INTRODUCTION TO THE STUDY OF COGNITION

Before you even arrived at your first class this morning, you had engaged in numerous cognitive acts: recognizing the sound of your alarm clock and the time depicted on its face, saying "good morning" to your roommate, and categorizing your cereal as a breakfast food. You also had to remember the day of the week so that you knew which classes to attend, you decided which clothes to wear, and you paid attention as you crossed the road to get to your first class. Perhaps you even engaged in some creative thinking as you doodled while waiting for class to start. These are all examples of the cognitive processes—the mental processes—at work. Cognition both allows us to operate in the real world, and makes life richer.

Humans are captivated by how the mind works, and this fascination makes its way into popular culture. Stories about cognitive functioning and the connection between the brain and the mind are in newspapers and on TV all the time. Films about memory—whether the loss of memory (*Memento*) or implanted memories (*Total Recall*, *Inception*)—have become top-grossing hits. Books about consciousness (Dennett, *Consciousness Explained*, 1991), intelligence (Herrnstein & Murray, *The Bell Curve*, 1994), language (Pinker, *The Language Instinct*, 1994), memory (Foer, *Moonwalking with Einstein: The Art and Science of Remembering Everything*, 2011), and the relation between talent, practice, and success (Gladwell, *Outliers: The Story of Success*, 2011) were bestsellers. Articles in popular magazines discuss insight in problem solving (Lehrer, "The Eureka Hunt," 2008) and creativity in business (Gladwell, "Creation Myth," 2011). The appeal of the mind holds even for scientists: Since 2001, psychological topics related to cognition or neurocognition have made the cover story of *Scientific American* magazine numerous times. The discipline of cognitive psychology has historically encompassed the study of the cognitive or mental processes, and provides the research upon which so many popular films and bestselling books are based. However, more recently, there has been a broadening of research on cognition to include neuroscience, computer science, linguistics, and philosophy, which has spawned a new discipline: cognitive science.

While much of the research on cognitive processes takes place in laboratories, for the cognitive scientist, life itself is an experiment in cognition: Everywhere one looks, it is possible to see evidence of mental processes at work. Dr. Weisberg's daughter used to be a competitive ice-skater, and every day she would go for practice sessions. The ice would be full of skaters, practicing the jumps, spins, and other moves they would need for their competitive programs. The practice sessions were not purely athletic endeavors; we can dissect what is happening at a cognitive level as each skater practices on a crowded ice rink.

First, *memory* is involved (Chapters 2–4). The main task facing those skaters is to master their material, so that they remember the correct sequence of jumps, glides, spins, and twists in their programs. Sometimes during a competition a skater begins to move in an erratic way, losing synchronization with the music: The skater has temporarily forgotten the program. The pressure of competition often causes skaters to forget or misremember a sequence of movements that was remembered easily many times during practice.

A second cognitive task facing the ice-skaters involves *visual* and *spatial processing* (Chapter 5): Each skater has to know the boundaries of the skating rink and the spatial configuration of their routine within those boundaries. They must also recognize other skaters as people to be avoided and determine their own and others' speed and direction, to determine if any collisions are likely. Sometimes younger skaters run out of space and cannot perform a jump because they are too close to the wall. Such skaters are not able to accurately calculate the space available for the move they hoped to carry out. This occurs much more rarely with experienced skaters, indicating that those visual-processing skills have developed over years of practice. This is one example of the general importance of knowledge in cognitive functioning.

Third, *attention* is involved in our skaters' practicing (Chapter 6). To a spectator, the scene on the ice has a chaotic quality, as all those youngsters zoom this way and that, each seemingly concentrating only on improving his or her own skills. And yet there are very few collisions; the skaters are typically able to practice their routines while avoiding each other. This requires both *selective* attention—each skater pays attention to his or her own skating routine while ignoring the practice routines of others—and *divided* attention (i.e., multitasking). As each skater is attending to his or her own routine, he or she must determine where other skaters are headed, so as not to be in the same place at the same time as anyone else. While watching a group of skaters of mixed levels of expertise, one quickly sees that the inexperienced skaters have problems with the multitasking demands of the practice session; they cannot concentrate on practicing their programs while at the same time attending to and avoiding the other skaters. The more-experienced skaters, in contrast, are able to avoid collisions while at the same time working on a jump or spin. So one of the consequences of the development of skill is an increase in the ability to multitask. Another way to put this is to say that the knowledge of the experienced skaters is useful in dealing with the attentional demands of the practice session.

Additional cognitive skills can also be seen in the skaters' practice sessions. Some-times, one hears a coach give instruction to a skater: "Do you remember how crisply Jane does that tricky footwork at the end of her program? It would be good if you could move like that as you do yours." Presumably, the coach and the skater are able to communicate because both of them can recall Jane's appearance as she skates. They are able to use *imagery* (Chapter 7) to remember how Jane looked as she did her footwork. The coach can use the memory of how Jane looked as the basis for judging the quality of the skater's footwork, and the skater can use her memory of Jane's performance as the basis for her own attempt to do the footwork.

Other cognitive skills necessary for optimum ice-skating performance are the *acquisition and use of concepts* (Chapter 8) and *language processing* (Chapters 9 and 10). A

coach may revise a routine by saying, "I'd like you to insert a Biellmann spin here—it's a layback where you pull your free leg over your head from behind." This example makes it evident that language is an important vehicle through which we *acquire concepts*. The skater will recognize a layback and use the coach's elaboration to understand what must be added to produce a Biellmann spin. In so doing, our hypothetical skater has just acquired a new concept. Also, the skaters' coaches constantly monitor the skaters' performance on the ice. One may hear a coach call out, "Keep that free leg up" while the skater spins, and one sees an immediate change in the posture of the skater. The skater processes the coach's linguistic message and adjusts his or her movements accordingly.

Finally, sometimes a coach and skater will change the routine during the practice session. The coach might decide that something more is needed in the way of jumps, for example, or that the choreography needs refinement. Or the skater might ask for some addition to the program, perhaps to make it more challenging. In these examples, the coach or skater has *made a decision under uncertainty* concerning the structure of the program (Chapter 11). Neither the coach nor skater is certain that the proposed changes will be helpful, but they have weighed the available information and decided that it would be beneficial to make a change. When changing the program, the coach and skater have identified *problems to solve* (Chapter 12) and *creative thinking* plays a role in producing changes in the program (Chapter 13).

These examples are by no means extraordinary. Surely each of us could compile, from any randomly selected day, a long list of phenomena in which cognitive processes are centrally involved: seeing a friend today, and picking up the thread of a conversation begun yesterday; using directions acquired online to drive to a new restaurant; being impressed with the creativity of a new song produced by your favorite group. Cognitive processes are at the core of everything we do.

In the past 30 years there has been an explosion in the study of human mental processes, and the momentum shows no signs of slowing down (Robins, Gosling, & Craik, 1999). New developments in the study of cognition have come from many disciplines, and are now best encompassed under the general term *cognitive science*. First, many areas which researchers had in the past studied only peripherally, if at all, such as imagery, language processing, and creative thinking, have come under investigation and have begun to yield their secrets. Second, in many areas, interdisciplinary cross-fertilization has occurred. Cognitive psychologists and neuroscientists regularly collaborate in the study of the relationship between the brain and cognitive processes, to determine the specific cognitive skills lost when a patient suffers a stroke or accident, or to discover, for example, which parts of the brain are most active when someone learns or recalls information. Those studies have increased our understanding of both normal and abnormal neurocognitive functioning. Linguists, cognitive psychologists, and computer scientists have made advances in our understanding of language processes. Philosophers of mind contribute to the study of cognition by clarifying the concepts and theoretical issues within cognitive psychology, including issues related to consciousness and the relation of mind and brain. Third, cognitive scientists have developed new ways of analyzing how we learn, organize information, and carry out cognitive tasks, most notably the computer-based information-processing perspective.

WHY DO WE NEED TO STUDY COGNITION SCIENTIFICALLY?

A psychologist once remarked that being considered an expert in the field of psychology is difficult because since everyone has psychological states, everyone thinks that they know everything there is to know about psychology. When students are introduced to the scientific study of cognition, including much new terminology and numerous new concepts, they sometimes wonder why it is necessary to study cognition scientifically. Don't we all know how memory functions, since we each use our memory all the time? Don't we know about attention, from our own experiences attending to events in the environment? We all possess what we could call a commonsense cognitive psychology. Why do we need to learn all this jargon to describe and explain phenomena with which we are already familiar?

The scientific study of cognition is of value is because, contrary to what laypeople believe, they do not know very much about their own cognitive processes. Nisbett and Wilson (1977) found that humans often are extremely bad at giving accurate explanations for their own behavior. A recent bestseller, *Blink*, begins with an example of art-history experts knowing that a supposedly ancient Greek sculpture is a fake, but even the experts could not explain how or why they could detect the fraud (Gladwell, 2005). Thus, even experts in a field cannot discern the processes that underlie their cognitive abilities.

In many places in this book, we discuss research findings that are surprising or counterintuitive. The dangers of texting while driving are well known, and 39 states have banned the practice (Governors Highway Safety Association, n.d.). However, one example of a nearly universal lack of knowledge about cognitive processes is seen in recent legislation in many states banning the use of hand-held cell phones while driving. Such laws seem totally reasonable: Statistics have shown that using a cell phone while driving increases the risk of accidents, and most people assume that the dangerous aspect of cell-phone use is taking one hand off the steering wheel to hold and dial the phone. Legislators then enact laws banning *hand-held* cell phones. However, experimental studies of people driving in a simulated vehicle while talking on a cell phone have found that hands-free cell phones are just as dangerous as hand-held phones (Strayer, Drews, & Crouch, 2006). Driving while talking on a cell phone—hands-on *or* hands-free—is as dangerous as driving drunk (Strayer et al., 2006; these findings are discussed further in Chapter 6), and increases the risk of a collision fourfold (Redelmeier and Tibshirani, 1997). The problem with talking while on a cell phone is not that your hands are occupied—it is that your *mind* is.

Only 10 states in the United States have passed laws prohibiting cell phones while driving for all drivers, but not a single state bans hands-free phones (as of 2012; http://www.ghsa.org/html/stateinfo/laws/cellphone_laws.html). That means that no state has a policy that is consistent with the research findings (several additional states ban all cell phone use by those under 18 only). The legislators' lack of knowledge about and/or understanding of the cognitive issues underlying cell-phone use could have tragic consequences (Redelmeier & Tibshirani, 1997). This real-life example illustrates why we have to study cognition scientifically; although we each possess the cognitive processes and use them all the time, in actuality most of us do not know very much about the finer points of how they work.

OUTLINE OF CHAPTER 1

This chapter has several purposes. We first examine two uses of the term *cognitive psychology*, to set the stage for discussion of the development of modern cognitive science over the past 150 years, culminating in the recent ascendance of cognitive psychology as a major area within contemporary psychology. Many disciplines contributed to what has been called "the Cognitive Revolution" in the 1950s and 1960s, in which the study of mental processes supplanted behaviorism, which had been opposed to the study of consciousness and mental events. As part of our discussion of the cognitive revolution, we will consider the question of how cognitive scientists can study mental processes, which cannot be seen, and which may not be accessible to us at a conscious level.

As we have already noted, the modern study of cognition is made up of many different domains of academic inquiry, ranging from traditional research in psychology, to modern techniques for the study of brain and behavior, as well as theories and methods from areas outside psychology, such as linguistics and computer science. The final major portion of the chapter provides a more detailed introduction to how those disciplines have come together in the contemporary study of cognition.

COGNITIVE PSYCHOLOGY: A SUBJECT MATTER AND A POINT OF VIEW

The term *cognitive psychology* has two uses: It describes a subject matter, and it also describes a point of view or philosophy concerning how one studies that subject matter. The *subject matter* of cognitive psychology is the *mental processes*. These include memory; perceptual processes, such as pattern recognition (e.g., recognition of objects, words, sounds, etc.), attention, and imagery; language, including comprehension and production, and related phenomena, such as conceptual knowledge; and the class of activities traditionally called thinking, or the "higher mental processes," including problem solving and creativity, and logical reasoning and decision making. *Cognitive psychology as a point of view*, or a scientific philosophy, refers to a set of beliefs concerning how those topics are to be studied (e.g., Neisser, 1967). According to the cognitive perspective, understanding behavior—such as remembering your mother's birthday, solving a math problem, or reading words on a page—requires that we analyze the mental processes that underlie that behavior. This perspective can be contrasted with behaviorism, which was based on the belief that behavior could be understood by determining the external stimulus conditions that brought it about, and not worrying about internal mental processes.

Studying Hidden Processes

Accepting the cognitive point of view raises a difficult question: How can one study cognitive or mental processes, which occur internally and therefore cannot be examined directly? Students often propose a simple method for studying internal processes: Have the person report on what he or she is thinking. That is, perhaps we can use *subjective reports* as the basis for studying hidden processes. This is a reasonable suggestion,

but there is a basic difficulty with subjective reports. Suppose I tell you that right now I am imagining a dollar bill. How can you tell if my report is accurate? I may be lying about what I am thinking, or perhaps I am mistaken (and am really thinking about the candy bar I'd like to buy with that dollar). The fact that subjective reports cannot be *verified*—that is, the fact that we cannot tell whether they are accurate—means that they cannot be used as evidence for internal processes; other types of evidence must be found. Instead of subjective reports, we need objective data.

The question of whether and how one can study mental phenomena—which cannot be seen directly—had been a point of disagreement among psychologists for 100 years, until the advent of the cognitive revolution. We discuss this question in detail later in the chapter, after we place it in historical context. In our view, the cognitive scientist's study of hidden mental processes is no different than the activities carried out by scientists in many disciplines (e.g., biology, chemistry, physics) or, indeed, the activities carried out by ordinary folks in our understanding of events in the world. We deal with hidden processes all the time.

PSYCHOLOGY AS A SCIENCE

Wundt and Introspection

The beginning of psychology as a science is traced to Wilhelm Wundt's establishment of the first psychological laboratory in 1879, in Germany (Boring, 1953). Until that point, the sorts of phenomena now studied by psychologists were investigated by researchers in physics and biology, as well as in philosophy. Students from all over the world came to study with Wundt, and many of those new psychologists returned to their home countries and established their own laboratories. Wundt and his followers could be considered the first cognitive psychologists, because they were interested in several mind-related topics, including consciousness. However, there were a number of important differences between Wundt's psychology and modern cognitive psychology.

First, the specific topics of Wundt's research differ from the topics of contemporary cognitive-psychology experiments. Wundt and his followers were interested in determining the basic *elements* or *structure* of conscious experiences, in the same way that chemists of that era were attempting to determine the basic elements of chemical compounds. While many modern cognitive scientists are also interested in the study of consciousness, the subject matter of modern cognitive science encompasses many other phenomena, such as those outlined above. Second, the methods of studying cognitive processes have also changed significantly over the 125-plus years since Wundt, his students, and colleagues began their work. In those days, it was believed that one could study consciousness by training observers to analyze their own experiences into their basic components and to report on them. This method was called *introspection*, which means *looking inside*. An example of a task used in introspectionist investigations of consciousness would be to present the names of two animals, say *dog* and *cow*, and ask the participant to judge which animal is larger in size, and then to provide an introspective report of what occurred between the presentation of the task and the production of a response.

Introspection required more than a casual report, however. The observer had to be trained to avoid *the stimulus error*, which was reporting the unanalyzed conscious experience in terms of commonsense, everyday language, rather than analyzing it into more basic components (Mandler & Mandler, 1964). For example, if, after making the judgment that a cow is larger than a dog, the observer reported, "I imagined a cow standing next to a dog, and mentally compared their heights and lengths," that would be an example of the stimulus error. If the observer correctly engaged in introspection, he would convey more "raw" perceptual impressions, and might say something like: "An image of a large nonmoving bulk and smaller one. . . . A feeling of movement. . . . An image of one end of the small bulk, and then the other. . . . A verbal image 'the cow is bigger.' . . . Production of the verbal response."

The "Imageless Thought" Controversy

When introspection was applied to the study of conscious experience, several difficulties arose. First, the results obtained in different laboratories were not consistent. Some investigators, such as Titchener, one of Wundt's earliest students, insisted that virtually all thought relied on imagery, based on the results of his introspection studies, while others reported that their studies showed that thinking could also be carried out *without* imagery (see discussion in Mandler & Mandler, 1964). Those conflicting findings raised questions about the usefulness of introspection, since seemingly identical investigations had produced opposite results. Whether "imageless thought" could occur became a major controversy, and resulted in many psychologists becoming dissatisfied both with the focus of psychology being the "mind," and with the use of introspection as a scientific technique. One outcome of the imageless thought debate was the rise of a group of psychologists who wanted psychology to be a science of *behavior*—the behaviorists (Leahey, 1992).

Behaviorism and the Question of Consciousness

The strongest reaction against attempts to use introspection to analyze the structure of conscious experience came from John Watson (1913), the founder of American behaviorism. Watson wrote forcefully against the value of studying conscious experiences, because of the already-noted problems with verification of introspective reports. He proposed that psychology should follow the example of the established sciences, such as physics and chemistry, whose methods were only concerned with phenomena that were observable and directly measurable. When physicists studied the effects of gravity on falling objects, for example, they measured the height of the fall, weight of the objects, and time to fall. In his behaviorist manifesto—"Psychology as the Behaviorist Views It"—Watson (1913) advocated a similar perspective for psychology: "psychology must . . . never use the terms consciousness, mental states, mind, content, introspectively verifiable, imagery and the like . . ." (pp. 166–167) because the scientist cannot directly observe those things. Psychologists should study only observable events: environmental stimuli and behavior.

Watson promoted the now-familiar stimulus–response (S–R) approach to the analysis of behavior. He believed that there was a law-like relationship between

environmental stimuli and behavioral responses, with every behavioral act being brought about by one measurable stimulus, and each stimulus producing only one response. Therefore, it should be possible to analyze behavior to such an exact degree that, for any response that occurred, the psychologist could know exactly what the stimulus had been; and if a given specific stimulus occurred, one could say exactly what the response would be. In Watson's view, the main task of psychology was to be able to predict and control behavior through presentation of environmental stimuli. One should not try to measure hypothesized internal psychological states, which might not even exist. Furthermore, Watson proposed that by strictly controlling the environment in which an organism grew up, he could determine the trajectory of a person's life:

> Give me a dozen healthy infants, well-formed, and my own specified world to bring them up in and I'll guarantee to take any one at random and train him to become any type of specialist I might select—doctor, lawyer, artist, merchant-chief and, yes, even beggar-man and thief, regardless of his talents, penchants, tendencies, abilities, vocations, and race of his ancestors. (Watson, 1930, p. 104)

Thus, Watson adopted a radical stance to the study of psychology, claiming that there are no mental processes that play any causal role in a behavioral chain.

The second major advocate of behaviorism was B. F. Skinner, who championed what is known as *operant conditioning*. Based on the ideas of Thorndike (1898, 1911), Skinner proposed that the consequences of behaviors—reinforcements and punishments—would determine whether those behaviors increased in frequency and intensity, or whether they decreased (Skinner, 1938). If a behavior was reinforced, it would become more likely to happen in the future; if punished, less likely. Like his predecessor Watson, Skinner rejected mentalistic explanations of behavior as unscientific. Skinner's principles of operant conditioning were derived from maze running and key pressing in animals. The book *Verbal Behavior* (1957) marked his attempt to apply conditioning principles to complex human behaviors, such as the development of language in a child. In Skinner's view, children acquire a language by mimicking what they have heard and by being reinforced for their utterances (e.g., by delighted parents or by more quickly receiving what they want). Thus, language learning is brought about by the same learning mechanisms that are evident in lower-level animals; there is no need in a scientific theory for mentalistic or cognitive explanations of any skill or behavior. As we shall see, the inability of the behavioristic framework to account for complex phenomena, such as language, problem solving, and creativity, would eventually lead to the paradigm's loss of favor (a paradigm is a theoretical framework that helps to guide research within a topic area).

TOWARD A NEW COGNITIVE PSYCHOLOGY

The development of behaviorism resulted in reduced interest in the study of cognition in the first half of the 20th century, particularly in America. However, even at this time there was still interest in cognitive processes among some psychologists and philosophers. As one example, William James, a philosopher with interests in the

study of behavior, presented discussions of complex human psychological phenomena. Second, there were a number of centers of psychological research in Europe in which the full-fledged study of human cognitive processes went on. Thus, this work was available in books and journal articles when other psychologists began to become interested once again in cognition. Finally, developments in several areas outside of psychology, including linguistics and computer science, provided psychologists with new ways of analyzing complex psychological phenomena. Those new perspectives greatly stimulated the development of modern cognitive science.

Cognitive Stirrings in America

William James was an American philosopher who wrote a two-volume survey of psychology, *Principles of Psychology* (1890/1950), in which he addressed many issues that were to become important to modern cognitive psychologists (e.g., Estes, 1990). James provided detailed descriptions of his own *phenomenological* experiences, that is, his personal experiences of psychological phenomena. For example, he described the experience of selectively attending to some event or object at the expense of paying attention to others. Attention was "the taking possession of the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. . . . It implies withdrawal from some thing in order to deal effectively with others" (1890, pp. 403–404). James also described his phenomenological experiences of remembering, and presented descriptions of experiences, which led him to distinguish between *primary* and *secondary* memory (approximately corresponding to the distinction between short- and long-term memory that has been studied extensively by today's cognitive psychologists). Both these areas—attention and the question of the structure of memory—became foci of research in modern cognitive psychology.

It should be noted that James's use of phenomenological analysis is not the same as the introspection carried out by Wundt and his followers. James was not interested in analyzing his conscious experience into its component parts, but, rather, attempted to present a detailed and accurate description of the conscious experiences themselves. This work was important because James discussed complex cognitive phenomena, such as shifts in attention or remembering, not merely simple sensory experiences. James is also considered to be a *functionalist*, because his explanations often emphasized the purpose or function of psychological and mental phenomena (Leahey, 1992), and how they allow people to adapt to their environment: "Man, whatever else he may be, is primarily a practical being, whose mind is given him to aid in adapting him to this world's life" (James, 1898).

The Study of Cognition in Europe

A number of European investigators were engaged in research on topics within the realm of cognitive psychology, not only during the late 1800s, but even when behaviorism dominated American psychology during the first half of the 20th century.

Ebbinghaus and the Study of Memory
Hermann Ebbinghaus was a German psychologist who is credited with bringing scientific techniques to the study of memory. He insisted on using material that was

not associated with any previously learned information, and thus devised *nonsense syllables*, meaningless consonant-vowel-consonant strings such as REZ and TOQ, to determine how many repetitions he needed to learn new lists of items, and how long he could retain the information after having learned it. He used the method of rote rehearsal—simply repeating the items again and again. With this method, he could objectively measure the amount of time needed to memorize a list. However, from a modern perspective, Ebbinghaus's analysis was lacking, as he did not make any inferences about the internal processes that accomplished remembering. Ebbinghaus also was the first researcher to systematically study forgetting. He retested his memory for the lists he had learned after 1, or 2, or 30 days. In this way, he was able to measure the amount of memory loss (or forgetting) as a function of time (Ebbinghaus, 1885/1964).

Ebbinghaus's work on memory had a great influence on the study of cognition many years after his death. Through the middle of the 20th century, a number of American psychologists who wanted to study human functioning without having to appeal to mental processes used Ebbinghaus's (1885/1964) research as their model, because of his rigorous scientific methods (see, for example, chapters in Cofer & Musgrave, 1961, 1963). Although Ebbinghaus's approach ignored the study of underlying mental processes, his work did demonstrate that one could study memory in the psychological laboratory. Ebbinghaus's research and that of those who followed him brought the study of memory to the attention of many experimental psychologists.

Donders's Subtractive Method

F. C. Donders, a researcher from Holland who was a contemporary of Wundt, developed techniques for *mental chronometry*—the measurement of the time to carry out basic operations within an act of cognition (Donders, 1868/1969). For example, Donders might seat a person in front of a light, and tell him to press a button whenever the light came on. Imagine that it takes, on average, 250 milliseconds (equal to $^1/_4$ sec.) for a person to *detect* the light and *respond* to it. The *reaction time* (RT) to the light is thus 250 milliseconds (msec). In another condition, the person would be told to press a button on the left if light A came on, but a button on the right if light B came on. This takes (hypothetically), on average, 400 msec. The second task requires *detection* of the light, *discrimination* of whether light A or light B has turned on, and the *response*. Let us say that the experimenter wants to determine the length of the discrimination stage in the second task. The *subtractive method* allows one to do that. The second task takes 400 msec; the first task takes 250 msec. The only difference between the tasks is *discrimination*, so that process must require the additional 150 msec. Thus, we have *decomposed* those tasks into their parts and measured the time needed to carry out one of them. (Note the similarity to Wundt's attempts to decompose conscious cognitive phenomena.)

The subtractive method provided a way of measuring mental processing that was based on objective measurement—that is, on the time needed to carry out various tasks. The subtractive method became important in modern cognitive psychology in the 1960s, when Sternberg (1966) used reaction time to measure how we recall information from memory. The logic of Donders's subtractive method has influenced the design of many cognitive psychology experiments, and RT is now a common

measure used by many researchers. The subtraction method also plays an important role in neurocognitive research, as we shall see shortly.

Gestalt Psychology: Perception and Problem Solving

The Gestalt psychologists, who worked in Germany and then in the United States, mainly during the first half of the 20th century, carried out investigations of several areas of human cognition. They were interested in the study of perceptual situations in which the organization or form of the whole situation produced an experience that could not be anticipated from analysis of the elements or parts that made it up. The term *Gestalt*, German for *form*, has entered our ordinary vocabularies, as well as being a part of the technical vocabulary of psychology. An example of a situation of interest to the Gestalt psychologists is presented in Figure 1.1a: The perceptual experience of a triangle is accomplished by focusing on the organization, or Gestalt, of the elements (rather than the individual parts themselves). Thus, we impose an organization on the three Pac-Man–type figures by mentally filling in the lines between them.

The Gestalt psychologists also investigated reversible figures, such as the one shown in Figure 1.1b. When one studies such figures, it is common to see a sudden reversal, from a vase to two faces in profile (and back to a vase). Thus, a reversible figure is *one* stimulus that produces *two* responses. The existence of such figures disproves the behaviorists' belief, proposed by Watson (1913), that it would be possible to specify precisely a *single* response to any individual stimulus. Cognitive psychologists believe that the ambiguous faces/vase picture can produce two different responses because the person can cognitively analyze it in two different ways. Reversible figures are very simple illustrations of the necessity to analyze internal processes in order to understand observable behavior (e.g., the person first reports seeing a vase, then the two faces).

The Gestalt psychologists also carried out research on more complex human cognition, most notably problem solving and creative thinking (e.g., Duncker, 1945; Maier, 1930; Wertheimer, 1923, 1959). They believed that complex thought processes could not be broken down into simple elementary processes, and that the performance of

(a)   (b)
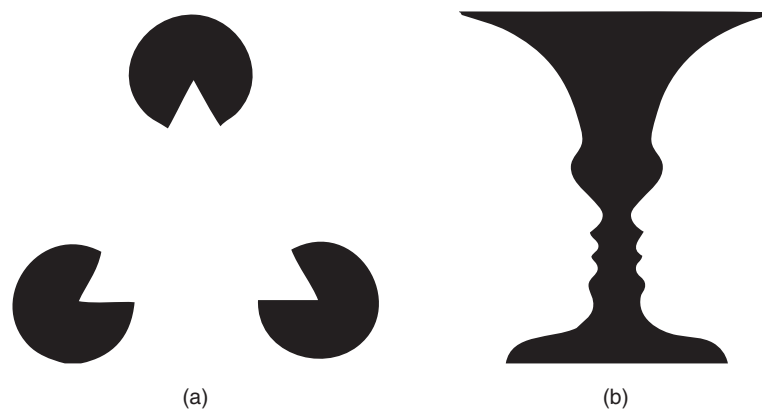
Figure 1.1   Gestalt demonstration: These figures illustrate how the perceiver is involved in the interpretation of a stimulus. (a) Kanizsa triangle. (b) Reversible figure: Vase/faces.

lower animals (e.g., pigeons, rats) on simplified versions of problem solving tasks would not shed light on human cognitive abilities. The Gestalt psychologists also emphasized the method of collecting *verbal protocols*, where participants were instructed to verbalize their thoughts, providing a stream-of-consciousness verbalization as they solved problems. Verbal protocols were different from the reports obtained by Wundt and Titchener during introspection, since the participants were not trying to break their conscious experiences into basic elements. Research has demonstrated that protocols can provide a useful record of thought processes that can be verbalized (Ericsson & Simon, 1980) and used as a supplement to other means of assessing cognitive activity.

Bartlett's Analysis of Memory

Sir Frederick Bartlett (1932, 1958), an English psychologist, carried out a long series of investigations of memory during the first half of the 20th century. Bartlett proposed that remembering information depends on more than the passive "stamping in" of the information in the person's memory. He suggested, instead, that people are *active* participants in cognitive processing and that they use their knowledge to interpret and remember information. Bartlett's view thus contrasted with Ebbinghaus's (1885/1964) adherence to rote rehearsal to memorize meaningless nonsense syllables. Bartlett theorized that much of what people remember consists of their interpretations of the material, rather than the material itself, and thus they actively *construct* their memory. He demonstrated that the person's interpretation of the material that is to be recalled plays a crucial role in remembering. When memorizing a verbal passage, for example, we most likely use a *schema*—a cognitive structure that helps us organize and make sense of the new material. Please perform the sample experiment in Box 1.1 before reading further.

BOX 1.1 BRANSFORD AND JOHNSON (1972) PASSAGE

Have a paper and pencil ready before going further. Please read the following passage once, at normal speed, and then try to recall it on paper.

The procedure is actually quite simple. First you arrange things into different groups depending on their makeup. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that is the next step; otherwise you are pretty well set. It is better to do too few things at once than too many. Remember mistakes can be expensive. At first the whole procedure will seem quite complicated. Soon, however, it will become just another fact of life.

Write the passage as well as you can from memory. After you do that, go on reading the text.

Now read the passage again, with the hint that the passage is about *washing clothes*, and again try to write as much as you can from memory.

The passage in Box 1.1 is so designed that it is almost impossible to understand or to recall fully without being told what it is about. Bransford and Johnson (1972) asked participants to study the *washing clothes* passage and others like it for later recall. Half the people were given the title "Washing Clothes," to make the passage

easier to understand. Presentation of the title *before* the passage made it much more comprehensible and also increased recall greatly. Providing the title *after* the passage did not facilitate either comprehension or recall. These results indicate that recall of the passage depended on activation of a schema (e.g., your knowledge about washing clothes), which improved comprehension of the passage as it was being read. Providing a framework for comprehension after the fact did not help. Bransford and Johnson's results are strongly supportive of Bartlett's view that one's interpretation of events plays a crucial role in memory for those events. Bartlett's emphasis on active processing of information became very important in psychologists' explanations of many cognitive phenomena, as we will see in Chapter 3.

Toward a New Cognitive Psychology: Summary

We have just seen that there were researchers—James, Donders, the Gestalt psychologists, Bartlett—interested in the study of cognition even when most American psychologists accepted the behaviorist viewpoint. The work of those individuals provided a foundation for the development of the cognitive revolution in psychology around the middle of the 20th century. Critical developments in psychology, linguistics, and computer science helped propel the study of cognitive processes to the forefront, as we will see in the next section.

THE COGNITIVE REVOLUTION

Despite European openness to the study of mental structures and processes, resistance toward mentalistic explanations of psychological phenomena remained high among many psychologists in the United States until the middle of the 20th century. At that time, dissatisfaction with strict behaviorism among psychologists, as well as developments in several disciplines outside psychology—most notably linguistics and computer science (Kendler, 1987)—culminated in a new orientation to the study of psychology, which Simon (1980) referred to as a "revolution," now known as the *cognitive revolution*.

Revolt Against Behaviorism

Many psychologists interested in understanding complex behaviors, such as language, memory, and problem solving, began to view strict behaviorism as inadequate to the task. Even from within the ranks of behaviorists, some suggested that mentalistic concepts and analyses of what was taking place internal to the learner might be critical in explanations of human (and even animal) behavior. For example, E. C. Tolman (1932) studied the behavior of rats in a maze similar to the one depicted in Figure 1.2. He first allowed the rats to explore the maze, then he put them in the Start Box, and reinforced them with food for running down the straight pathway (Path 1) to the Goal Box. Once they had learned that task, he blocked the pathway at Block Point A. The rats typically then avoided Block A by using the triangular Path 2. However,
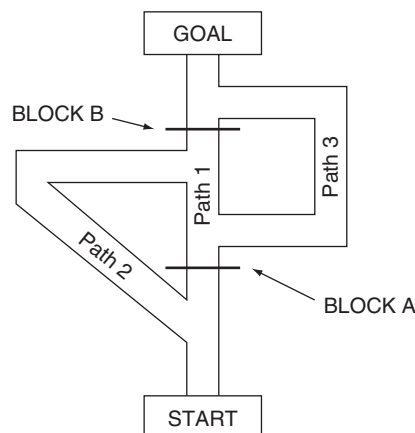
Figure 1.2 Tolman maze.

if Block Point B is used, only Path 3 will get the rats to the Goal Box (and to food). When they encountered Block B, the rats would run back and take Path 3 (ignoring Path 2). Behaviorism predicted that the rats' responses should be dependent only on the strength of pathway/reinforcement contingencies, but they were not. The rats chose pathways based on the most efficient way to the goal box. Tolman proposed that the only way to explain those results was to hypothesize that the rats had developed a "cognitive map" during their exploration of the maze, and that the internal map was being used to guide their behavior.

Given what we now know about how animals efficiently forage in the wild for food (MacArthur and Pianka, 1966) and find their way home after traveling long distances (Gould & Gould, 2012), the notion of a cognitive map does not seem revolutionary. However, during Tolman's time, it was a significant change in psychological theorizing, because it postulated a *mental representation*—an *internal* version of the environment—that played a critical role in an organism's response to a stimulus (such as the maze). Tolman and others working within a behaviorist framework (e.g., Woodworth, 1938) helped turn the tide to what became known as S-O-R psychology (stimulus-organism-response). In this "cognitive" elaboration of behaviorism, any law-like connections between environmental stimuli and behavioral responses are assumed to be filtered through the knowledge and habits of the organism. The door was opened in the United States for cognitive processing to become part of scientific inquiry.

Using Behavior to Infer Inner States
Behaviorism had what one could call two negative effects on early psychology: (1) a rejection of the study of consciousness and related mental phenomena, which had been the subject matter of interest to many of the founders of psychology; and (2) a shift away from the study of complex human activities, such as thinking, problem solving, and decision making. However, behaviorism also made a positive contribution to psychology through its emphasis on tying all concepts to observable behaviors. Although cognitive psychology considers the study of mental processes to be the key focus of

scientific inquiry, it does use the behavior of people and animals as the basis for theorizing about cognitive processes. For example, if we are interested in studying whether a person bilingual in French and English has equal facility with both languages, we could ask her to read aloud identical words in either French or English, and measure her response time. If she was faster reading the French words, we could conclude that she was more facile with that language. Thus, her behavior in the word-reading task would shed light on her underlying cognitive processes and skills. We could also measure brain activity in areas known to be connected to language and word recognition, to determine if there is a difference in neural activity as our person reads French versus English words.

Most of the research detailed in this book uses behavioral responses as the basis for making inferences about underlying cognitive processes, and to develop theoretical models of cognitive abilities. A quick perusal of the graphs depicted within the book also shows that reaction time (RT) is a popular way to analyze the time sequence, and processing constraints, of cognitive processes.

Chomsky and Linguistics

The linguist Noam Chomsky became a major voice in the early years of the cognitive revolution. His work was important in two ways. First, he published a strongly negative review of Skinner's book *Verbal Behavior* (1957), in which Skinner had attempted to explain language acquisition using classical and operant conditioning principles (Chomsky, 1959). Within that review, Chomsky managed to present a negative critique of the whole enterprise of attempting to explain complex human behavior on the basis of conditioning. Second, he offered a view of the structure of language and of language development that had important implications for psychology. Chomsky argued that, contrary to Skinner, language development is based on innate language-specific principles, not on simple learning mechanisms that apply equally to a rat's learning how to run through a maze and a pigeon's learning how to peck a key to receive food. Furthermore, he considered those innate language abilities to be human-specific, since we are the only known species that possesses language.

In Chomsky's view, the most impressive aspect of human language was its creativity: We almost never say exactly the same sentence twice. Furthermore, we have no trouble producing new utterances as needed, and understanding the new sentences that others produce. As an example of the novelty in language, consider the following sentence: *George Washington was the King of England*. It is highly unlikely that anyone has ever spoken or written that sentence before, but it is a perfectly grammatical sentence, and you were able to read it and understand it (while recognizing it as false). Chomsky proposed that the ability to produce an unlimited number of grammatical sentences is due to human language being a rule-governed system; that is, we all learned a system of rules when we learned to talk. Furthermore, in discussing how children learn to speak, Chomsky concluded that the linguistic input to the developing child—the language that the child hears around her—is too simple to account for the complexity of the young child's speech. That is, an average 3-year-old's sentence-production abilities are too advanced to be accounted for purely on the basis of what she has heard. This idea has been called the argument of the *Poverty of the Input* (Pinker, 1994): The

linguistic input to the developing child is, by itself, too "poor" to enable language to develop as richly as it does. If the environmental input is not sufficient to support the normal language development of children, then, Chomsky argued, nature must provide a language-specific set of guidelines or rules that are activated by hearing speech, and these help a child organize incoming speech.

Chomsky's theorizing had several important effects on psychology. If human language was rule-governed, and could not be understood in terms of conditioning, then many psychologists were led to question the basic assumptions concerning behavioristic explanations of *other* complex behaviors. In addition, since Chomsky's innate language-learning principles are specific to language, he introduced the concept of cognitive *modularity*—the rules for learning and carrying out one skill (in this case, language) are located in a specific *module*, or processing unit, separate from the rules for other skills (such as vision or problem solving; see also Fodor, 1983). To illustrate, learning the grammatical rules of a language does not help someone to develop the mathematical competence necessary to balance a checkbook.
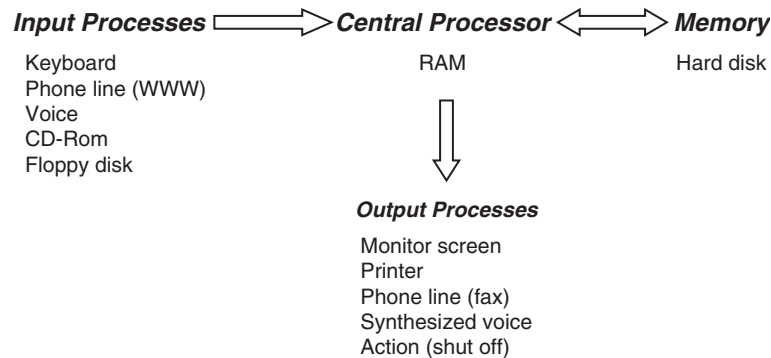
The question of whether cognition depends on specific modules versus general processing mechanisms is one that has stimulated debate in modern cognitive science, and we will have occasion to address it numerous times in later chapters. Chomsky's concept of modularity and his view of language in particular (and cognition in general) as a rule-based system provided much of the basis of the information-processing model of human cognition.

The Computer Metaphor and Information-Processing Models

The invention of computers, and their increasing availability in academic circles in the 1950s and 1960s, had the indirect effect of changing many psychologists' beliefs about mental processes and whether they could be studied objectively. Computers were able to carry out tasks, such as arithmetic and problem solving, that require cognition (i.e., mental processes) when humans carry them out. Computer scientists used terms like *information processing* to describe what happens when a computer carries out a program. Programs specify the series of internal states that a computer undergoes between presentation of some input data and production of some output as it carries out some task, such as adding two numbers. A diagram of the processing components of a typical computer is presented in Figure 1.3. Let us say that the computer is running a program that gives you the phone number of a person whose name you enter using the keyboard. The computer's memory contains a database, listing people by name and phone number. When you type in a name, it is placed in the central processor, where the program uses it as input. The program takes the name and attempts to match it to items within the database in memory. If there is a successful match, the phone number is transferred from memory to the central processor, where it is then produced as output—either as a number on the screen, as printed output, or as spoken output.

Thus, in carrying out this simple task, the computer goes through a series of internal states (e.g., taking in information, scanning memory, transferring information from memory to the central processor, etc.). In theory, at least, those internal states could be specified, as long as you knew the design of the program that was running and the data that the program was using.

Input Processes ⟹ Central Processor ⟺ Memory

Keyboard	RAM	Hard disk
Phone line (WWW)		
Voice		
CD-Rom		
Floppy disk		

⟱

Output Processes

Monitor screen
Printer
Phone line (fax)
Synthesized voice
Action (shut off)

Figure 1.3   Information-processing components of a computer.

These facts led many to believe that we could study and interpret human mental processes as analogous to a computer carrying out a task by running through a program. Researchers in computer science, most notably Alan Newell and Herbert Simon (e.g., Newell, Shaw, & Simon, 1958; Newell & Simon, 1972), proposed that humans could also be described as information-processing devices, similar in some important respects to computers, although obviously made of different sorts of stuff. It is not that cognitive scientists believe that we have silicon chips in our heads; the analogy of the mind as a computer is at a *functional* level, or at the level of the software. Newell and Simon proposed that one should conceive of a human carrying out any task that involved cognition (i.e., thinking) as if he or she were a computer carrying out a program. If human mental processes are similar to the series of internal states produced as a computer carries out a program, then one should be able, in principle, to devise computer programs that mimic or *simulate* human thinking.

The concept of *modularity*, just introduced in the discussion of Chomsky's analysis of language as a cognitive module, is also illustrated in computers. Computers are not general, all-purpose machines. If you buy a new computer, you will be asked what types of software you want—word processing, a graphics package, statistical software, and so on. These will be loaded separately. Likewise, psychologists typically study cognitive skills in isolation from each other; it is assumed that the programmed rules for human mathematical computations are distinct from those for constructing sentences, or for imagining the face of a friend. The modularity seen in computer information-processing leads to the expectation that human cognition might also exhibit modularity. Although there have been challenges to the information-processing approach to cognition (such as parallel distributed processing models, which will be discussed later in this and other chapters), it has proved a useful framework for thinking about how people carry out various cognitive tasks.

Study of Cognition in Humans

Tolman's (1932) research on maze learning in rats, which led to the concept of a cognitive map, was an early attempt to study cognitive phenomena in lower organisms using objective methods. However, many psychologists interested in human cognition felt that Tolman's research was limited in its applicability to more complex cognitive

processes that humans could carry out. To the new generation of cognitive psychologists (e.g., Miller, 1956; Miller, Galanter, & Pribram, 1960), human thinking was more than internal stimuli and responses. One early influential cognitive psychologist was Allan Paivio (e.g., 1971; 2006), a researcher interested in the effects of visual imagery on memory. An example of a study similar to those carried out by Paivio is given in Box 1.2; please carry out the demonstration before reading further.

BOX 1.2 DEMONSTRATION OF MEMORY FOR WORD PAIRS

Please get a pencil and paper before reading further. Below is a list of pairs of words. Each pair is followed by one of two words: REPEAT or IMAGE. If the word pair is followed by REPEAT, then repeat the pair five times to yourself, and then rate how hard it was to pronounce the pair, on a scale from 1 (very easy) to 5 (very hard). Write the rating in the space after the pair. If the word pair is followed by IMAGE, then take about five seconds to form an image of the words in the pair interacting, and then rate how hard it was to do that on a scale of 1 (easy) to 5 (hard). Write that rating in the blank. When you have finished, continue with the "Test for Word Pairs."

		Rating
diamond – coffee	IMAGE	_____
sauce – coin	REPEAT	_____
beggar – world	IMAGE	_____
factory – claw	IMAGE	_____
marriage – window	REPEAT	_____
cattle – stone	REPEAT	_____
money – slipper	IMAGE	_____
gem – hospital	REPEAT	_____
street – gift	IMAGE	_____
hotel – pepper	REPEAT	_____

Test for Word Pairs

Here are the first words from each pair in the top of the box. Without looking at the pairs, try to recall the second word and write it down. Then go back and check whether you recalled more of the words from the *imagery* pairs or the *repetition* pairs.

diamond –

sauce –

beggar –

factory –

marriage –

cattle –

money –

gem –

street –

hotel –

In a series of studies, Paivio (1971) demonstrated that people recalled information more easily when they used imagery as the basis for learning. Chances are that you, too, remembered more words in the imagery pairs than the repetition pairs in the demonstration in Box 1.2. In his research, Paivio first asked people to rate, on a 1–7 scale, how easily they could think of an image for the meaning of many concrete (e.g., *bell*) or abstract (e.g., *independence*) words (Paivio, Yuille, & Madigan, 1968). He then showed that words that had been ranked high in imageability (e.g., *car*) were recalled more easily than words that were low in concreteness (such as *idea*; for a review of many studies, see Paivio, 1971). Paivio proposed that participants could easily form images when they studied concrete words, thereby creating a *dual code*—both visual and verbal—for these words, and thus making them easier to recall. Paivio's research was important because it was an attempt to deal directly with cognitive processes and to use mentalistic concepts—in this case imagery—as a component part of the explanation of complex behavior.

THE COGNITIVE REVOLUTION: SUMMARY

By the early 1960s, many changes had taken place in psychology. There were criticisms raised about the adequacy of S–R analyses of behavior, both from within psychology and from outside. There were also a number of researchers who had embarked on research programs directed toward the understanding of cognitive processes. Several of these programs originated in Europe (e.g., Bartlett, the Gestalt psychologists), but there was also interest in human cognition among U.S. psychologists (e.g., Paivio, 1971) and linguists (Chomsky, 1959, 1965). In addition, the advent of computers provided a concrete example of a physical system that carried out processes that resembled human cognition. This raised the analogy of the mind as a computer, and the possibility that humans and computers were similar at a functional level. These streams of research came together in the 1960s to form the new discipline of cognitive psychology.

THE NEW COGNITIVE PSYCHOLOGY

Publication of the book *Cognitive Psychology*, by Ulric Neisser (1967), was evidence that the new cognitive viewpoint in psychology had become a dominant paradigm within psychological research. This book had several important effects, one of which was giving a name to the new developments. Neisser also used the computer metaphor to organize the presentation of material concerning human functioning. The organization of Neisser's book followed information as it worked its way into the organism, as outlined in Figure 1.4. According to his analysis, information passed through a series of stages, from perceptual processes to memory, from which it could be recalled when needed. Imagine the cognitive processes involved when we meet an old acquaintance, John, on the street. The first stage involves registering the parts or features of the stimulus, for example, the lines, angles, and curves of the stimulus, out of which a
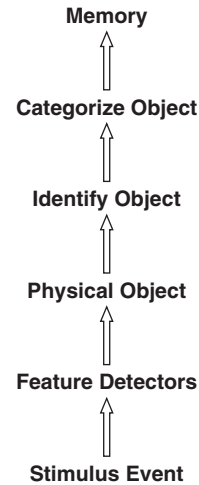
Memory

⇧

Categorize Object

⇧

Identify Object

⇧

Physical Object

⇧

Feature Detectors

⇧

Stimulus Event

Figure 1.4   Information-processing model; bottom-up processing.

representation of John is constructed. The next stage might be recognizing that a visual object has been presented. The object would then be classified as a person, then as our friend John specifically, and finally stored in memory as a recent encounter with John. The information could then be used as needed, for example, as the basis for affirmative answer if someone asked, "Did you see John today?"

The coverage in Neisser's book was most heavily concentrated at the perceptual end of the information-processing sequence, such as pattern recognition and attention. Less than 10% of Neisser's book was concerned with the "higher mental processes," (e.g., memory, concept formation, and problem solving). Neisser acknowledged this lack of balance, and commented that at the time not very much was known about the higher processes. This book, on the other hand, will have about two-thirds of its pages devoted to the higher processes. This is because we have learned much about these topics over the years since Neisser's pioneering book was published. Another change from Neisser's book to the present one is an increase in emphasis on the role of knowledge in even the "lower-level" or perceptual processes. Neisser did discuss the role of knowledge in memory and perception, but we will place much more emphasis on the role of knowledge in all our cognitive functioning. That is why our book begins with memory, as information we have already stored in memory influences even lower-level processes such as perception.

An example of an information-processing model of human cognition that follows a *serial* path—outlining a *series* of stages in processing, as discussed by Neisser—is shown in Figure 1.5. The model deals with the visual processing of letters. The first stage of processing involves analysis of the letter into its important parts, or *features*, which are then used to identify the letter. When recognizing an A, for example, the features activated would be two slanted lines (/ and \) adjoined at the top, and a horizontal line (−). Once the features of the input have been identified, the bundle of features would first be identified as a physical object, and then identified as a specific letter. Finally, the results of this analysis can be stored in memory ("I saw an A").
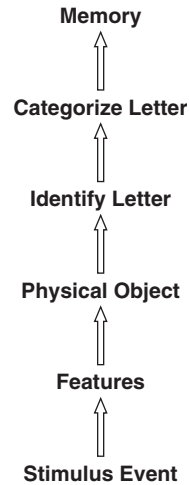
Memory

⇑

Categorize Letter

⇑

Identify Letter

⇑

Physical Object

⇑

Features

⇑

Stimulus Event

Figure 1.5 Letter-recognition model.

Posner, Boies, Eichelman, and Taylor (1969) conducted research using Donders's subtractive method to specify the stages that took place as people processed linguistic symbols, such as letters. The basic procedure involved presentation of pairs of upper- and/or lowercase letters to the participant, such as AA, aa, aA, or AB. In one condition, the participants were instructed to press one of two buttons, corresponding to whether two letters were *physically identical* (such as AA, aa) or physically different (Aa or AB). In a second condition, the judgment was based on whether the letters had the *same name* (AA, aa, and Aa) or different names (AB). People were faster to judge that physically identical letters are the same (AA, aa; average response time = 859 msec) than to judge that upper- and lowercase letters are (Aa; average response time = 955 msec).

The results of the Posner et al. (1969) study (as depicted in Figure 1.6) indicate that the first stage of letter recognition is based on the visual form of the letters; the second stage involves recall of the letter name from memory. On the basis of these results, Posner and his colleagues concluded that information about letters is processed through several stages, with each stage becoming more removed from the physical stimulus. Each stage thus utilized a different *code* to make the judgments: first a visual code (where AA has the advantage over Aa), then a name code (where AA and Aa judgments are equal). Thus, by carefully controlling the properties of the stimuli and the judgment that the participants were asked to make, it was possible to specify stages in the processing of the letter pairs.

The study of cognition has burgeoned since Neisser's classic book; Psychwatch.com lists over 60 scientific journals devoted to cognitive psychology and cognitive neuropsychology. Robins et al. (1999) provided a concrete measure of the development of the cognitive perspective over the end of the 20th century. They analyzed the number of times keywords such as "cognitive" or "cognition" were used in articles published in journals in psychology between 1950 and 1997, how often cognition-related articles were cited in those journals, and the number of dissertations that were related to cognitive psychology. As illustrated in Figure 1.7, the prevalence of articles, citations,
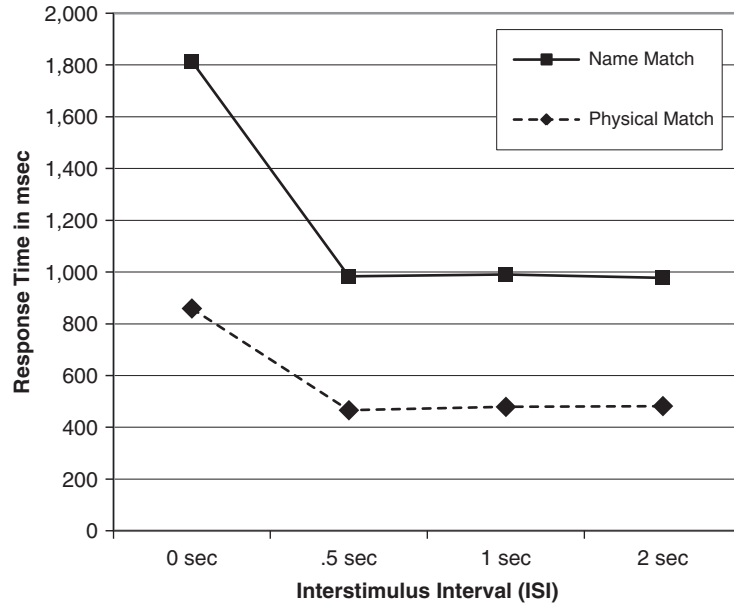
Figure 1.6 Posner et al. (1969) data illustrating the response time to whether two stimuli matched physically (A A) or in name (e.g., A a), per interstimulus interval (the time between when the second stimulus followed the first).
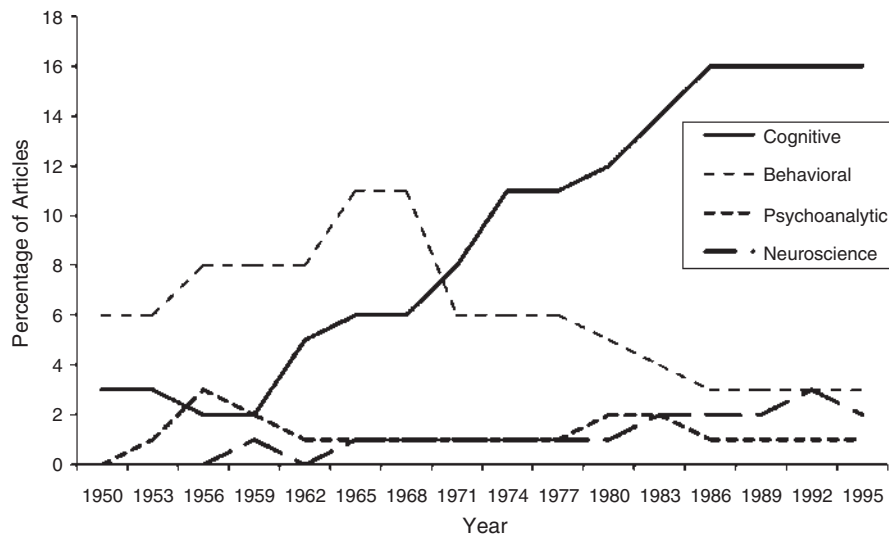
Figure 1.7 Robins et al. (1999) results, showing the increase in publications related to cognitive topics in recent history.
Adapted from Figure 4 in Robins et al., 1999.

and dissertations related to cognition continued to grow from the 1950s (surpassing the relative influence of the behavioral and psychoanalytic schools). Cognitive psychology citations, articles, and so on also surpassed those in neuroscience. However, Robins et al. (1999, Figure 4) also reported that membership in the Society of Neuroscience has increased dramatically in recent years. It is thus likely that neuroscience citations, articles, and dissertations will increase dramatically in future years as that field continues to grow.

FROM COGNITIVE PSYCHOLOGY TO COGNITIVE SCIENCE

The contributions from linguistics and computer science that helped spark the cognitive revolution guaranteed that the field of *cognitive science* would be interdisciplinary in its approach. Longuet-Higgins coined the term *cognitive science* in 1973, and it encompasses not only psychology, but also computer science, linguistics, philosophy, and neuroscience. Technological advances in the fields that fall under the cognitive science umbrella have also led to theoretical and empirical advances in the study of cognition. Notable contributions have come from computer science, with the advent of parallel distributed processing computer models, and from neuroscience, with the invention of neuroimaging techniques, which provide a window on the brain's activity.

DISTRIBUTED MODELS OF COGNITION

Parallel Distributed Processing Models

We have seen how the development of the computer served to stimulate research in cognitive psychology. An important modern development in the information-processing viewpoint has been the advent of what are called *parallel distributed processing* (PDP) models, also known as *connectionist* models (McClelland, Rumelhart, & the PDP Research Group, 1986; Rumelhart, McClelland, & the PDP Research Group, 1986). These models were stimulated by advances in computer theory, which led to the idea that efficient processing could be carried out by *parallel processors*, carrying out many activities at the same time, or in parallel. This sort of processing can be contrasted with the *serial* processing of information in the traditional information processing models, such as that in Figure 1.4, in which activities are carried out one at a time, or in a series of steps. As an example of parallel processing, when you see a word, you don't identify the letters separately left to right, but rather recognize all letters simultaneously (McClelland et al., 1986). Furthermore, information about the whole word plays a role in the recognition of the individual letters. That is, your knowledge about the whole word plays a role in your recognition of its parts. This is why word recognition is so rapid. This is a basic change from serial processing models such as those in Figures 1.4 and 1.5.

Connectionist models use an analogy of the nervous system in which multiple neurons operate in tandem, and each neuron may have tens of thousands of connections to other neurons. Furthermore, in PDP models, connections among neurons are built
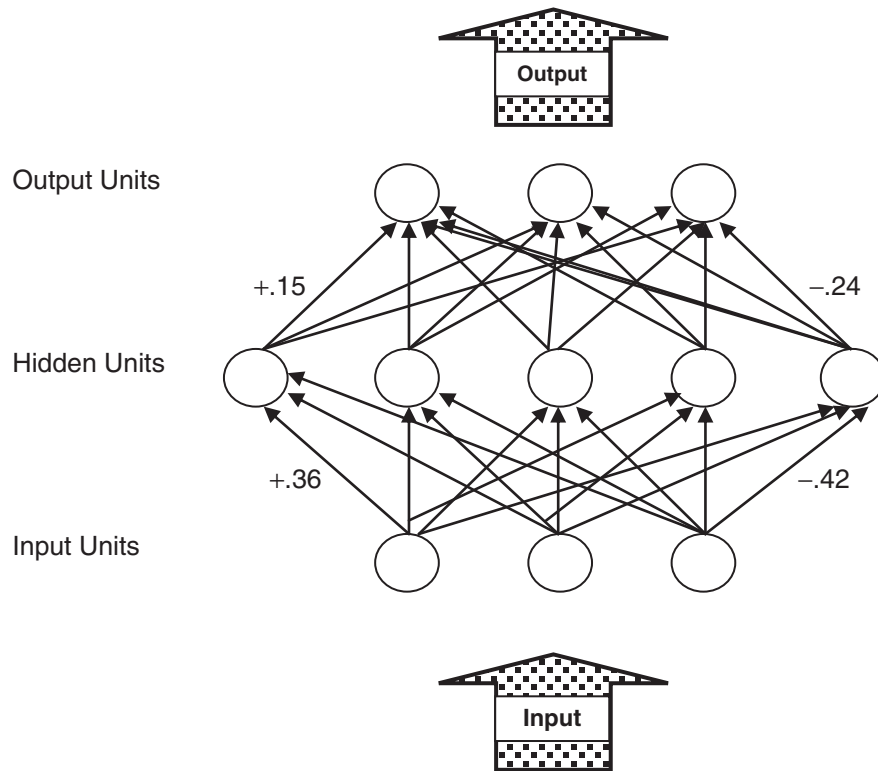
Figure 1.8 Parallel distributed processing (PDP) model.

up based on their working together in processing information; thus *learning* takes place with exposure to information or environmental stimuli.

The basic form of a PDP model is shown in Figure 1.8. Parallel distributed processing models differ from traditional information-processing models in that they are not divided into separate parts, such as the central processing unit and long-term memory storage (see Figure 1.3). Rather, parallel distributed processing models assume that the processing system works as one large unit. This means that there is no passing of information from one discrete component of the system to another, as in the information-processing model presented in Figure 1.4. Rather, the whole processing system works together. The typical parallel distributed processing model is built of several sorts of basic elements, called *units* or *nodes*. *Input* units (bottom row of Figure 1.8) respond to stimuli from outside, like sensory receptors in the nervous system. *Output* units (top row) produce output that can be connected to response systems, analogous to neurons that control muscles and glands. *Hidden* units (middle row) receive input from other units, rather than from the world, and send outputs to other units in the network, rather than to the outside world. They are considered hidden because they do not communicate with the external world in any way, and are comparable to neurons within the central nervous system.

As in the nervous system, the nodes or units of the network receive input, which can be *excitatory* (causing the unit to become active) or *inhibitory* (reducing the activity in the unit). The sum of the excitatory and inhibitory activity stimulating a node must be higher than the node's *threshold* for it to produce an output (and thereby send its message on to other connected units). The threshold of an individual node, and the strength of the connections among nodes, is based on learning. The past frequency with which a unit has been activated will determine its individual threshold; and units that have fired together in the past are correlated and thus develop stronger interconnections (again, in the same way as neurons in the brain).

The strengths of connections among some units are shown by the numbers in Figure 1.8. A higher number means that the unit sends a stronger message to those units to which it is connected, and the $+/-$ signs indicate whether the message is excitatory or inhibitory. So, for example, a connection of $+.15$ is excitatory, while a connection of $-.24$ is inhibitory. Units that fire often will also have lower thresholds, and thus require less activation to fire. For instance, the set of nodes that represent your best friend's name probably has a low threshold because of how often you use that name.

One important component of parallel distributed processing models is that they can explain how knowledge is acquired and then is used to influence later cognitive functioning. For example, once a person has become proficient in reading and word recognition, connectionist models can explain how and why letters are recognized better in words than by themselves, and why highly familiar words are recognized more quickly than less-familiar words (we present an exposition of such a model in Chapter 5).

Bayesian Models of Cognitive Processes

Another type of computer model, based on conditional ("If . . . , then . . . ," or *Bayesian*) reasoning, has become popular in recent years in multiple areas, to explain topics as diverse as visual scene perception (Yuille & Kersten, 2006), inductive learning (Tenenbaum, Griffiths, & Kemp, 2006), and semantic memory (Steyvers, Griffiths, & Dennis, 2006). These models are called *Bayesian* models because they are based on an early theory of conditional reasoning that was developed by Thomas Bayes (c. 1701–1761; Bayes's work was published in 1763). As do connectionist models, these Bayesian models "learn" complex information from simpler data. Hierarchical Bayesian models (e.g., Gelman, Carlin, Stern, & Rubin, 2003; Good, 1980) permit learning at various levels of abstraction (e.g., learning complex grammatical rules) better than most connectionist models. However, explanatory differences between connectionist and Bayesian models have become less stark as connectionist models have become more sophisticated. Some PDP models are now capable of "learning" structured, abstract knowledge (Rogers & McClelland, 2004, 2008), and of allowing that structured knowledge to constrain later learning (McClelland et al., 2010).

Both types of distributed learning models have shown success in modeling aspects of visual perception, categorization, and language learning, and much work has been stimulated by this perspective. We review several parallel distributed processing and Bayesian models of cognition in later chapters.

Neurocognition

An important addition to modern cognitive science is the use of evidence from neurological research to understand cognitive functioning. Linking brain structures to cognitive functioning has a long history, dating back at least to Galen (129-199/217), a Roman physician of the second century. Historically, most of the knowledge concerning the functioning of the nervous system during cognitive processing was obtained indirectly—through studies of people and animals with brain damage. Modern advances have produced great increases in our knowledge, by allowing detailed mapping of brain structures in intact living organisms and direct measurement of brain activity as people are carrying out cognitive tasks.

Studies of Brain Structure and Function

The first great developments in the study of brain structure and cognitive functioning occurred almost two centuries ago. In the 1820s, Flourens showed that experimentally produced brain damage, or *lesions*, in certain areas of the brains of animals led to specific deficits in movements. Those results led to the *doctrine of localization*—the idea that specific brain areas controlled specific parts of the body (Gall & Spurzheim, 1809, 1810). Since it is not possible, due to ethical considerations, to experimentally induce brain damage in humans, much early information concerning human brain function during cognition was obtained from post-mortem examinations of the brains of individuals who had experienced various sorts of problems during their lives. For example, Broca (1861) studied a man who had lost the ability to speak (although he could understand speech perfectly well). Broca linked this language impairment to a relatively small area in the left hemisphere, in the frontal lobes adjacent to the motor cortex. This area now bears the name *Broca's area* (see Figure 1.9). People who have shown language-production deficits as the result of a stroke or accident have until
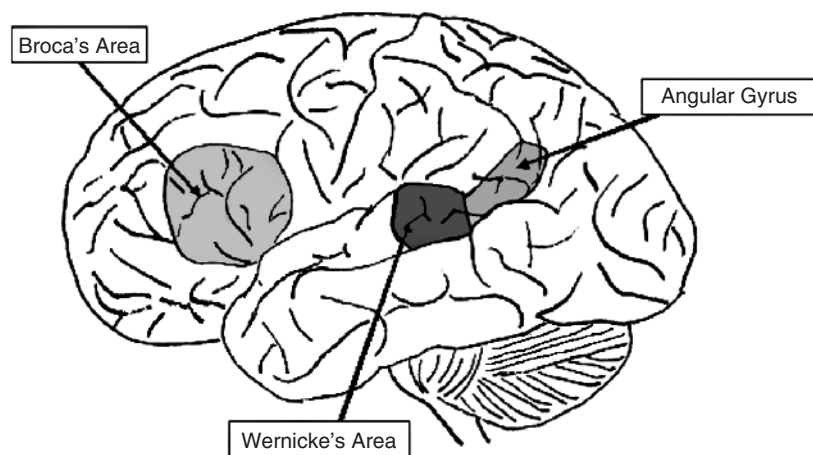

**Figure 1.9** Diagram of Broca's area (and other speech areas) in left hemisphere.

recently been referred to as "Broca's aphasics" (*aphasia* means *without speech*); now the term *agrammatics—without grammar*—is often preferred, as we will see in Chapter 10. Broca's discovery also supported the *doctrine of lateralization*—the idea that each hemisphere is dominant for particular functions, with language largely controlled by the left hemisphere.

Almost all neuroscience research seeks to answer a basic question: Which part of the brain controls which psychological process? The answers to that question are sometimes referred to as brain:function correlates, or structure:function correlations. The methods of Flourens and Broca are still in use today, although modern research on *neurocognition* or *cognitive neuroscience* has provided more detailed evidence on the relation between the brain and cognitive processes than did their pioneering studies. Contemporary studies using animals and humans have yielded valuable information on the role of specific brain areas in particular behaviors. In some of the animal studies, brain areas are lesioned, and the effects on behavior are noted (although techniques for producing lesions and measuring the resulting brain damage are much more sophisticated than in Flourens's day). Following Broca, there have also been many detailed clinical studies of humans with brain damage caused by illness or injury. In addition, there have been studies of individuals who have had parts of their brains removed for medical reasons, such as to remove tumors, or to reduce the severity of life-threatening seizures. These studies have provided indirect evidence concerning the role of various brain structures in human cognition. Lastly, advanced technologies—to be reviewed shortly—have allowed neuroscientists a window into the normally functioning brain, to determine which brain parts are most active when it processes information. Figure 1.10 depicts the four lobes of the cerebral cortex (the wrinkled outer structure of the brain) and the functions associated with each, based on past neuroscience evidence.

The Dissociation Method

Unfortunately, nature often carries out neuropsychological "experiments" on humans that investigators are prevented from carrying out because of ethical concerns. Strokes, accidents, and surgery may all cause damage to the brain, resulting in specific cognitive deficits. Evidence exists that *physiological modularity* may apply to some cognitive skills: Damage to distinct brain areas causes distinct patterns of psychological malfunction. Imagine that a lesion in brain area A interferes with the person's ability to identify objects by sight (known as *visual agnosia*: *a-gnosia* comes from the Greek for *without knowing*). The person is not blind, since he or she can pick up the object if asked, and does not run into things, but he or she no longer recognizes the objects being picked up. However, if the object is put in the person's hand, he immediately tells you what it is. At a skill level, we have here a *dissociation* between identification based on vision and touch (*tactile* or *haptic* identification)—the two processes are separable, and the visual agnosia is based on a lesion in what we will call area A.

The symptoms of such a patient can tell us that area A is involved in visual identification of objects. However, there are at least two possibilities concerning how that area functions in recognition of objects. It might be that area A is necessary for only *visual* identification of objects, and that it has nothing to do with the identification of
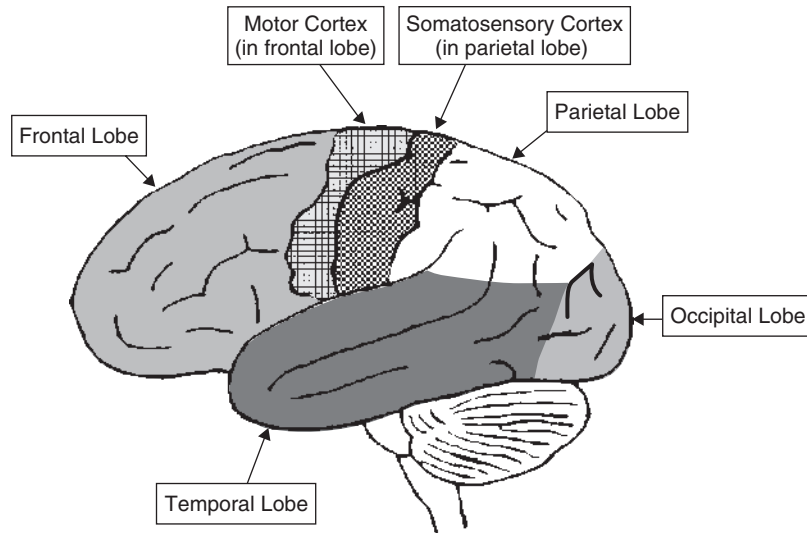
	FUNCTIONS
Frontal Lobe	Planning, selective attention, inhibition of responses, memory strategies, problem solving; contains motor cortex, speech production area (in left hemisphere)
Parietal Lobe	Contains somatosensory cortex; integration of senses, visual attention, and coordination of motor movement
Occipital Lobe	Visual processing
Temporal Lobe	Memory, object recognition, auditory processing, speech comprehension (in left hemisphere)

Figure 1.10   Lobes of the cerebral cortex and their functions.

objects by touch, say. That is, there might be two separate identification systems, one dealing with identification through vision and the other through touch. However, it could also be true that area A is part of a general *object-identification system* that affects *both* visual and tactile recognition of objects, but identification by vision is simply a more difficult task than tactile identification. Damage to area A might disrupt the general object-identification system enough to interfere with the hard task but not the easy one. Thus, finding a dissociation, by itself, does not tell the investigator exactly how the processing system in the brain is organized.

The gold standard for neuropsychologists is to find a *double dissociation*, which is exhibited if skill A is impaired in one patient, but skill B is intact, while another patient shows the opposite: impairment in skill B but normal performance in skill A. Such a

pattern then suggests that, not only are skills A and B psychologically modular, but they are also neurologically distinct. In the agnosia example, we would need to find another brain region (call it area B) in which a lesion interferes with identification of objects by touch, but leaves visual identification unaffected. Since the person with the lesion in area B can do the visual task but cannot do the tactile identification, one can no longer say that the tactile task might simply be easier than the visual. It must be the case that the tasks are carried out separately, or else we could not find people who performed oppositely on them.

## Anatomical Measures of Brain:Function Correlates

Several new techniques allow detailed mapping of damaged brain structures in living organisms. The CT scan (computerized tomography) is a sophisticated X-ray technique that produces cross-sectional pictures or slices of brain structure. CT scans cannot provide information on which part of the brain is most active in functioning during a given activity; they are limited to telling us the exact location of a person's brain damage. Magnetic resonance imaging (MRI) is another sophisticated technique that can be used to reveal the structure—but not the function—of any part of the body, including the brain. It is based on the fact that chemical molecules in living cells respond to magnetic fields (Huettel, Song, & McCarthy, 2004). The part of the body to be studied is placed in the center of a machine that generates a strong magnetic field. When the magnet is turned on, the molecules respond to the field by all turning in a specific direction; when the field is turned off, the molecules return to their normal state. As they go back to normal, they produce electromagnetic waves that can be measured and processed by a computer. Different types of molecules respond slightly differently to the magnetic field, so the pattern of responding can be used to determine the structure of the part being studied. This technique produces highly detailed structural cross-sections of the brain, much like CT scans (but without exposure to X-rays). Advances in MRI technology now allow measurements of brain function as well (see the following section).

Studies of Brain Function: Measures of Brain Activity

Recent development of a number of neuroimaging techniques have allowed investigators to go beyond studying the structure of the nervous system to examination of the functioning of the nervous system as people carry out cognitive tasks. Most of the techniques to be described in this section are noninvasive: The person does not have to be operated on in order to make the brain areas accessible to measurement. These techniques have resulted in great advances in our knowledge of how the brain functions online. We begin our discussion, however, with a method that is invasive, and so is limited largely to the study of animals.

Electrical Activity of Single Neurons
In animal studies, very thin wires, or *microelectrodes*, are placed in specified brain areas, and the brain activity of individual neurons is measured when the animal is carrying out some task (such as viewing visual stimuli on a screen). This was a technique used by

(a)   (b)   (c)
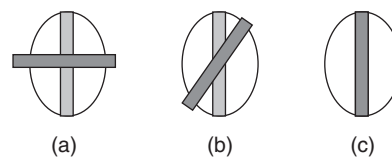
Figure 1.11   Receptive field of a single cell, from Hubel and Wiesel's (1959) research. (a) Little to no activation. (b) Moderate activation. (c) High activation.
The ovals depict the on-center receptive field of a cell, with inhibitory surround. The dark gray bar is a bar of light that falls within the receptive field of the cell. The degree of activation of the cell depends on the extent to which the stimulus bar falls on the receptive field, relative to the inhibitory surround.

the Nobel Prize–winning team of Hubel and Wiesel (1959) when they determined that individual neurons in the visual cortex of a cat processed lines of specific orientation in specific parts of the visual field (see Figure 1.11). Such experiments are especially enlightening when primates (monkeys, chimpanzees, gorillas) are used, as primate brains are very similar to human brains. However, since this technique cannot be carried out on humans for ethical reasons, this limits our ability to study electrical activity in single neurons during complex activities such as language or deductive reasoning, which are not carried out to the same degree in animals.
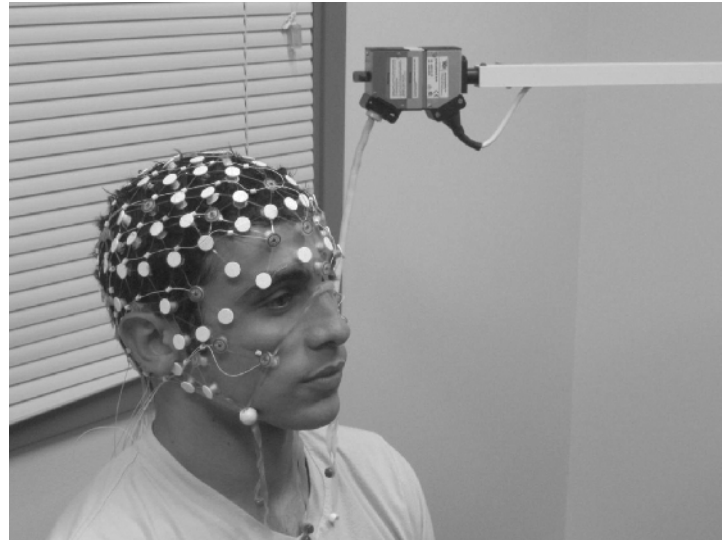
Electroencephalography (EEG)

An early recording technique that was used to obtain information about the relationship between brain function and cognitive processing is the electroencephalogram (EEG). Electrical recording devices, or *electrodes* (small discs of metal), are placed on the scalp, as shown in Figure 1.12a, and the electrical activity under the electrodes is recorded and displayed in graphic form, as shown in Figure 1.12b. The EEG provides a safe and easy way to gather information on which parts of the brain are electrically active during various tasks. In fact, it is now routinely used on human infants to gauge their information processing, such as when viewing faces (e.g., Bazhenova, Stroganova, Doussard-Roosevelt, Posikera, & Porges, 2007). Aside from the gel that is used to increase conductance, EEG's main methodological drawback is that it measures activity in very large brain areas at once. Figure 1.12b depicts the activity patterns of various regions of the brain, based on the set of electrodes shown in Figure 1.12a, each of which is measuring activity from a large number of neurons.

To obtain more specific information about brain functioning during cognitive processing, researchers sometimes measure *evoked potentials*, which are recordings of electrical activity *evoked* in response to specific stimuli. The electrical *potential* (electrical activity) is evoked, or stimulated, by the presentation of the stimulus. This procedure requires that the participant be repeatedly exposed to some stimulus, say a smiling or a neutral face (Bazhenova et al., 2007). As the infant (or adult) observes the stimulus face, brain activity is recorded, and the records are averaged. These responses are also called *event-related potentials* (ERPs).

Electrical Stimulation of Brain Areas

In the 1940s, neurosurgeon Wilder Penfield, working at McGill University in Montreal, developed a technique that became known as the Montreal procedure: Patients

(a)
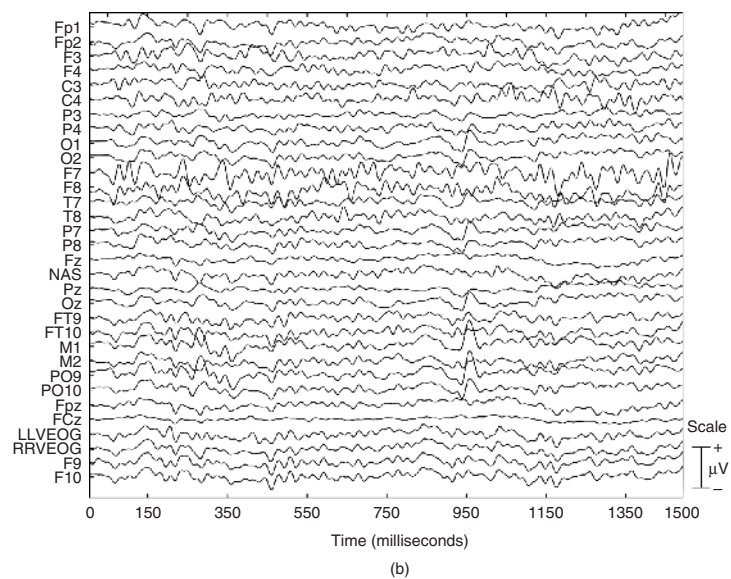
(b)

Figure 1.12   (a) Picture of a person in an electroencephalogram (EEG) cap and (b) EEG waves.
With thanks to the Langlois Social Development Lab at the University of Texas at Austin.

whose skulls had been opened because they were about to undergo brain surgery (typically for epilepsy) would have small electrical currents delivered to parts of their brain while conscious. Penfield could then determine which parts of the brain were most responsible for epileptic seizures, and thus only ablate (remove) those areas during surgery (Jasper & Penfield, 1951/1954). Using this method, he mapped the parts of the body related to subsections of the somatosensory cortex and motor cortex

(see Figure 1.10, cortex map). Neurosurgeons still use the technique when removing tumors or conducting brain surgery (see cnn.com/2008/HEALTH/08/01/open .brain.surgery/index.html); by determining the specific regions of the brain responsible for speech and other important functions for an individual, doctors will try to avoid damaging critical areas during the surgery.

A similar but less invasive technique is transcranial magnetic stimulation (TMS). It was first used by Barker, Jalinous, and Freeston (1985) to test the relationship between brain structure and function. Magnets are placed on the skull, and magnetic fields are used to disrupt (or enhance) neural activity in the region of the brain under the magnets. The researcher can have the person engage in a task, say, reading a book aloud, then introduce TMS to see if it affects the person's reading performance. The advantage to this technique is that it is noninvasive; however, TMS cannot be used universally, as it has been shown to cause seizures, especially in people who may be prone to them.

PET Scans and Cerebral Blood Flow

Brains require three main things to survive and to carry out their functions: glucose, oxygen, and nutrients. All three of these substances are carried by blood. When a brain area is active, blood uptake at that area is enhanced. This knowledge forms the basis for both positron emission tomography (PET) scans and cerebral blood flow (CBF) measures, which provide information on brain functioning. During PET scans, a small amount of radioactive glucose (or oxygen) is injected into the bloodstream. When it reaches the brain, any areas that are active take up this glucose during metabolism and thereby become slightly radioactive. Sensitive recording devices allow researchers to measure the radioactivity, and thereby to determine which brain areas are active during different sorts of cognitive tasks.

Cerebral blood flow techniques operate the same way, but measure overall blood flow. A 2-D or 3-D picture of the brain can then show the most active areas of the brain during some cognitive activity, with red and yellow areas depicting higher levels of activity. The main drawback is that PET scans usually take 40 seconds or more for brain activity to translate into an image (www.nida.nih.gov/NIDA_notes/ NNVol11N5/Basics.html), whereas sometimes faster measurements are needed.

fMRI

As you read earlier, MRI uses magnetic fields to construct images of the brain (see Figure 1.13). More active parts of the brain require the blood to deliver more oxygen and glucose. *Functional magnetic resonance imaging* (*fMRI*) allows researchers to record brain activity as a person carries out various tasks, by measuring changes in the magnetic properties of blood as it undergoes changes in oxygenation levels. As active brain areas take up oxygen and glucose from the blood, the blood's response to a magnetic field changes. Thus, activity in various areas in the brain can be measured indirectly, by the response to the magnetic field of the blood in that area. Furthermore, since fMRI can provide an image every second, it gives a more real-time picture of the brain than PET scans. A quick Internet search will show you a color picture of activity levels depicted in an fMRI; highly active areas appear in red or yellow; moderate to low levels of activation will appear in blue or green.

Figure 1.13   An fMRI machine and output depicting the structure of an individual's brain and skull from different perspectives.
With thanks to the Imaging Research Center at the University of Texas at Austin.

In using fMRI to measure brain areas active in carrying out some cognitive task, the simplest method involves a modern variation on Donders's (1868/1969) subtraction method for using reaction time measures to assess cognitive processes. In using the subtraction method for fMRI, two sets of brain recordings are compared: one obtained during the critical condition in which one is interested, and the other from a control condition that differs from the critical condition by one cognitive operation. In that way, any differences in brain activation are the result of the operation in which the two conditions differ. In other words, the critical condition differs from the control condition because of the *insertion* of the operation of interest in the critical condition. If a study of this sort is designed correctly, it results in what one could call *pure insertion*, which is important if the results are to be interpreted clearly. If pure insertion is not carried out, then the critical condition will differ from the control in more than one way, and it will be impossible to interpret the results, since any differences in brain activation might be due to any of those differences.

Conclusion

These new neuroimaging techniques have helped to supplement traditional studies of brain-damaged patients in determining brain:function correlates. Structural measures, such as CAT scans, take a picture of the brain, and areas of damage can be correlated with patient symptoms. Other measures, such as PET scans, CBF, and fMRI, measure the uptake of blood, glucose, or oxygen to determine which parts of the brain are most active as people perform a given task. These techniques have been useful tools in the study of a wide range of cognitive processes, including memory, pattern recognition, attention, imagery, unconscious processing, and decision making. Findings from neurocognitive studies will be discussed throughout many chapters in the book.

DEVELOPMENT OF MODERN COGNITIVE SCIENCE: SUMMARY

A number of research endeavors have come together to form modern-day cognitive science. In the late 1950s, there was a renewed interest in the study of consciousness and higher cognitive processes, such as language and problem solving. There was also a reaction against behaviorism, with its emphasis on external stimuli and responses, and its rejection of the study of mental phenomena. Developments in linguistics emphasized the structural complexity of human language, and stimulated psychologists to examine the rules by which other higher-level processes might be operating. The development of computers provided psychologists with a concrete example of a system that could carry out complex "mental" operations, without raising problems as to whether or not the internal states actually could be studied directly. Advances in neurocognitive research have also expanded cognitive psychologists' ideas of the kinds of evidence they could use to study cognitive phenomena in intact brains. All of these endeavors have led to a thriving and interdisciplinary science devoted to the study of cognition.

COGNITIVE SCIENTISTS' STUDY OF HIDDEN PROCESSES

As noted earlier in the discussion, the term cognitive psychology labels both a subject matter—the study of the cognitive processes—and a philosophy of science—the belief that cognition can be understood by analyzing the mental processes underlying behavior. This belief leads to a question that we touched on in passing earlier in this chapter: How can one apply scientific methods to the study of mental processes, which are by definition invisible and unobservable? Students sometimes wonder if we can ever say anything meaningful about those mysterious hidden processes. In the discussion of behaviorism, we noted that one lasting influence of the behavioristic perspective was the use of behavioral responses as the basis for drawing conclusions about hidden mental processes. We also mentioned that such a method is similar to the way we think about many phenomena in our ordinary day-to-day interactions with the world. That is, we ordinary folks think about hidden phenomena all the time. Furthermore, scientists in other disciplines have no problem dealing with phenomena that cannot be seen.

Because of the importance of this question, let us consider in some detail how cognitive scientists do in fact study hidden processes. We can begin considering a situation in everyday life in which people deal with phenomena for which they have no direct evidence.

Car Talk

On National Public Radio until recently there was a program called "Car Talk," where listeners called in with questions about problems with their cars. The two resident experts, mechanics with years of experience, provided a diagnosis of the problem, without ever seeing the caller's car. Furthermore, they sometimes made diagnoses

concerning engine problems that they as mechanics had never before encountered. How could they make correct diagnoses without direct evidence for the phenomenon in question? The answer is obvious: They were using a listener's reported observations of the car's "behavior" (its performance problems) combined with their extensive knowledge of how cars work to draw conclusions about defective interior or hidden components. So we see a situation in which people formulate a hypothesis about what is happening inside a car from the available evidence, without being able to see the car itself or its presumably malfunctioning inner components. In a similar manner, scientists in many disciplines deal with phenomena that cannot be seen. One well-known example comes from molecular genetics: the discovery of the double helix of DNA.

The Double Helix

The discovery of the structure of DNA is a case in which scientists were able to discover the structure of a system without direct visual evidence. The hypothesis that the DNA molecule is in the shape of a double helix was proposed in 1953 by James Watson and Francis Crick (Weisberg, 2006a). No one had seen the double helix of DNA at the time it was proposed (and no one has seen it yet, as electron microscopes are not powerful enough to penetrate to that level of analysis). Thus, Watson and Crick did not have pictures of a helical structure on which to base their analysis of DNA. How then could they determine the structure of a molecule that they could not see? They began their work with an idea of what the structure might be, and they used this idea to interpret the results of experiments in biochemistry and biophysics. They built a model of the molecule that could explain the results of those experiments, which was presented to the scientific community in an article published in *Nature*, a scientific journal (Watson & Crick, 1953). Other scientists raised no crucial objections, and furthermore determined that Watson and Crick's proposed model was consistent with still other research findings. The scientific community thus accepted the double helix as the structure of DNA, although no one had ever seen it directly. Thus, if a scientist's model or theory can explain experimental results, and is useful in predicting future research findings, then one can say that the phenomenon described by the theory exists (even if one cannot see it).

Mental Processes

Cognitive scientists work in much the same way as the *Car Talk* mechanics and Crick and Watson: We use the available evidence—psychological and neuropsychological evidence based on reaction time and other behavioral data—to develop models of cognitive processes, such as object recognition, mathematical problem solving, and memory retrieval. We then use those models to derive hypotheses about other phenomena in the same domain, and we design experiments to collect data relevant to those hypotheses. Models are refined or altered in response to the data from the experiments, which then leads to new predictions and further experiments. As an example, let us consider the hypothesis that the ability to remember information sometimes depends on *rehearsal* of that information. Assume that rehearsal is an internal mental

process that involves vocalizing the to-be-remembered items again and again to oneself. We predict that more rehearsal leads to better memory. How could one test that hypothesis? Before reading further, please carry out the demonstration experiment in Box 1.3.

BOX 1.3 REHEARSAL DEMONSTRATION: MEMORY SPAN FOR SHORT VERSUS LONG WORDS

Have a pencil and blank piece of paper ready. If you do not have them, please get them before reading further. Below are four columns of words. DO NOT LOOK AT THE WORDS YET. Your task is to read each word in the first column as many times as you can in an interval of about 10 seconds (cover columns 2, 3, and 4 with your hand as you do so). If you will not disturb anyone, read the words aloud. When you have read the words in the first column, try to write as many of them as you can *from memory*, in the order in which you read them. Do not look back at the list. When you have finished recalling the words in the first column, do the same for each of the other columns: Read each of the words as many times as you can in 10 seconds, write them in order from memory, and then go on to the next column.

disk	finger	picture	book
phone	bucket	sofa	glass
pen	package	berry	boat
head	number	tower	lamp
plant	electricity	buckle	nail
sound	fantasy	operation	paint

Box 1.3 presents a modified version of an experiment by Baddeley, Thomson, and Buchanan (1975), which tested the hypothesis that rehearsal is important for remembering certain kinds of information (such as words in a list). Experimental participants heard a string of unrelated words and then attempted to recall them in the order in which they had been presented. In some strings, all the words were short, only one syllable in length (as in the first and last columns in Box 1.3), while in others the words were longer, up to three syllables in length (as in the middle columns). Baddeley and coworkers reasoned that if the participants rehearsed the words by repeating them, then longer words would not receive as many rehearsals as shorter words in the same period of time (e.g., the 10-second interval for each list). Therefore, recall for longer words should be worse than for shorter words, and that was what the researchers found. If you recalled more words from the first and last columns than from the middle two, then you confirmed their results. This example shows how one can study hidden psychological processes through indirect methods, as in the examples discussed earlier from auto repair and the discovery of DNA. Cognitive scientists can obtain evidence and then formulate hypotheses about cognitive processes that can never be seen.

Neurophysiological Evidence for Mental Processes

Another possible type of evidence for mental processes comes from neurophysiological studies. Since cognitive skills are carried out by the brain, perhaps we can study memory

processes (such as rehearsal), by recording brain activity while people study words. However, some caution is necessary in interpreting the results of neurophysiological studies alone. Let us assume that a researcher believes that people sometimes memorize information by internally rehearsing it, as Baddeley et al. (1975) tried to demonstrate in the experiment just discussed. The researcher decides to record brain activity as the participants try to remember strings of words. Assume that the participants report that they rehearsed the words to themselves in order to memorize them, and that the researcher detects activity in the same specific area in the brain for each participant. Would those brain records alone be useful in demonstrating that the words were remembered through the use of rehearsal? Not conclusively, because we have no way of knowing that the brain activity is indeed the record of *rehearsal*. We have the participants' reports that they rehearsed, but we know that such reports cannot be verified and so cannot serve by themselves as psychological evidence for rehearsal. Therefore, the records of brain activity simply indicate that some parts of the brain were active during the participants' attempts at memorizing; they do not tell us that the activity was internal rehearsal. For example, perhaps the people were using visual images instead of verbal rehearsal to remember the words. We need some independent *psychological* evidence that the participants were indeed rehearsing the words.

Instead of only relying on participants' reports that they were using rehearsal, a researcher could have a person engage in Baddeley et al.'s (1975) study from Box 1.3, with one small addition. The researcher could verify that rehearsal processes actually were taking place by having people rehearse *aloud*. Only then would it be legitimate to claim that the neurocognitive measures indicate that rehearsal (or any other process) is taking place in a particular part of the brain, and one would have to "subtract" the neural activity due just to vocalizing alone (but not rehearsal). The study of neural activity can then lead to further hypotheses about the psychological processes involved in various cognitive phenomena, so the investigation can work both ways. For example, if we give people stories to memorize, and the brain activity for that task is in an area different from that involved in studying lists of words, this could indicate that memorizing stories involves processes different from simple rehearsal. Thus, once we have provided support for an analysis of some phenomenon through cognitive methods, neurophysiological evidence can be very useful in expanding and enriching that analysis, as we shall see in many places throughout this book.

This completes our introduction to the study of cognitive processes. We now turn to an outline of the themes that will serve to organize the discussion in the book.

THEMES OF THE BOOK

There are several key themes that have guided the organization of this book, and our analysis of research connected to cognitive processes.

1. Cognitive processes are knowledge-based; cognition is a *constructive* and interpretive activity, not based only on incoming information.

2. Cognition is best explored via a functional approach.

3. Cognitive processes are often modular, but also involve significant integration to accomplish cognitive tasks.

4. Cognition is best understood via historical and contemporary coverage of research.

Next we explain each of these overarching themes and why we have found them useful in our thinking.

Cognitive Processes Are Knowledge-Based

We will emphasize the important role that our knowledge plays in virtually all cognitive processes. This emphasis on the constructive and interpretive nature of cognition was seen many years ago in the work of Bartlett, which was briefly discussed earlier (and which is considered in more detail in Chapter 3). Even when one examines the lower processes, such as pattern recognition and attention, one finds that experience plays a crucial role there as well, such as when we find it easier to read textbooks in our major field of study than textbooks outside our major. Those processes are constructive as well. In order to get a feeling for the role played by knowledge in cognition, we will briefly examine two ways of analyzing how people might carry out a low-level cognitive process: recognizing printed words.

One model of word recognition is shown in Figure 1.14a. As we discussed earlier, at an early sensory level, the person would engage in detection of the individual lines and angles—the *features*—making up each letter of the word. Then he would combine the features to recognize individual letters, and then combine the letters to recognize the whole word. In this way of looking at the process of recognition, a stimulus (e.g., the word) proceeds through the system by earlier stages feeding information into later stages. Information gets from the external world into the system in a *bottom-up process*, that is, it works its way into the organism's mind from outside. In this analysis, knowledge plays no role in the initial processing of information.

However, research in a number of domains indicates that our knowledge plays an important role in processing the stimuli in the environment. For example, when we are reading, common words are recognized more quickly than rare words (Paap, McDonald, Schvaneveldt, & Noel, 1987); and experts in a field (such as engineering) recognize words related to their profession more quickly than do nonexperts (Gardner, Rothkopf, Lapan, & Lafferty, 1987). Thus, in our Figure 1.14b model, in addition to the arrows going up from the bottom, there must also be arrows going from the top downwards. *Top-down processing* (as shown in Figure 1.14b) illustrates that what we know about the world influences how we process incoming information, even at the most basic levels of cognition.

It is easy to find examples of top-down processing in our ordinary activities. Anyone who has watched hockey on television knows that it is sometimes extremely difficult to follow the puck. One sees a tangle of players, with arms, legs, skates, and sticks going every which way at once, and suddenly the crowd is screaming and the puck is in the net. The commentator, usually a former player, gives a description of the puck's path, going from that player's stick, off that player's elbow, hitting another player's skate, through the goaltender's legs, and into the goal. The television audience
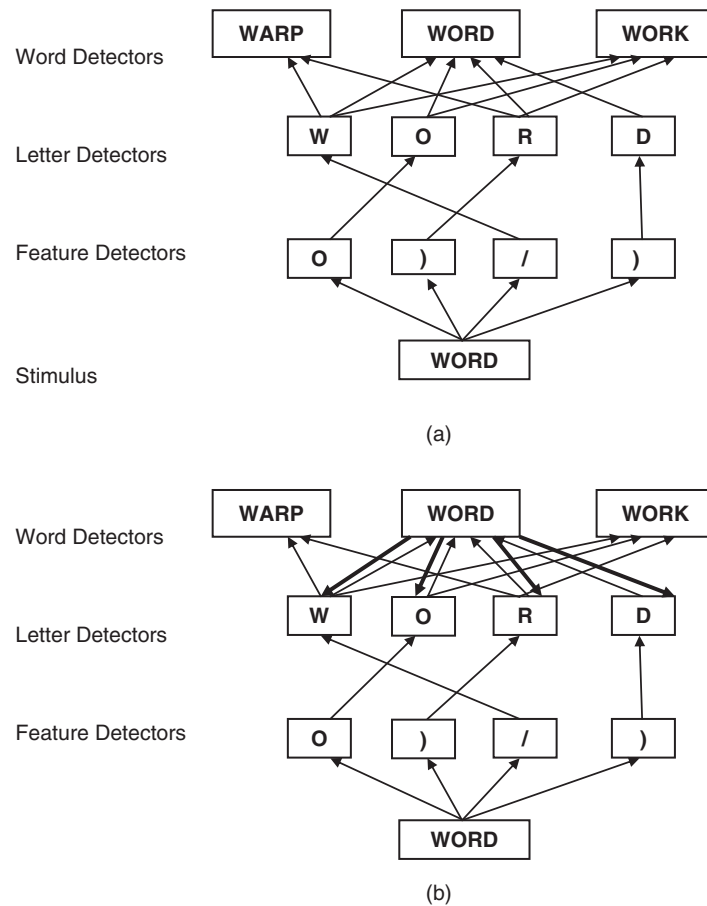
Figure 1.14   Information-processing model of word recognition. (a) In bottom-up processing, connections are one-way, from the stimulus to feature detectors to letter detectors to word detectors. (b) Top-down processing is illustrated by the bold arrows indicating feedback from the (higher) words level to the features level.

may respond with disbelief that the commentator was able to see the puck's multiple trajectories, until a slow-motion replay confirms the commentator's report. The reason that the analyst can see what untrained members of the audience cannot is due to his knowledge of the game. In fact, the effects of knowledge show up in virtually every cognitive endeavor—from pattern recognition and attention to problem solving and creative thinking (for examples, see Ericsson, Charness, Feltovich, & Hoffman, 2006).

The idea that all of our functioning depends on our knowledge will be expressed in several different ways throughout the book. In this chapter we have referred directly to the role in knowledge in cognitive functioning, but we have also talked about the *constructive* aspects of cognition, referring back to Bartlett (1932). We will also sometimes talk about cognitive processes as *active* processes, with the individual playing

an active role in processing information. All those terms are different ways of saying the same thing.

If it is true that our mental functioning depends on what we already know (in other words, on top-down processing), then a logical place to begin the analysis of cognition is with memory—the processes involved in the acquisition, storage, and use of knowledge. We thus begin this book with three chapters on memory research and theory. Once we have an understanding of the basic factors underlying memory, we will use them as the basis for organizing the cognitive phenomena presented in the remainder of the book.

Functional Approach

As James (1890) pointed out more than a century ago, the real interest in cognitive skills is in their purpose or function. Discovering the subprocesses that one carries out when memorizing statistical equations or historical dates describes *what* people do; it is also important to find out *why* people memorize information or recognize objects. The functional approach assumes that there is some underlying logic or reason for why a particular skill is accomplished or structured the way it is. The reason may be based on that individual (a given strategy has worked well for her in the past), or species-based (some skills have evolved in all humans because they were adaptive). Sometimes, there is even a function for the systematic errors that people make, or for what on the surface seems to be a breakdown in processing. For example, in Chapter 4, we explore the possibility that there is an advantage even to forgetting information (Anderson & Schooler, 1991). We try to provide a functional analysis of each major cognitive skill throughout the book.

Modularity and Integration of Cognitive Processes

In cognitive psychology books such as this one, cognitive activities such as memory, mental imagery, and language are covered as discrete topics, and presented in separate chapters. In universities, those topics are studied in separate advanced seminars. This organization corresponds to the concept of modularity, which was a cornerstone of Chomsky's theory and the ensuing information-processing approach. Neuropsychological research also bears out the functional independence of various cognitive skills—some brain-damaged patients can lose one skill (e.g., the ability to recognize objects in agnosia) without losing other skills (e.g., the ability to speak, or to remember new information), whereas other patients may have the opposite set of symptoms (e.g., intact ability to recognize objects, but loss of the ability to speak). There is ample evidence for the general concept of modularity.

But we also want to stress that many cognitive skills are accomplished by interaction among modules, and that some skills, such as memory and attention, may play a role in carrying out the functions of many other modules. It is not always possible to specify precisely where one particular process ends and another begins. As an example, one important part of possessing the concept of a dog is the ability to recognize dogs (visual pattern recognition), and to retrieve an image of a favorite dog from your childhood (memory and mental imagery). Both pattern-recognition and mental imagery are based

on visual stimuli stored in memory. Thinking of the concept "dog" may also activate the individual speech sounds necessary to say the word, thereby invoking language processing. Thus, conceptual knowledge is integrally tied to pattern recognition, visual imagery, memory, and language. Additional examples of the relations between cognitive abilities will be made explicit in many places throughout the text, and we provide cross-references from a given topic to related topics in other areas.

Historical and Contemporary Coverage of Research

As already demonstrated in this chapter, cognitive science, although relatively new as a paradigm, has a long and rich history. We use that history as the foundation for our presentation of material in all the chapters that follow. In each chapter, we present the pioneering research and theoretical development of each topic area, and then balance this approach with coverage of contemporary theories and experiments. This will allow you to see the evolution of thought within cognitive science. A historical approach also helps keep modern researchers humble, as one sees that many "new" ideas have been around for a long time. Each chapter also includes neuropsychological findings relevant to cognitive topics, which are often based on the latest technological advances in neuroscience.

Outline of the Book

The book is divided into several sections. As noted, we begin with the study of memory, in Chapters 2–4, because so many of our other cognitive skills are dependent on what we have already learned and can remember. Consistent with our historical orientation to the study of cognition, Chapter 2 begins with a discussion of one of the earliest cognitive models of memory, the multi-store model proposed by Atkinson and Shiffrin (1968), and a more current incarnation of short-term memory—Baddeley's concept of working memory (e.g., Baddeley, 1986). The second half of the chapter analyzes empirical support for the hypothesis that there are separate memory systems for storing factual information, autobiographical episodes, and skills we have learned. Chapter 3 examines the processes involved in the *encoding* of new information in memory and *retrieval* of that information when it is needed. Chapter 4 focuses on errors of memory—both when information is lost during forgetting and when we misremember details about events or facts.

The second section of the book is devoted to coverage of lower-level processes, including perception and attention, although, following our theme of top-down processing, we will consider the influence of knowledge on those processes. Chapter 5 examines visual pattern recognition—the recognition of words, objects, and people in the environment. Chapter 6 considers the closely related question of attention—how humans determine what aspects of the environment to which they attend, and whether there are limits on how much information we can pay attention to simultaneously. Chapter 7 examines research and theories related to imagery. The study of imagery brings together research in memory and pattern recognition, neurocognition, and the study of consciousness.

The third section of the book consists of three chapters concerned with concepts and language. Chapter 8 focuses on how our conceptual knowledge of diverse categories such as *odd numbers*, *fruits*, and *furniture* is represented in memory. Chapters 9 and 10 examine research and theory concerning language comprehension and production, respectively. The analysis will consider comprehension and production at various linguistic levels—sounds, words, and sentences. We will consider how language develops, why we make speech errors, and how we understand sentences. As mentioned earlier, Chomsky's theory of how language is structured and acquired was an important impetus in the development of modern cognitive psychology. We consider Chomsky's views and how psychologists have responded to him. In addition, Chapter 10 examines language impairments caused by damage to specific parts of the brain.

In the final section of the book, we focus on the topics in cognitive psychology that have traditionally been encompassed under thinking. Chapters 11–13 examine research and theorizing about logical thinking/decision making, problem solving, and creativity, respectively. Among the topics to be considered are whether humans are always able to think logically, how we make decisions in the face of less than complete information (Chapter 11), how we solve problems (Chapter 12), and the relationship between creative thinking and ordinary thinking (Chapter 13).

This has been enough in the way of background. We are now almost ready to begin our examination of human cognitive processes and their interrelations at the center: the functioning of memory. However, before we go there, it will be useful to review the material covered in this chapter.

REVIEW QUESTIONS

In order to help maximize the information obtained from each chapter, we have provided a set of review questions for each. Those questions, presented at the end of each chapter, will help you remember the information in the chapter if you use them in the right way. When you go over each question, the first thing to do is to try to answer it from memory, even if you are pretty sure that your answer is incorrect. Trying to remember the information, even if you are not successful, will increase the chances that you will remember the information after you learn the answer. Here are the review questions for Chapter 1.

1. Give an example of a situation in which our commonsense psychology is incorrect.

2. Why was Wundt an important figure in the development of modern cognitive psychology?

3. How did Wundt's methods differ from those of modern researchers?

4. What were behaviorism's main objections to the research on consciousness in early psychology?

5. What were the streams of research during the first half of the 20th century that helped pave the way for the development of modern cognitive psychology and how did each of them contribute?

6. How does modern cognitive science deal with the problem of studying hidden mental processes?

7. What is the relation between neuroscientific evidence and behavioral evidence in the development of theories of cognition?

8. Why was behaviorism rejected by many psychologists interested in the study of complex human functioning?

9. What developments in areas outside of psychology contributed to the cognitive revolution, and what were those contributions?

10. Why was Paivio's research significant in the development of modern cognitive psychology?

11. What changes have occurred in cognitive science between the publication of Neisser's groundbreaking book *Cognitive Psychology* and the one you are now reading?

12. How has the study of neurocognition contributed to our understanding of cognitive phenomena?

13. Briefly describe several techniques used to measure brain functioning related to cognitive processes.

14. What does it mean to say that cognitive processes are *constructive*?

15. What does it mean to say that cognitive functioning might be based on a *modular* system?