record onto the blank paper.

There have been many fits and starts in the study of memory over time since Aristotle. For example, St. Augustine, in Chapter 10 of his Confessions, presents a surprisingly modern account of memory. Most other anticipations of psychology date from the Renaissance and later periods and are largely developments in scientific methods and approaches. By the mid-1800s, more observational or empirical methods were adopted. By the time psychology appeared, the general procedures of scientific inquiry were well developed. Given the progress in scientific fields such as physics, biology, and medicine by the mid-1800s, it is not surprising that the early psychologists thought the time was ripe for a science of the mind.

Early Psychology

Four early psychologists are of particular interest for cognitive psychology. They are Wilhelm Wundt, Edward Titchener, Hermann von Ebbinghaus, and William James.

WILHELM WUNDT To a large extent, the early psychologists were students of Wilhelm Wundt (1832–1920) (Benjamin, Durkin, Link, Vestal, & Acord, 1992). Beginning in 1875, Wundt directed more than 200 doctoral theses on psychological topics (Leahey, 2000). Wundt continually updated his book Principles of Physiological Psychology, reporting new results from his laboratory. He also founded the first psychology journal, Philosophical Studies (neither of these titles matches its modern connotations). Unfortunately, Wundt’s later interests went largely unrecognized until recently (Leahey, 2000). His work on language, child psychology, and other applied topics foreshadowed some modern insights but was rejected or ignored at the time.

In terms of psychology, Wundt believed that the study of psychology was “of conscious processes and immediate experience”—what today we consider areas of sensation, perception, and attention. To study these, in addition to extensive use of response time measures, Wundt used the method of Selbst-Beobachtung. Translated literally as “self-observation,” this generally is known as introspection, a method in which one looks carefully
inward, reporting on inner sensations and experiences. Wundt intended this to be a careful, reliable, and scientific method in which the observers (who were also the participants) needed a great deal of training to report only the elements of experience that were immediate and conscious. Reports in which memory intruded were to be excluded.

**EDWARD TITCHENER** For American psychology in Wundt’s tradition, the most important figure was Edward Titchener, an Englishman who came to Cornell University in 1892. Working with Wundt convinced Titchener that psychology’s progress depended critically on introspection. Topics such as mental illness and educational and social psychology (including Wundt’s broader interests) were “impure” because they could not be studied this way. Titchener insisted on rigorous training for his introspectors, who had to avoid “the stimulus error” of describing the physical stimulus rather than the mental experience of it. Moreover, Titchener made himself the final authority on whether introspection reports were correct or not. By these means, Titchener studied the structure of the conscious mind, the sensations, images, and feelings that were the very elements of the mind’s structure. He called this **structuralism**, an early movement or school of psychological thought (see Figure 1-1). Such a system was destined for difficulties. It is unscientific that one person, Titchener, would be the ultimate authority to validate observations. As other researchers used introspective methods, differences and contradictory results began to crop up, producing disputes, hastening the decline of Titchener’s once-powerful structuralism.

**HERMANN VON EBBINGHAUS** In contrast to Titchener’s structuralism, there was the theoretically modest but eventually more influential work of Hermann von Ebbinghaus (see Chapter 6). Ebbinghaus was a contemporary of Wundt in Germany, although he never studied with Wundt in person. Ebbinghaus’s achievements in studying memory and forgetting are all the more impressive because he worked outside the establishment of the time. Historical accounts suggest that Ebbinghaus read Wundt’s book, decided that a study of the mind by objective methods was possible, and set about the task of figuring out how to do it.

Lacking a formal laboratory and in an academic position with no like-minded colleagues, Ebbinghaus had to rely on his own resources, even to the extent that he alone served as a subject in his research. Ebbinghaus’s aim was to study memory in a “pure” form. To do this, he needed materials that had no preexisting associations, so he constructed lists of **nonsense syllables**, consonant-vowel-consonant (CVC) trigrams that, by definition, had no meaning. Ebbinghaus would learn a list (e.g., of 16 items) to a criterion of mastery (e.g., two perfect recitations), then set the list aside. Later, he would relearn the same list, noting how many fewer trials he needed to relearn it. His measure of
learning was the “savings score,” the number (or proportion) of trials that had been saved in memory between the first and second sessions. With this method, Ebbinghaus studied forgetting as a function of time, degree of learning or over-learning, and even the effect of nonsense versus meaningful material (he compared forgetting curves for nonsense syllables and meaningful poetry).

Ebbinghaus's work, described in his 1885 book, was acclaimed widely as a model of scientific inquiry into memory; for instance, Titchener praised Ebbinghaus's work as the most significant progress since Aristotle (1919; cited in Hall, 1971). It is difficult to point to another psychologist of his day whose contributions or methods continue to be used. The field of verbal learning owed a great deal to Ebbinghaus. The Ebbinghaus tradition, depicted in Figure 1-1, is one of the strongest influences on cognitive psychology.

WILLIAM JAMES American philosopher and psychologist William James, a contemporary of Wundt, Titchener, and Ebbinghaus, provided at Harvard an alternative to Titchener’s rigid system. His approach, functionalism, was influenced by the writings of Darwin, in which the functions of consciousness, rather than its structure, were of interest. Thus, James asked questions such as “How does the mind function?” and “How does it adapt to new circumstances?”

James’s informal analyses led to some useful observations. For example, he suggested that memory consists of two parts: an immediately available memory that we are currently aware of and a larger memory that is the repository for past experience. The idea of memory being divided into parts, based on different functions, is popular today. Indeed, the first serious models of human cognition included the two kinds of memory James discussed in 1890.

Probably because of his personal distaste for experimentation and his far-reaching interests, James did not do much research. However, his far-reaching ideas were more influential than any of Titchener’s work, as evidence by his classic 1890 book Principles of Psychology. James’s influence on the psychology of memory and cognition was delayed, however, for it was John B. Watson, in 1913, who solidified a new direction in American psychology away from both the structuralist and functionalist approaches. This new direction was behaviorism.

Behaviorism and Neobehaviorism

Not all of American psychology from 1910 through the 1950s was behaviorist. The fields of clinical, educational, and social psychology, to name a few, continued in their own development in parallel to behaviorism. Furthermore, there were changes within behaviorism that smoothed the transition to cognitive psychology. This was a kind of neobehaviorism with some unobservable, mediating variables. Nonetheless, it was still a behaviorist environment.
Most people who take introductory psychology know of John B. Watson, the early behaviorist who stated in his 1913 “manifesto” that observable, quantifiable behavior was the proper topic of psychology, not the fuzzy and unscientific concepts of thought, mind, and consciousness. Attempts to understand the “unobservables” of mind were inherently unscientific, in his view, and he pointed to the unresolved debates in structuralism as evidence. Thus psychology was redefined as the scientific study of observable behavior, the program of behaviorism. There was no room for mental processes because they were not observable behaviors.

Why did such a radical redefinition of psychology’s interests have such broad appeal? Part of this was a result of the work that Pavlov and others were doing on conditioning and learning. Here was a scientific approach that was going somewhere compared to the endless debates in structuralism. Furthermore, the measurement and quantification of behaviorism mirrored successful sciences such as physics. Modeling psychology on the methods of these sciences might help it become more scientific (Leahey, 2000, calls this mentality “physics envy”). One of behaviorism’s greatest legacies was the emphasis on methodological rigor and observables, traditions continued to this day.

During the behaviorist era, there were a few psychologists who pursued cognitive topics—Bartlett of Great Britain, for example—but most American experimental psychology focused on observable, learned behaviors, especially in animals (but see Dewsbury, 2000, for a history of research on animal cognition during the behaviorist era). Even the strongly cognitive approach of Tolman—whose article “Cognitive Maps in Rats and Men” (1948), a molar (as opposed to molecular) approach to behaviorism, is still worth reading—included much of the behaviorist tradition: concern with the learning of new behaviors, animal studies, and interpretation based closely on observable stimuli. Gestalt psychology, which emigrated to the United States in the 1930s (Mandler & Mandler, 1969), always maintained an interest in human perception, thought, and problem solving but never captured the imaginations of many American experimentalists.

Thus the behaviorist view dominated American experimental psychology until the 1940s, when B. F. Skinner emerged as a vocal, even extreme, advocate. In keeping with Watson’s earlier sentiments, Skinner also argued that mental events such as thinking have no place in the science of psychology—not that they are not real, but that they are unobservable and hence unnecessary to a scientific explanation of behavior.

**Emerging Cognition: The Winds of Change**

It is often difficult to determine precisely when historical change takes place. Still, many psychologists look kindly on the idea that there was a cognitive revolution in the mid- to late 1950s, with a relatively abrupt change in research activities, interests, and the scientific beliefs, a definitive break from behaviorism (Baars, 1986). Because of the nature and scope of these changes, the current approach is seen by some as a revolution in which behaviorism was rejected and replaced with cognitive psychology, although some historians claim that this was not a true scientific revolution but merely “rapid, evolutionary change” (see Leahey, 1992). In either case, the years from 1945 through 1960 were a period of rapid reform in
experimental psychology. The challenges to neobehaviorism came both from within its own ranks and from outside, prodding psychologists to move in a new direction.

**WORLD WAR II** Lachman, Lachman, and Butterfield (1979) made a point about this growing dissatisfaction among the neobehaviorists. They noted that many academic psychologists were involved with the U.S. war effort during World War II. Psychologists accustomed to studying animal learning in the laboratory were “put to work on the practical problems of making war . . . trying to understand problems of perception, judgment, thinking, and decision making” (p. 56). Many of these problems arose because of soldiers’ difficulties with sophisticated technical devices: skilled pilots who crashed their aircraft, radar and sonar operators who failed to detect or misidentified enemy blips, and so on.

Lachman et al. (1979) were very direct in their description of this situation:

Where could psychologists turn for concepts and methods to help them solve such problems? Certainly not to the academic laboratories of the day. The behavior of animals in mazes and Skinner boxes shed little light on the performance of airplane pilots and sonar operators. The kind of learning studied with nonsense syllables contributed little to psychologists trying to teach people how to operate complex machines accurately. In fact, learning was not the central problem during the war. Most problems arose after the tasks had already been learned, when normally skillful performance broke down. The focus was on performance rather than learning; and this left academic psychologists poorly prepared. (pp. 56–57)

As Bruner, Goodnow, and Austin (1956) put it, the “impeccable peripheralism” of stimulus–response (S–R) behaviorism became painfully obvious in the face of such practical concerns.

To deal with practical concerns, wartime psychologists were forced to conceive of human behavior differently. The concepts of attention and vigilance, for instance, were important to understand sonar operators’ performance; experiments on the practical and theoretical aspects of vigilance began (see especially Broadbent, 1958, Chapter 6). Decision making was a necessary part of this performance, too, and from this came such developments as signal detection theory. These wartime psychologists rubbed shoulders with professionals from different fields—those in communications engineering, for instance—from whom they gained new outlooks and perspectives on human behavior. Thus these psychologists returned to their laboratories after the war determined to broaden their own research interests and those of psychology as well.
VERBAL LEARNING  Verbal learning was the branch of experimental psychology that dealt with humans as they learned verbal material, composed of letters, nonsense syllables, or words. The groundbreaking research by Ebbinghaus started the verbal learning tradition (see Chapter 6), which derives its name from the behaviorist context it found itself in. Thus, verbal learning was defined as the use of verbal materials in various learning paradigms. Throughout the 1920s and 1930s there was a large body of verbal learning research, with well-established methods and procedures. Tasks such as serial learning, paired-associate learning, and, to an extent, free recall were the accepted methods.

Verbal learners were similar to the behaviorists. For example, they agreed on the need to use objective methods. There also was widespread acceptance of the central role of learning, conceived as a process of forming new associations, much like the learning of new associations by a rat in a Skinner box. From this perspective, a theoretical framework was built that used a number of concepts that are accepted today. For example, a great deal of verbal learning was oriented around accounts of interference among related but competing newly learned items.

The more moderate view in verbal learning circles made it easy for people to accept cognitive psychology in the 1950s and 1960s: There were many indications that an adequate psychology of learning and memory needed more than just observable behaviors. For instance, the presence of meaningfulness in “nonsense” syllable had been acknowledged early on; Glaze (1928) titled his paper “The Association Value of Nonsense Syllables” (and apparently did so with a straight face). At first, such irksome associations were controlled for in experiments, to avoid contamination of the results. Later, it became apparent that the memory processes that yielded those associations were more interesting.

In this tradition, Bousfield (1953; Bousfield & Sedgewick, 1944) reported that, with free recall, words that were associated with one another (e.g., car and truck) tended to cluster together, even though they were arranged randomly in a study list. There were clear implications that existing memory associations led to the reorganization. Such evidence of processes occurring between the stimulus and the response—in other words, mental processes—led verbal learners to propose a variety of mental operations such as rehearsal, organization, storage, and retrieval.

The verbal learning tradition led to the derivation and refinement of laboratory tasks for learning and memory. They borrowed from Ebbinghaus’s example of careful attention to rigorous methodology to develop tasks that measured the outcomes of mental processes in valid and useful ways. Some of these tasks were more closely associated with behaviorism, such as the paired-associate learning task that lent itself to tests of S–R associations in direct ways. Nonetheless, verbal learning gave cognitive psychology an objective, reliable way to study mental processes—research that was built on later (e.g., Stroop, 1935)—and a set of inferred processes such as storage and retrieval to investigate. The influence of verbal learning on cognitive psychology, as shown in Figure 1-1, was almost entirely positive.

LINGUISTICS  The changes in verbal learning were a gradual shifting of interests and interpretations that blended almost seamlessly into cognitive psychology. In
contrast, 1959 saw the publication of an explicit, defiant challenge to behaviorism. Watson's 1913 article was a behaviorist manifesto, crystallizing the view against introspective methods. To an equal degree, Noam Chomsky's 1959 article was a cognitive manifesto, a rejection of purely behaviorist explanation of the most human of all behaviors: language.

A bit of background is needed. In 1957, B. F. Skinner published a book titled *Verbal Behavior*, a treatment of human language from the radical behaviorist standpoint of reinforcement, stimulus–response associations, extinction, and so on. His central point was that the psychology of learning—that is, the conditioning of new behavior by means of reinforcement—provided a useful and scientific account of human language. In oversimplified terms, Skinner's basic idea was that human language, "verbal behavior," followed the same laws that had been discovered in the animal learning laboratory: A reinforced response increased in frequency, a nonreinforced response should extinguish, a response conditioned to a stimulus should be emitted to the same stimulus in the future, and so on. In principle, then, human language, a learned behavior, could be explained by the same mechanisms given knowledge of the current reinforcement contingencies and past reinforcement history of the individual.

Noam Chomsky, a linguist at the Massachusetts Institute of Technology, reviewed Skinner's book in the journal *Language* in 1959. The first sentence of his review noted that many linguists and philosophers of language “expressed the hope that their studies might ultimately be embedded in a framework provided by behaviorist psychology” and therefore were interested in what Skinner had to say. Chomsky alluded to Skinner’s optimism that the problem of verbal behavior would yield to behavioral analysis because the principles discovered in the animal laboratory “are now fairly well understood . . . [and] can be extended to human behavior without serious modification” (Skinner, 1957, cited in Chomsky, 1959, p. 26).

But by the third page of his review, Chomsky stated that “the insights that have been achieved in the laboratories of the reinforcement theorist, though quite genuine, can be applied to complex human behavior only in the most gross and superfi- cial way. . . . The magnitude of the failure of [Skinner’s] attempt to account for verbal behavior serves as a kind of measure of the importance of the factors omitted from consideration” (p. 28, emphasis added). The fighting words continued. Chomsky asserted that if the terms *stimulus, response, reinforcement*, and so on are used in their technical, animal laboratory sense, then “the book covers almost no aspect of linguistic behavior” (p. 31) of interest. To Chomsky, Skinner’s account used the technical terms in a nontechnical, metaphorical way, which “creates the illusion of a rigorous scientific theory [but] is no more scientific than the traditional approaches to this subject matter, and rarely as clear and careful” (pp. 30–31).

To illustrate his criticism, Chomsky noted the operational definitions that Skinner provided in the animal laboratory, such as for the term *reinforcement*. But unlike the distinct and observable pellet of food in the Skinner box, Skinner claimed that reinforcement for human verbal behavior could even be administered
by the person exhibiting the behavior, that is, self-reinforcement. In some cases, Skinner continued, reinforcement could be delayed for indefinite periods or never be delivered at all, as in the case of a writer who anticipates that her work may gain her fame for centuries to come. When an explicit and immediate reinforcer in the laboratory, along with its effect on behavior, is generalized to include nonexplicit and nonimmediate (and even nonexistent) reinforcers in the real world, it seems that Skinner had brought along the vocabulary of scientific explanation but left the substance behind. As Chomsky bluntly put it, “A mere terminological revision, in which a term borrowed from the laboratory is used with the full vagueness of the ordinary vocabulary, is of no conceivable interest” (p. 38).

Chomsky’s own view of language, emphasizing its novelty and the internal rules for its use, is discussed in Chapter 9; there, the influence of linguistics on cognitive psychology (Figure 1-1) is described in detail. For now, the essential message is the impact of Chomsky’s review. Language was an important behavior—and a learned one at that—to be understood by psychology. An approach that offered no help in understanding this was useless.

To a significant number of people, Chomsky’s arguments summarized the dissatisfactions with behaviorism that had become so apparent. The irrelevance of behaviorism to the study of language, and, by extension, any significant human behavior, was now painfully obvious. In combination with the other developments—the wartime fling with mental processes, the expansion of the catalog of such processes by verbal learning, and the disarray within behaviorism itself—it was clear that the new direction for psychology would take hold.

Section Summary

- The modern history of cognitive psychology began in 1879 with Wundt and the beginnings of experimental psychology as a science.
- The behaviorist movement rejected the use of introspections and substituted the study of observable behavior.
- Modern cognitive psychology, which dates from approximately 1960, rejected much of the behaviorist position but accepted its methodological rigor. Many diverse viewpoints, assumptions, and methods converged to help form cognitive psychology. This was at least a rapid, evolutionary change in interests, if not a true scientific revolution.

Cognitive Psychology and Information Processing

If we had to pick a date that marks the beginning of cognitive psychology, we might pick 1960. This is not to say that significant developments were not present before this date, for they were. This is also not to say that most experimental psychologists who studied humans became cognitive psychologists that year, for they did not. As with any major change, it takes a while for the new approach to catch on and for people to decide that the new direction is worth following. However, several significant events clustered around 1960 that were significant departures from what came before.
Just as 1879 is considered the formal beginning of psychology, and 1913 the beginning of behaviorism, so 1960 approximates the beginning of cognitive psychology.¹

Let’s pick up the threads of what came before this date. One significant thread was Chomsky’s 1959 review, a forceful argument against a purely behaviorist position. Chomsky argued that the truly interesting part of language was exactly what Skinner had omitted: mental processes and cognition. Language users follow rules when they generate language, rules that are stored in memory and operated on by mental processes. In Chomsky’s view, it was exactly there, in the organism, that the key to understanding language would be found.

Researchers in verbal learning and other fields were making the same claim. As noted, Bousfield (1953) found that people cluster or group words together on the basis of the associations among them. Memory and a tendency to reorganize clearly were involved. Where were these associations? Where was this memory? And where was this tendency to reorganize? They were in the person, in memory and mental processes.

During the 1950s, there were reports on attention, first from British researchers such as Colin Cherry and Donald Broadbent, that were related to the wartime concerns of attention and vigilance. Again, mental processes were being isolated and investigated—no one could deny their existence any longer, even though they were unseen, mental processes. A classic paper, Sperling’s monograph on visual sensory memory, appeared in 1960. (MacLeod [1991] noted an increase around 1960 of citations to the rediscovered Stroop [1935] task.)

Another startling development of this period was the invention of the modern digital computer. At some point in the 1950s, some psychologists realized the relevance of computing to psychology. In some interesting and possibly useful ways, computers behave like people (not surprising, according to Norman, 1986, p. 534, because “the architecture of the modern digital computer . . . was heavily influenced by people’s naive view of how the mind operated”). They take in information, do something with it internally, then produce some observable product. The product gives clues to what went on internally. The operations done by the computer were not unknowable because they were internal and unobservable. They were under the control of the computer program, the instructions given to the machine to tell it what to do.

The realization that human mental activity might be understood by analogy to this machine was a breakthrough. The computer was an existence proof for the idea that unobservable processes could be studied and understood. Especially important was the idea of symbols and their internal manipulation. A computer

¹Gardner (1985, p. 28) stated, “There has been nearly unanimous agreement among the surviving principals that cognitive science was officially recognized around 1956. The psychologist George A. Miller . . . has even fixed the date, 11 September 1956.” Miller recalled a conference from September 10 to 12, 1956, at MIT, attended by leading researchers in communication and psychology. On the second day of the conference, there were papers by Newell and Simon on the “Logic Theory Machine,” by Chomsky on his theory of grammar and linguistic transformations, and by Miller himself on the capacity limitations of short-term memory. Others whom Gardner cited suggest that, at a minimum, the five-year period 1955 to 1960 was the critical time during which cognitive psychology emerged as a distinct and new approach. By analogy to psychology’s selection of 1879 as the starting date for the whole discipline, 1960 is special in Gardner’s analysis: In that year, Jerome Bruner and George Miller founded the Center for Cognitive Studies at Harvard University.
is a symbol-manipulating machine. The human mind might also be a symbol-manipulating system, an idea attributed to Allen Newell and Herb Simon. According to Lachman et al. (1979), their conference in 1958 had a tremendous impact on those who attended. Newell and Simon presented an explicit analogy between information processing in the computer and that in humans. This important work was the basis for the Nobel Prize awarded to Simon in 1978 (see Leahey, 2003, for a full account of Simon’s contributions).

Among the indirect results of this conference was the 1960 publication of a book by Miller, Galanter, and Pribram called *Plans and the Structure of Behavior*. The book suggested that human problem solving could be understood as a kind of planning in which mental strategies or plans guide behavior toward its goal. The mentalistic plans, goals, and strategies in the book were not just unobservable, hypothetical ideas. Instead, they were ideas that in principle could be specified in a program running on a lawful, physical device: the computer.

**MEASURING INFORMATION PROCESSES**

**Getting Started**

The aim of cognitive psychology is to reverse engineer the brain in much the same way that engineers reverse engineer devices that they can’t get into. Putting it simply, we want to know: What happens in there? What happens in the mind—or in the brain, if you prefer—when we perceive, remember, reason, and solve problems? How can we peer into the mind to get a glimpse of the cognition that operates so invisibly? What methods can we use to obtain some scientific evidence on mental processes?

**Guiding Analogies**

With the development of cognitive psychology, the seemingly unrelated fields of communications engineering and computer science supplied psychology with some intriguing ideas and useful analogies that were central to developing the cognitive science.

**CHANNEL CAPACITY** To highlight one, psychologists found the concept of channel capacity from communications engineering useful (a similar, more popular term would be bandwidth). In the design of telephone systems, for instance, one of the built-in limitations is that any channel—any physical device that transmits messages or information—has a limited capacity. In simple terms, one wire can carry just so many messages at a time, and it loses information if capacity is exceeded. Naturally, engineers tried to design equipment and techniques to get around these limitations to increase overall capacity.

Psychologists noticed that, in several ways, humans are limited-capacity channels, too. There is a limit on how many things you can do, or think about, at a time. This insight lent a fresh perspective to human experimental psychology. It makes sense to ask questions such as: How many sources of information can people pay attention to at a time? What information is lost if we overload the system? Where is the limitation, and can we overcome it?
THE COMPUTER ANALOGY  Even more influential than communications engineering was computer science. Computer science developed a machine that reflected the essence of the human mind. Because those things are unseen when both computers and humans do them, there was good reason for drawing the computer analogy to cognition. Basically, this analogy said that human information processing may be similar to the steps and operations in a computer program, similar to the flow of information from input to output. If so, then thinking about how a computer does various tasks gives some insights into how people process information.

IN DEPTH  Interpreting Graphs

If you’re good at interpreting data in graphs, do not bother with the rest of this box; just study the figures. Some students struggle with graphs, not understanding what is being shown. Because you will encounter a lot of graphs in this text, you need to understand what you are looking at and what it means. Take a moment to go through these graphs to see how they are put together and what to pay attention to.

Figure 1-2 (see on page 20), is a graph of response time data, the time it takes to respond to an item. We abbreviate response time as RT, and it is usually measured in milliseconds (ms), thousandths of a second (because thought occurs so fast). In the figure, the label on the y-axis is “Vocal RT”; these people were making vocal responses (speaking), and we measured the time between the onset of a multiplication problem and the vocal response. The numbers on the y-axis show you the range of RTs that were observed. The dependent variable is always the measure of performance we collected—here it is vocal RT—and it always goes on the y-axis.

The x-axis in the left panel is labeled “Multiplication problems,” and we’ve plotted two problems, 2 × 3 and 6 × 9. It is customary to show a more general variable than this on the x-axis, as shown in the right panel. There you see a point for a whole set of small multiplication problems, from 2 × 3 up to 4 × 5; a set of medium-size problems such as 2 × 7 and 8 × 3; and a set of large problems, such as 6 × 8 and 9 × 7. So the x-axis label in the right panel says “Size of problem.” Notice that the y-axis is now in whole seconds, to save some space.

Now the data. The points in the graph are often a mean or average of the dependent variable, RT in this case. Both panels show two curves or lines each, one for college students and one for fourth-grade students (Campbell & Graham, 1985), for multiplication problems. Notice that the curves for fourth-graders are higher. Looking at the y-axis in the left panel, the average fourth-grader took 1,940 ms to answer “6” to the problem 2 × 3, compared to 737 ms for the average college student. In the right panel, the average fourth-grader took about 2,400 ms to respond to small problems, 4,100 ms to medium, and 4,550 ms to large. Compare this much greater increase in RT as the problems get larger with the pattern for college students: There was still an increase, but only from 730 ms to about 900 ms.

Why did Campbell and Graham find that fourth-graders were slower? No doubt because college students have had more practice in doing multiplication problems than fourth-graders. In other words, college students know multiplication better, have the facts stored more strongly in memory, and so can retrieve them more rapidly. It is a sensible, cognitive effect that the strength of information in memory influences the speed of retrieval. And it is easily grasped by looking at and understanding the graphed results.
Time and Accuracy Measures

How we peer into the mind to study cognition depends on using acceptable measurement tools to assess otherwise unseen, unobservable mental events. Other than Wundt’s method of introspection, what can be used? There are many measures, but two of the most prominent behavioral measures are (a) the time it takes to do some task and (b) the accuracy of that performance. Because these measures are so pervasive, it is important to discuss them at the outset.

RESPONSE TIME Many research programs in cognitive psychology rely heavily on response time (RT), a measure of the time elapsed between some stimulus and the person’s response to the stimulus (RT is typically measured in milliseconds, abbreviated ms; a millisecond is one thousandth of a second). Why is this so important, especially when the actual time differences can seem so small, say, on the order of 40 to 50 ms?

It has been known for a long time that individual differences among people can be revealed by RT measures. In 1868, the Dutch physiologist Donders (1868/1969) observed that RT is more informative and can be used to study the “Speed of Mental Processes.” A moment’s reflection reveals why cognitive psychology uses response times: Mental events take time. That’s important—the mental processes and events we want to understand occur in real time and can be studied by measuring how long they take. Thus, we can “peer into the head” by looking at how long it takes to complete certain mental processes.

Here’s an example of this kind of reasoning from measuring RTs. Research in mathematical cognition studies how we remember and use mathematical knowledge. Consider two simple arithmetic problems, such as $2 \times 3 = ?$ and $6 \times 9 = ?$ The left panel of Figure 1-2 shows the time it took some fourth-graders and some college
adults to solve these problems (Campbell & Graham, 1985). There are two important effects: an obvious age difference in which children were slower than adults, and an effect related to the problems, longer RT for $6 \times 9$ than for $2 \times 3$. The right panel shows comparable functions for a range of multiplication problems, from small ones such as $2 \times 3$ to medium (e.g., $7 \times 3$) and large (e.g., $6 \times 9$) problems. For both age groups, the curves increase as the size of the problems increases, commonly known as the problem size effect (e.g., Stazyk, Ashcraft, & Hamann, 1982).

Think of the basic assumption again: Mental processes take time. The implication is that longer time is evidence that some process or subprocess took longer in one case than in the other. What could account for that? Most adults agree that $6 \times 9$ is harder than $2 \times 3$, but that by itself is not very useful; of course a harder decision will take longer to make. But why would $6 \times 9$ be harder? After all, we learned our multiplication facts in grade school. Haven't we had sufficient experience since then to equalize all the basic facts, to make them pretty much the same in difficulty? Apparently not.

So what accounts for the increase in RT? It is unlikely that it takes longer to perceive the numbers in a larger problem—and also unlikely that it takes longer to start reporting the answer once you have it. One possibility is that smaller problems have a memory advantage, perhaps something to do with knowing them better. This might date back to grade school, such as the fact that problems with smaller numbers (from 2 to 4) occur more frequently in grade-school textbooks (Ashcraft & Christy, 1995; Clapp, 1924). Another possibility is that smaller problems are easier to figure out or compute in a variety of ways. Aside from simply remembering that $2 \times 3$ is 6, you could also count up by 2s or 3s easily and rapidly. But counting up by 6s or 9s would take longer and be more error prone (LeFevre et al., 1996).

The point here is not to explain exactly why solving one kind of problem takes longer than another (see Ashcraft, 1995 or Geary, 1994). Instead, the point is to show how we can use time-based measures to address interesting questions about mental processing (for an exposition of how to use more than just the mean response time to explore cognition, see Balota & Yap, 2011).

**ACCURACY** In addition to RT measures, we are often interested in accuracy, broadly defined. The earliest use of accuracy as a measure of cognition was the seminal work by Ebbinghaus, published in 1885. As you will read in Chapter 6, Ebbinghaus compared correct recall of information in a second learning session with recall of the same material during original learning as a way of measuring how much material had been saved in memory.

Figure 1-3 is a classic serial position graph, showing the percentage of items correctly recalled. The x-axis indicates each item's original position in the list. In this experiment (Glanzer & Cunitz, 1966), the list items were shown one at a time, and people had to wait 0, 10, or 30 seconds before they could start reporting the answer once you have it. One possibility is that smaller problems have a memory advantage, perhaps something to do with knowing them better. This might date back to grade school, such as the fact that problems with smaller numbers (from 2 to 4) occur more frequently in grade-school textbooks (Ashcraft & Christy, 1995; Clapp, 1924). Another possibility is that smaller problems are easier to figure out or compute in a variety of ways. Aside from simply remembering that $2 \times 3$ is 6, you could also count up by 2s or 3s easily and rapidly. But counting up by 6s or 9s would take longer and be more error prone (LeFevre et al., 1996).

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**FIGURE 1-3** Serial position curves, showing the decrease in accuracy at the end of the list when 0, 10, or 30 seconds of backward counting intervenes between study and recall. (Based on Glanzer & Cunitz, 1966.)
recall the items. Making it even more difficult, the retention interval was filled with counting backward by threes (see Chapter 5 for details). Here, it is clear that memory was influenced by an item's position in the list—recall was better for early items than for those in the middle. Also notice the big effect that delaying recall with backward counting had at late positions. So, we cannot conclude that early list items always had an advantage over late list items—look how accurately the very last items were recalled when there was no delay. Instead, the overall bowed shape of the graph tells us something complex and diagnostic about memory: Recalling the items from the end of the list may depend on a different kind of memory than recalling the early words, and maybe that memory that can be disrupted by activity-filled delays.

More modern variations on simple list-learning tasks look not only at proportion correct on a list, but also at incorrect responses, such as any recalled words that were not on the studied list (called intrusions). Did the person remember a related word such as apple rather than the word that was studied, pear? Was an item recalled because it resembles the target in some other way, such as remembering G instead of D from a string of letters? Of course, this approach is similar to the Piagetian tradition of examining children's errors in reasoning, such as failure to conserve quantity or number, to examine their cognitive processes.

In more complex situations, accuracy takes on richer connotations. For instance, if we ask people to read and paraphrase a paragraph, we do not score the paraphrase according to verbatim criteria. Instead, we score it based on its meaning, on how well it preserves the ideas and relationships of the original. Preserving the gist is something memory does well (e.g., Neisser, 1981). However, remembering exact, verbatim wording is something we seldom do well, perhaps because this level of detail is often not needed (see Chapter 8).

Section Summary

- Although channel capacity was an early, useful analogy in studying information processing, a more influential analogy was later drawn between humans and computers: that human mental processing might be analogous to the sequence of steps and operations in a computer program. Computers still provide an important tool for theorizing about cognitive processes.
- Measuring information processes, the mental processes of cognition, has relied heavily on time and accuracy measures. Differences in response time (RT) can yield interpretations about the speed or difficulty of mental processes, leading to inferences about cognitive processes and events. Accuracy of performance, whether it measures correct recall of a list or accurate paraphrasing of text, also offers evidence about underlying mental processes.

INFORMATION PROCESSING AND COGNITIVE SCIENCE

Here we present a standard theory of human cognition along with major outlines that are widely accepted.
The Standard Theory

Figure 1-4 illustrates the standard theory of memory (Atkinson & Shiffrin, 1968, 1971), often called the modal model. It is one of the first models to receive widespread acceptance. The basic system includes three components: sensory memory, short-term memory, and long-term memory. At the input end, environmental stimuli enter the system, with each sense modality having its own sensory register or memory. Some of this information is selected and forwarded to short-term memory, a temporary working memory system with several control processes at its disposal. The short-term store can transmit information to and retrieve information from long-term memory. It was also the component responsible for response output, for communicating with the outside world. If consciousness is anywhere in the system, it is here.

Let’s use the multiplication example described earlier to trace the flow of processing through Figure 1-5. You read “2 × 3 = ?” and encode the visual stimulus into a visual sensory register; encoding is the act of taking in information and converting it to a usable mental form. Because you are paying attention, the encoded stimulus is passed to short-term memory (STM). This STM is a working memory system where the information you are aware of is held and manipulated. For this example, the system may search long-term memory (LTM) for the answer. A control process in working memory initiates this search, while others maintain the problem until processing is completed. After the memory search, LTM “sends” the answer, 6, to STM, where the final response is prepared and output, say by speech.

Each step in this sequence consumes some amount of time. By comparing these times, we start to get an idea of the underlying mental processing. As you saw in Figure 1-2, a problem such as 2 × 3 takes about 700 ms to answer, compared to more than 1,000 ms for 6 × 9 (values are taken from Campbell & Graham, 1985). The additional 300 ms might be due to long-term memory retrieval, say because of differences in how easily the problems can be located in LTM.
Although the modal model provided a useful summary, we often needed something more focused to explain our results. A common technique is to conceptualize performance in terms of a process model, a small-scale model that delineated the mental steps involved in a task and made testable predictions. Formally, a process model is a hypothesis about the specific mental processes that take place when a particular task is performed.

**A Process Model**

Although the modal model provided a useful summary, we often needed something more focused to explain our results. A common technique is to conceptualize performance in terms of a process model, a small-scale model that delineated the mental steps involved in a task and made testable predictions. Formally, a **process model** is a hypothesis about the specific mental processes that take place when a particular task is performed.

**A PROCESS MODEL FOR LEXICAL DECISION** A task that is often used in research in cognitive psychology to explore process models is the **lexical decision task**, a timed task in which people decide whether letter strings are or are not English words (see Meyer, Schvaneveldt, & Ruddy, 1975; this task and representative results are discussed further in Chapter 7). In this task people are shown a series of letter strings. The task is to decide on each trial whether they form a word. So, the letter string might be a word, such as MOTOR, or a nonword, such as MANTY. People are asked to respond rapidly but accurately, and response time is the main dependent measure.

Logically, what sequence of events must happen in this task? In the process model shown in Figure 1-5, the first stage involves **encoding**, taking in the visually presented letter string and transferring it to working memory. Working memory polls long-term memory to assess whether the letter string is stored there. Some kind of **search** through long-term memory takes place. The outcome
of the search is returned to working memory and forms the basis for a *decision*, either “yes, it’s a word,” or “no, it’s not.” If the decision is yes, then one set of motor *responses* is prepared and executed, say, pressing the button on the left; the alternative set of responses is prepared and executed for pressing the other button.

**LEXICAL DECISION AND WORD FREQUENCY** Say that our results revealed a relationship between RT and the frequency of the words (word frequency is almost always an influence on RT in lexical decision). We might test words at low, medium, and high levels of frequency in the language: ROBIN occurs infrequently, about twice per million words; MOTOR is of moderate frequency, occurring 56 times per million; and OFFICE is of high frequency, occurring 255 times per million (Kucera & Francis, 1967; the most frequent printed word in English is THE, occurring 69,971 times per million). *It takes longer to judge words of lower frequency than higher-frequency words* (Allen & Madden, 1990; Whaley, 1978). This is the **word frequency effect**. Other variables also affect response times, but word frequency is enough for our example.

For the sake of argument, say that average responses to low-frequency words, such as ROBIN, took 650 ms; those to medium-frequency words, such as MOTOR, took 600 ms; and those to high-frequency words such as OFFICE took 550 ms. What does the process model in Figure 1-5 tell us about such a result? Logically, we would not expect that word encoding would be influenced by frequency, with high-frequency words being easier to see. So, we assume that encoding is unaffected by word frequency and is relatively constant.

Likewise, all three cases will net a successful search. So, we would not expect time differences in the decision stage because the decision is the same (yes). And finally, “yes” responses should all take about the same amount of time for any word. Thus, the encoding, decision, and response stage times are constants, regardless of word frequency.

The only stage left is the search stage. On reflection, this seems likely to be influenced by word frequency. For instance, it could easily be that words used more frequently are stored more strongly in memory, or stored repeatedly (e.g., Logan, 1988); either possibility could yield shorter search times. Thus, we can tentatively conclude that word frequency has an effect on the search stage. Any factor that affects long-term memory search should influence this stage and should produce a time or accuracy difference. Using the numbers from earlier, the search process would take an extra 50 ms for each change from high to medium to low word frequency.

**Revealing Assumptions**

There are several assumptions that are made when doing a process analysis. It is important for you to understand such assumptions to better appreciate how theories and models of cognition are derived. We’ll use the foregoing example as a guide.

The first was the assumption of **sequential stages of processing**. It was assumed that there is a *sequence of stages or processes*, such as those depicted in
Figure 1-5, *that occur on every trial, a set of stages that completely account for mental processing*. Importantly, the order of the stages was treated as fixed on the grounds that each stage provides a result that is used for the next one. More to the point, this assumption implies that one and only one stage can be done at a time, which may not be the case in reality. The influence of the computer analogy is very clear here. Computers have achieved high speeds of operation, but are largely serial processors: They do operations one by one, in a sequential order. And yet there is no *a priori* reason to expect that human cognition has this quality in all situations.

The second assumption is that the stages were **independent and non-overlapping**. That is, *any single stage was assumed to finish its operation before the next stage could begin, and the duration of any single stage had no bearing or influence on the others*. Thus, at the beginning of a trial, encoding starts, completes its operations, and passes its result to the search stage. Then and only then could the search stage begin, followed after its completion by the decision and response stages. With these assumptions, the total time for a trial could be interpreted as the sum of the durations for each stage; because mental processes take time and because each stage is a separate, the total time could be viewed as the sum of the times for all the individual stages. In our earlier example, then, the 50-ms differences between ROBIN, MOTOR, and OFFICE were attributed to the search stage.

**PARALLEL PROCESSING** As research has been done, evidence has accumulated that casts doubt on the assumptions of serial, nonoverlapping stages of processing. Instead, there is some evidence that multiple mental processes can operate *simultaneously*—which is termed **parallel processing**. One example involves typing. Salthouse (1984) did a study of how skilled typists type and how performance changes with age. His data argued for a four-process model; the input stage encoded the to-be-typed material, a parsing stage broke large reading units (words) into separate characters, a translation stage transformed the characters into finger movements, and an execution stage triggered the keystrokes. Significantly, his evidence indicated that these stages operate in parallel: While one letter is typed, another is translated into a finger movement, and the input stage is encoding upcoming letters, even as many as eight characters in advance of the one being typed. Moreover, older adults counteracted the tendency toward slower finger movements by increasing their “look ahead” span at the upcoming letters (see Townsend & Wenger, 2004, for a thorough discussion of serial versus parallel processing).

In moving away from the simpler computer analogy, the cognitive science approach embraced the ideas that cognition needs to be understood with some reference to the brain. An important lesson we have learned from neuroscience is that the brain shows countless ways in which different cognitive components and processes operate simultaneously, in parallel. Furthermore, there is now ample neurological evidence that different regions of the brain are more specialized for different processing tasks, such as encoding, responding, memory retrieval, and controlling the stream of thought (Anderson, Qin, Jung, & Carter, 2007).
A second difficulty with the early assumptions of sequential stages and nonoverlapping processes arose when context effects were taken into account. A simple example of this is the speedup in deciding—that you are faster to decide MOTOR is a word if you have seen MOTOR recently (see “repetition priming” in Chapters 6 and 7). A more compelling demonstration comes from work on lexical ambiguity—the fact that many words have more than one meaning. As an example, Simpson (1981) had people do a modified lexical decision task, judging letter strings such as DUKE or MONEY (or MANTY or ZOOPLE) after they had read a context sentence. When the letter string and sentence were related—for instance, “The vampire was disguised as a handsome count,” followed by DUKE—the lexical decision on DUKE was faster than normal. The reason involved priming (see Chapters 6 and 7), the idea that concepts in memory become activated and hence easier to process. In this case, because the context sentence primed the royalty sense of the word count, the response time to DUKE was speeded up.

This was an issue for earlier cognitive models because there was no mechanism to account for priming. Look again at Figure 1-5; is there any component that allows a context sentence to influence the speed of the processes? No, you need a meaning-based component to keep track of recently activated meanings that would speed up the search process when meanings matched but not when they were unrelated.

Let's look more deeply at the influence of context on cognition. Information that is active in long-term memory, for example, can easily have an effect right now on sensory memory, the input stage for external stimuli. Here is a simple example:

As you read a sentence or paragraph, you begin to develop a feel for its meaning. Often you understand well enough that you can then skim through the rest of the material, possibly reading so rapidly that lower-level processes such as proofreading and noticing typographical errors may not function as accurately as they usually do. Did you see the mistake?

What? Mistake? If you fell for it, you failed to notice the missing b in the word typographical, possibly because you were skimming but probably because the word typographical was expected, predictable based on meaning. You may have even “seen” the missing b in a sense. Why? Because your understanding of the passage, its meaningfulness to you, may have been strong enough that the missing b was supplied by your long-term memory.

We call such influences top-down or conceptually driven processing when existing context or knowledge influences earlier or simpler forms of mental processes. It's one of the recurring themes in cognition (see Table 1-2). For another example, adapted from Reed (1992), read the following sentence:

FINISHED FILES ARE THE RESULT OF YEARS OF SCIENTIFIC STUDY COMBINED WITH THE EXPERIENCE OF MANY YEARS.

Now, read it a second time, counting the number of times the letter F occurs.
If you counted fewer than six, try again—and again, if necessary. Why is this difficult? Because you know that function words such as of carry very little meaning, your perceptual, input processes are prompted to pay attention only to the content words. Ignoring function words, and consequently failing to see the letter F in a word such as OF, is a clear-cut example of conceptually driven processing (for an explanation of the “missing letter effect,” see Greenberg, Healy, Koriat, & Kreiner, 2004).

OTHER ISSUES Another issue involves other, often slower mental processes that cognitive psychology is interested in. Some process models are aimed at accuracy-based investigations—percentage correct or the nature of one’s errors in recall. In a similar vein, many cognitive processes are slower and more complex. As you will learn in Chapters 11 and 12, studies of decision making and problem solving often involve processing that takes much longer than most RT tasks; for example, some cryptarithmetic problems (substitute digits for letters in the problem SEND + MORE; see Chapter 12) can take 15 to 20 minutes! A more meaningful measure of these mental processes involve a verbal report or verbal protocol procedure, in which people verbalize their thoughts as they solve the problems. This type of measure in cognitive research is less widely used than time and accuracy measures, but is important nonetheless (see Ericsson & Simon, 1980 for the usefulness of verbal protocols).

Cognitive Science

Cognitive psychology is now firmly embedded in a larger, multidisciplinary effort, focused on the study of mind. This broader perspective is called cognitive science. As noted earlier, cognitive science draws from, and influences, a variety of disciplines such as computer science, linguistics, and neuroscience, and even such far-flung fields as law and anthropology (e.g., Spellman & Busey, 2010). It is a true study of the mind, in a broad sense, as illustrated in Figure 1-6. In general, cognitive science is the study of thought, using available scientific techniques and including all relevant scientific disciplines for exploring and investigating cognition. One of the strongest contributions to this expanded body of evidence has been the consideration of the neurological bases and processes that underlie thought. We devote all of Chapter 2 to these neurological issues.

Section Summary

- The modal model of memory suggested that mental processing can be understood as a sequence of independent processing stages, such as the sensory, short-term, and long-term memory stages.
- Process models are appropriate for fairly simple, rapid tasks that are measured by response times, such as the lexical decision task.
- There is substantial evidence to suggest that cognition involves parallel processing and is influenced by context; for example, research on skilled typing
shows a high degree of parallel processing. Also, slower, more complex mental processes, such as those in the study of decision making and problem solving, may be studied using verbal protocols.

- Cognitive psychology is better understood as residing within the context of a broader cognitive science. This approach describes cognition as the coordinated, often parallel operation of mental processes within a multicomponent system. The approach is deliberately multidisciplinary, accepting evidence from all the sciences interested in cognition.

**THEMES**

Across the various topics in cognition, there are a number of themes that appear repeatedly. You won’t find sections in this text labeled with them. Instead, they crop up across several areas of cognitive science, in different contexts. If you can read a chapter and identify and discuss the themes that pertain to it, then you probably have a good understanding of the material. Table 1-2 provides a list and brief description of seven important themes that occur throughout the text.
TABLE 1-2 Seven Themes of Cognition

**Attention.** This is an all-important but poorly understood mental process. It is limited in quantity, essential to most processing, but only partially under our control. Is it a mechanism? A limited pool of mental resources? If attention controls mental processing, what controls attention? Why do some processes occur automatically, whereas others require conscious, attentive processing? How does attention make some things more available in mind, and others less so?

**Data-driven processing versus conceptually driven processing.** Some processes rely heavily on information from the environment (data-driven or bottom-up processing). Others rely heavily on our existing knowledge (conceptually driven or top-down processing). Conceptually driven processing can be so powerful that we often make errors, from mistakes in perception up through mistakes in reasoning. But could we function without it?

**Representation.** How is information mentally represented? Can different kinds of knowledge all be formatted in the same mental code, or are there separate codes for the different types of knowledge? How do we use different types of representation together?

**Implicit versus explicit memory.** We have direct and explicit awareness of certain types of memories; you remember the experience of buying this text, for example. But some processes are implicit; they are there but not necessarily with conscious awareness. This raises all sorts of interesting issues about the unconscious and its role in cognition; for instance, how do unconscious processes affect your behavior and thinking?

**Metacognition.** This is our awareness of our own thoughts, cognition, knowledge, and insight into how the system works. It is the awareness that prompts us to write reminders to ourselves to avoid forgetting. How accurate is this awareness and knowledge? Does it sometimes mislead us?

**Brain.** Far more than the cognitive psychology of the past, brain–cognition relationships and questions are a primary concern. It is important to understand how our neural hardware works to produce the kinds of thinking that we are capable of, and what its limitations are.

**Embodyment.** An emerging awareness in cognitive psychology is that the way we think about and represent information reflects the fact that we need to interact physically with the world—it’s called “embodied cognition.” How do we capture the world in our mental life? How do the ways that our bodies interact with the world influence our thinking? How do we incorporate and take into account physical realities in how we think about and process information?

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**Key Terms**

- accuracy (p. 21)
- attention (p. 30)
- behaviorism (p. 12)
- channel capacity (p. 18)
- cognition (p. 6)
- cognitive psychology (p. 5)
- cognitive revolution (p. 2)
- cognitive science (p. 2)
- computer analogy (p. 19)
- conceptually driven processing (p. 27)
- context effects (p. 27)
- control processes (p. 23)
- data-driven processing (p. 30)
- ecological validity (p. 7)
- embodiment (p. 30)
- empiricism (p. 9)
- encoding (p. 23)
- functionalism (p. 11)
- independent and nonoverlapping (p. 26)
- introspection (p. 9)
- lexical decision task (p. 24)
- long-term memory (p. 23)
- memory (p. 6)
- metacognition (p. 30)
- parallel processing (p. 26)
- process model (p. 24)
- reductionism (p. 7)
- response time (RT) (p. 20)
- sensory memory (p. 23)
- sequential stages of processing (p. 25)
- short-term memory (p. 23)
- standard theory (p. 23)
- structuralism (p. 10)
- tabula rasa (p. 9)
- verbal learning (p. 14)
- verbal protocol (p. 28)
- word frequency effect (p. 25)