CHAPTER 1

INTRODUCTION

Cognitive psychology and its more inclusive partner, **cognitive science,** exert a strong influence on psychology as a whole and promise a scientific understanding of the human mind in all its complexity and significance. The discipline that you will study in this book concerns itself with the science of mental life, as defined by contemporary research methods, theories, and findings. The questions raised by cognitive psychology typically have ancient roots in the study of philosophy; the answers provided by the science of the mind are recent and undergoing continual refinement. Here you will learn how far we have come in one of science's grandest quests: the mind seeking to understand itself.

Cognitive psychology, neuroscience, developmental psychology, evolutionary biology, anthropology, linguistics, philosophy, computer science, and other research programs that together make up the broad interdisciplinary field of cognitive science are thriving. Discoveries beckon in understanding how humans perceive, remember, imagine, think, and create.

Consider the despair of a child who struggles in school because of an impairment in the ability to read written language, a disorder called dyslexia. Dyslexia is one of several learning disorders that cognitive psychologists study to understand the specific breakdowns in cognitive processes that are at fault. The concepts and theories of cognitive psychology assist educators to understand learning disorders and design interventions that help with reading and other learning problems in school-age children.

Or consider the anguish of family members who lose a parent to the confusion and memory loss of dementia of Alzheimer's type. This disease causes a progressive deterioration in cognition that in advanced stages leaves the victim with a complete loss of memory and self-identity. It affects primarily individuals over the age of 65, with the risk level rising to nearly 50% by age 85. Given that more people are living to advanced ages, Alzheimer's disease will, unfortunately, become increasingly common. Our ability to diagnose, prevent, and possibly even cure this tragic disease will depend on advances in cognitive psychology and its close relative, cognitive neuroscience.

SCOPE OF COGNITIVE PSYCHOLOGY

Historical Perspective

William James (1890) defined the whole of psychology as "the Science of Mental Life, both its phenomena and their conditions" in his classic book titled *The Principles of Psychology* (p. 1). More than a century later, the field of cognitive psychology has fulfilled James's vision. The cognitive approach to psychology pervades all areas of psychology today and even some of its neighbor sciences. The term surfaces often, as in cognitive development, social cognition, cognitive neuroscience, cognitive therapy, and cognitive anthropology.

This turn of events has been surprising given that for many decades, psychologists selected the study of behavior over the study of cognition. Behaviorism referred to an approach that tried to make psychology objective, like physics and chemistry. It tried to eliminate the discussion of consciousness and introspective reports on the contents of consciousness. It tried to reduce psychology to the study of observable behavior. Thus, research on classical conditioning and operant conditioning was in vogue because they depended solely on environmental stimuli and observable responses. Inferences about the cognitive operations that intervened between the stimulus and the response were unwelcome during the behaviorist era.

Behaviorism was a reaction to several schools of thought in psychology that emerged in the late nineteenth and early twentieth centuries (Boring, 1957). Structuralism aimed to describe the elemental components of consciousness, specifically sensations, images, and feelings. This school was based on the method of introspection pioneered by Wundt and developed by Titchener. The problem with this approach is that different observers too often gave different introspective reports in the experimental conditions arranged by the researchers. Also, cognition did not necessarily register in consciousness. For example, in judging which of two weights is heavier, an individual is conscious of numerous sensations. However, the decision process itself seems to occur unconsciously as a form of imageless thought. Functionalism arose as an alternative school of thought to deal with these problems. Angell, Thorndyke, and other functionalists studied the mental processes that mediated between the environment and the organism. Functionalism addressed what the mind is for, rather than its structural components. Today's cognitive psychologists are concerned with both the structural architecture of the mind and the mental operations that mediate between stimuli and responses.

Despite the accelerating pace of change in the discipline, James's *Principles of Psychology* remains worthwhile reading more than a century later. Numerous concepts and hypotheses first described by William James in 1890 remain viable today. He included discussion of the pioneering work of Hermann Ebbinghaus, who systematically studied his own ability to learn lists of nonsense syllables. Ebbinghaus selected material that was unfamiliar to him to control for the effect of past learning and meaning. Instead of measuring his ability to directly recall a list he had learned in the past, Ebbinghaus used an indirect method of measuring the time taken to relearn a list that had once been learned to perfection but was later forgotten to a degree. Ebbinghaus calculated the savings in the time needed to relearn a partially forgotten list relative to learning a control list from scratch. This so-called method of savings foreshadowed the contemporary interest in indirect ways of assessing memory performance, as will be discussed in Chapter 4.

Defining Cognitive Psychology

Cognitive psychology refers to the study of human mental processes and their role in thinking, feeling, and behaving. Perception, memory, acquisition of knowledge and expertise, comprehension and production of language, problem solving, creativity, decision making, and reasoning are some of the broad categories of such study. Experimentation lies at the heart of cognitive psychology, but as we will see, mathematical models and computer simulations also play a role. Cognitive psychologists measure behavior in laboratory tasks in order to reach conclusions about covert mental processes. As we will also see, the related discipline of cognitive neuroscience uses neuroimaging methods that try to relate activity in the brain to the behavioral measurements.

The discipline often portrays the human mind as first a processor of information: the mind computes answers to problems in a manner analogous to the software of a computer. A digital computer represents an arithmetic problem, such as 21 + 14, in a symbolic code of zeros and ones according to an agreed convention. Specifically, each digit is represented by eight bits of information, where each bit takes the value of either zero or one. Then, a software program processes those symbols according to the rules of addition, yielding the correct answer, 35. Similarly, as you read this problem and verified the answer, your mind interpreted the numbers and processed the information. The analogy between mental processes and computation has proved fruitful and provides what is called the *information processing approach* to cognitive psychology.

But the human mind does more than process information the way a computer would. Information technically refers to a reduction in uncertainty about events. For instance, consider the toss of a coin as an event with an uncertain outcome. If it comes up heads, then the uncertainty about the event has been reduced (one bit of information has been transmitted, to be mathematically precise). Information is transmitted in this example, but the event is meaningless. Now, suppose that the coin is tossed again, but this time heads means you lose $500 and tails means you win $500. Are you ready for the toss? The outcome again reduces uncertainty by one bit, but more important, the toss now has meaning. It refers to other events that are significant to you. Meaning, not information in the mathematical sense, provides the focus of human mental life (Bruner, 1990).

Trigram	*Word*
WAQ	PIG
BEC	LIP
LOK	CUP
RIZ	BAT
TUZ	MAP
LUT	CAP
DOX	TAG
PEM	RIB
GAX	CAT
MIB	LOG

Figure 1.1 A demonstration of meaning in the cognitive function of memory.

Throughout this book, the fundamental importance of meaningfulness will be plain. A simple illustration concerns your ability to remember the items from two different lists. The first list in Figure 1.1 contains meaningless trigrams; each set of three letters carries few natural associations (unless your initials are there by accident). The second list contains three-letter words, each of which refers to an object that you have experienced in the world and know well. Study the trigram list for 30 seconds and then try to recall the items without looking. Then, do the same with the word list. Undoubtedly, you will find the meaningful list much easier to memorize.

The mind lives and breathes through meaning. Our use of symbols to refer to objects, events, and other experiences; our efforts to understand why experiences occur as they do; and ultimately our hope to understand the purpose of our own existence all reflect the human need for meaning.

Finally, the discipline of cognitive psychology assumes that the mind and brain are systems that emerged through evolution. They have adaptive functions that enable us to succeed as reproducing organisms. The structures of mind and brain must be related to these adaptive functions, just as the opposable thumb of primates is related to their ability to grasp objects. Systems for perceiving, remembering, and thinking have evolved in a manner that allows us to adapt to our environment. Understanding these systems in the context of neurophysiology and evolutionary biology provides another driving force in the discipline. The human mind did not emerge from the spotless laboratory of a computer scientist; rather, it emerged from the messy forces of biological development and survival. Adaptations to the environment persisted in subsequent generations through natural selection.

To understand the mind from an evolutionary perspective, psychologists make comparisons of, say, memory functioning across different species. Another useful method is to study the cognitive development of memory in a single species, from infancy through old age. Functions that develop rapidly early in life are assumed to be genetically specified predispositions that were naturally selected in the history of the species. For instance, a predisposition to learn and use spoken language seems to be coded in the human genome, whereas the use of written language is not. Speech is learned early and rapidly during the first few years of childhood, whereas reading and writing are learned later and more slowly.

Cognitive science may be defined as the study of the relationships among and integration of cognitive psychology, biology, anthropology, computer science, linguistics, and philosophy (Hunt, 1989). It represents an interdisciplinary effort to address basically the same issues that confront cognitive psychology. How is knowledge represented? How does an individual acquire new knowledge? How does the visual system organize sensory experiences into meaningful objects and events? How does memory work? As shown in Figure 1.2, these are among the problems that cognitive science attempts to understand in terms that make sense to scholars from diverse backgrounds.

> Cognitive psychology is only one of the cognitive sciences. Others include behavioral and cognitive neuroscience, cognitive anthropology, and computer science.

Cognitive science is not a coherent discipline in and of itself but rather a perspective on several disciplines and their associated questions (Hunt, 1989). Researchers who regard themselves as cognitive scientists typically have educational backgrounds in at most one or two of the contributing disciplines. Furthermore, they approach the issues of mind and brain with research methods unique to their disciplines. As Stillings and colleagues (1987), an interdisciplinary team of co-authors, explained in their pioneering text in cognitive science,

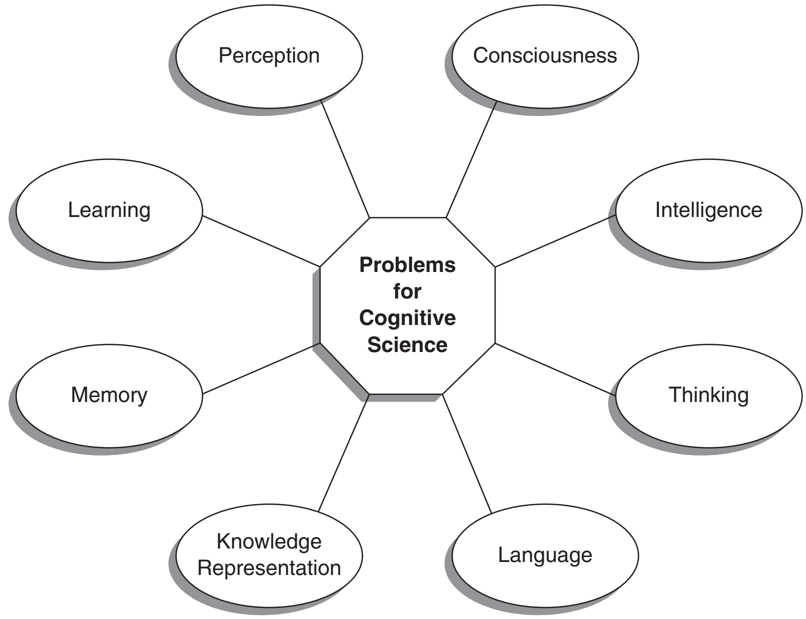

Figure 1.2 Eight critical areas of research in cognitive science and cognitive psychology.

> Psychologists emphasize controlled laboratory experiments and detailed, systematic observations of naturally occurring behaviors. Linguists test hypotheses about grammatical structure by analyzing speakers' intuitions about grammatical and ungrammatical sentences or by observing children's errors in speech. Researchers in AI [artificial intelligence] test their theories by writing programs that exhibit intelligent behavior and observing where they break down. Philosophers probe the conceptual coherence of cognitive scientific theories and formulate general constraints that good theories must satisfy. Neuroscientists study the physiological basis of information processing in the brain. (p. 13)

This book focuses on the theories, methods, and results of cognitive psychology. On occasion, we encounter arguments and evidence that might constitute an entire section or chapter in a text of another branch of cognitive science. The book tries to provide you with enough context to grasp the matter at hand without assuming that you have had a course in, say, neuroscience.

CORE CONCEPTS

Mental Representations

The information processing approach is built on the assumption that an organism's ability to perceive, comprehend, learn, decide, and act depends on mental representations. A **mental representation** is an unobservable internal code for information. It is helpful to contrast a mental representation of an object with a physical external representation. Take a robin, for example. Your mental representation of a robin codes information about the bird's shape, size, coloring, and perhaps even its distinctive song. An artist's drawing of a robin is an external representation of the real thing. It, too, may convey properly the bird's shape, size, and coloring, but it would certainly lack its song.

Now, close your eyes and imagine a robin. You are using your mental representations of birds to create an image that only you can experience. Some mental representations can be consciously experienced as images that are similar to visual, aural, and other kinds of perceptions. Unlike the artist's sketch, they cannot be observed by anyone but you. Mental representations are private and are perceived, if at all, only by their owners. Not all mental representations are perceived as images, and their owners may not be conscious of them. Even with the new technologies for examining the brain, scientists cannot read your thoughts because they cannot process your conscious or unconscious mental representations. Observing patterns of neural activity is not the same as experiencing mental representations. Look again, in your mind's eye, at the robin. Can you hear its song? Perhaps, but you will hear the real song of a robin only if you have acquired a mental representation of how a robin sounds. If you confuse it with the song of a cardinal or sparrow, that is because your mental representation is in error.

> All perceptions, memories, flights of imagination, and dreams occur because of mental representations that code information.

Mental representations, then, provide the basis for all cognitive abilities. To perceive your environment, you must compute mental representations of the objects around you and the events that are taking place. To comprehend and learn from this book, you must mentally represent the information that is conveyed through language. All that you know about the world, and your only basis for acting on the world, is found in your mental representations.

Stages of Processing

Another basic concept of cognitive psychology is that processes modify mental representations in a series of stages (Massaro & Cowan, 1993). To see this point, it is easiest to consider a specific task, such as the memory task presented earlier. To remember the trigrams, you needed to first perceive or encode them, meaning you had to read the letter combinations on the page. The encoding stage could be made harder by dimming the lights in the room so that the letters are not as legible. Next, you needed to store the encoded items in memory. The words were much easier to store than the meaningless letter combinations. Next, the items needed to be retrieved from memory, which was also easier with the meaningful material. Finally, the retrieved items needed to be spoken or written during the output stage of processing. So, to be able to recall WZT, you had to compute a mental representation during encoding, store this representation as an item on the list, retrieve the representation when trying to remember, and then convert the representation to a spoken or written word. **Stages of processing,** then, refers to the steps required to form, modify, and use mental representations in a cognitive task.

Serial Versus Parallel Processing

A fundamental question is whether cognitive processes occur one at a time or simultaneously during a given stage of processing. To illustrate, consider the encoding stage of the memory task. Is each item on the list encoded one at a time, or are all of them encoded simultaneously? **Serial processing** refers to cases in which cognitive operations occur one at a time in series. Are the letters P-I-G perceived one at a time or simultaneously? **Parallel processing** refers to cases in which cognitive operations occur simultaneously in parallel.

> Multiple cognitive operations occur at once in parallel processing, or they occur one at a time in serial processing.

Hierarchical Systems

In biology, the body is divided into systems composed of many component parts. These parts are arranged hierarchically. The respiratory system, the muscular system, the cardiovascular system, and the nervous system all are organized this way. For example, the nervous system divides into the peripheral branch and the central branch. The peripheral branch further divides into sensory versus autonomic components. As you know, the autonomic branch must be further divided into the components of the sympathetic system, on the one hand, and the parasympathetic system, on the other.

In cognitive psychology, the mind is also viewed as a hierarchical system composed of many component functions. For example, the mind can be divided into branches of perception, memory, and motor output. Memory is further divided into a working or short-term system and a long-term system. The long-term system appears to be composed of further subsystems, an issue that we examine in Chapter 5. The mind can be best described as a hierarchical arrangement of functional components that can be analyzed and studied in isolation (Simon, 1969). A core task of cognitive psychology is to determine the number and organization of these functional systems. The related field of cognitive neuroscience attempts to specify the brain structures that support each functional system.

Cognitive Architecture

The design or organization of the mind's information processing components and systems is referred to as its **cognitive architecture.** The distinction between a working memory system and a long-term memory system is an architectural distinction. Another such distinction is the organization of components or subsystems of, say, long-term memory. As a third example, some theorists contend that the mind is built from independent processing modules, with each **module** specialized for a particular function such as perceiving faces or recognizing speech. An alternative point of view is that the building blocks of the mind are flexible, general-purpose mechanisms that perform many diverse functions. Long-term memory is one general purpose mechanism in that it stores representations of both faces and speech sounds from the past to enable recognition in the present and future.

A fourth and final example is the distinction between symbolic and connectionist architectures. **Symbolic models** assume that the mind is built like a digital computer. Pioneering work on computers by von Neumann (1958) provided the foundation for such models. They assume that mental representations are symbols that are serially processed by a set of rules, just as the data in a computer are processed according to the rules of a program. Simon (1990) argued that "a system will be capable of intelligent behavior if and only if it is a physical symbol system . . . capable of inputting, outputting, storing, and modifying symbol structures, and of carrying out some of these actions in response to the symbols themselves" (p. 3). This class of architecture posits a centralized control over the flow of information from sensory input, through memory, to motor output. Shown in Figure 1.3 is Atkinson and Shiffrin's (1971) influential model of the control of

> Symbolic models explain cognition in terms of simulations that operate like a computer program that encodes, stores, and manipulates symbols.

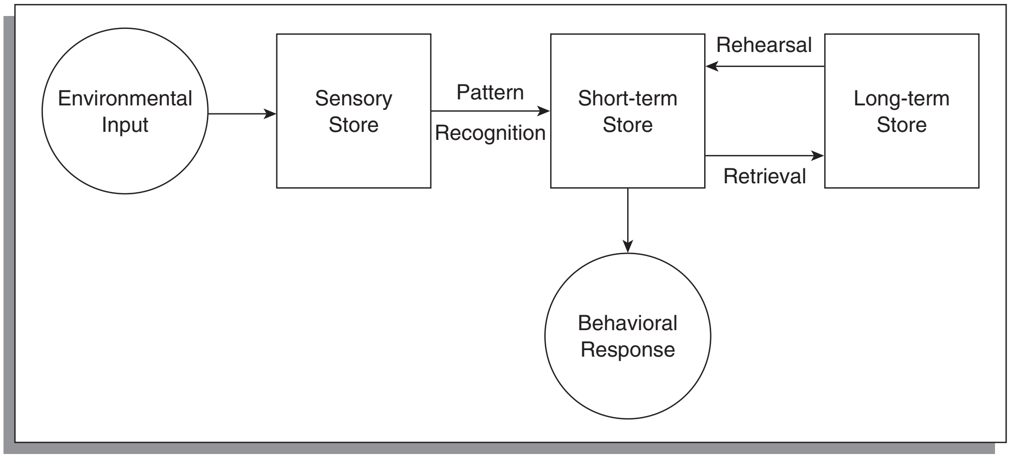

Figure 1.3 Cognitive architectures: Example of a symbolic model.

SOURCE: From Atkinson, R. C., & Shiffrin, R. M., The control of short term memory, in *Scientific American,* August 1971. Reprinted with permission.

short-term memory; it employs a symbolic architecture. Control processes, such as rehearsal, transfer information from a short-term memory store to a long-term store.

Connectionist models comprise an alternative class of cognitive architectures. Instead of looking to the digital computer, connectionist architectures try to use the structure of the brain itself as a model of the mind's structure. Instead of being based on a set of rules for operating on symbols, connectionist models are based on associations among numerous simple units called neurons. These are highly simplified units that bear scant resemblance to real neurons. However, the assumption is that a population of simple artificial neurons carries out computations that enable intelligent behaviors. Early connectionist models were proposed by McCulloch and Pitts (1943) and Hebb (1949). In connectionist architectures, there are no localized symbols to be processed. Instead, a mental representation is distributed over a population of neurons. Shown in Figure 1.4 is McClelland and Rumelhart's (1981) influential model of word recognition that uses a connectionist architecture. It employs three layers of units. The first layer represents visual features, the second represents letters, and the third represents words. Excitatory connections, shown by arrows, increase activation at a unit, whereas inhibitory connections, shown by dots, decrease it. Connectionist architectures are based on the spread of activation through local excitation and

Connectionist models explain cognition in terms of simulations of simple neuron-like units arranged in complex networks.

inhibition. Control of the flow of information is not centralized as it is in symbolic architectures.

Memory Stores

Atkinson and Shiffrin (1971) described a short-term store that retains information just attended to for several seconds (see Figure 1.3). They distinguished this kind of memory from a long-term store that retains information over intervals of several minutes, hours, days, weeks, months, or years. Furthermore, additional distinctions may be drawn. For example, in Atkinson and Shiffrin's model, during perceptual processing, very brief storage of information takes place in the visual or auditory registers—what is called sensory memory. Over the past 30 years, it has become clear that sensory, short-term, and long-term memory are, by themselves, insufficient to describe the complexity of memory stores. Long-term memory, for instance, is further divided into subsystems, as is described later in the book.

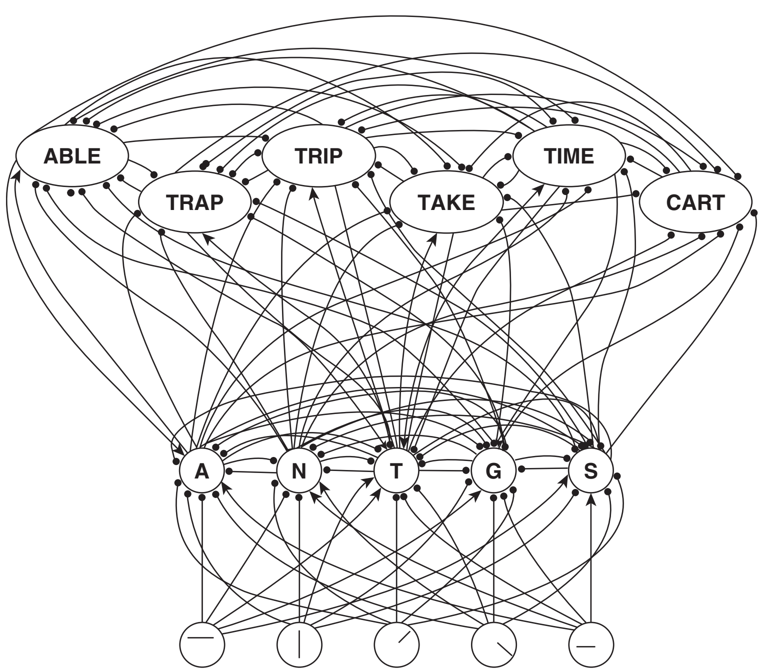

Figure 1.4 Cognitive architectures: Example of a connectionist model.

SOURCE: From McClelland, J. L., & Rumelhart, D. E. (Eds.). (1981). An interactive model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88,* 375-407. Copyright © American Psychological Association. Reprinted with permission.

Consciousness

Consciousness is certainly a core concept in cognitive psychology. But it has been a difficult one to investigate for many reasons, and progress has been slow. One major problem in studying consciousness is that the concept is not well-defined. People mean different things when they talk about consciousness, including the scientists who try to study it. Pinker (1999) explained that cognitive scientists often talk about consciousness as **self-knowledge**, even though this is not what the average person on the street means by the term at all. Self-knowledge refers to the capacity to represent the self mentally in addition to the objects, events, and ideas encountered in the external world. That is to say, included among the many kinds of knowledge that one has is knowledge about the self-concept. A human being can look in a mirror and recognize that she is viewing herself because she possesses knowledge about herself.

A second meaning of consciousness is **informational access,** the capacity to be able to report on mental representations and the processes that operate on them. Access consciousness includes the end products of our perceptual systems, allowing us to see, hear, smell, and touch the world around us and to feel the positions and tensions of our bodies. Some of these mental representations are attended to and maintained in short-term memory for several seconds. We seem to also have access to our emotional states and to our self-concept—an awareness of an executive, I, who interprets why things happen the way they do and makes decisions about how to behave in response. At the same time, many mental representations and the processes that operate on them are unconscious and unavailable for verbal report. Just as you do not have conscious access to workings of the cardiovascular system or the autonomic nervous system, you also do not have access to the processes that create vision or audition. For example, all of the processes that detect the lines that make up a single letter on this page, match the letter shape to a representation in memory, and specify where on the page the letter appears are unconscious. You have awareness only of the product—the perceived letters and words.

Finally, there is consciousness defined as **sentience,** the basic capacity for raw sensations, feelings, or subjective experience of any kind. How is it that a material object, the brain, can give rise to subjective experience? Trying to understand the relationship between consciousness as sentience and the brain has bedeviled philosophers and psychologists in what is known as the mind-body problem. A great deal is known about consciousness as self-knowledge and informational access. Despite mountains of books and articles on the problem, little if any progress has been made in understanding how, or even whether, the brain

> In cognitive psychology, the term *consciousness* can refer to self-knowledge, informational access, or sentience.

causes sentience. The positions on the mind-body issue are beyond our scope here; most of what you will learn about consciousness in this book concerns findings about self-knowledge and informational access.

Not all cognitive processing is accompanied by consciousness. Unconscious processes are fast, automatic, intuitive, and unreflective. These occur without the sentience, informational access, and self-knowledge associated with different aspects of consciousness. The cognitive processes that give rise to conscious awareness are, by contrast, slow, effortful, and deliberate. Many theories discussed throughout this book rely on a dual process of unconscious and conscious cognition. It is worth pointing out, however, that the unconscious processes posited in contemporary cognitive theories are not identical to the concept of the Freudian unconscious described in psychodynamic theory.

Emotion

The topic of emotion or affect has not traditionally been part of cognitive psychology. The information processing approach, and particularly the idea that the mind was a processor of symbols in a manner analogous to a digital computer, did not readily accommodate the study of fear, anger, sadness, happiness, and disgust. Instead, cognitive psychology focused on "cool" cognition and left the study of "hot" cognition—thoughts infused with emotion—to other areas such as social, personality, and clinical psychology (Phelps, 2006). However, the recent focus on cognitive neuroscience and on connectionist models that adopt the architecture of the brain as the basis for understanding the mind has placed emotion in the mainstream of cognitive psychology.

A fundamental debate centers on the basic structure of emotion. There is a long tradition of research suggesting that certain emotional states are genetically prewired categories of physiological and behavioral patterns. These affective states are universally experienced and recognized as social stimuli through facial expressions (Ekman, 1972). Human beings throughout the world can readily interpret the facial expressions of fear versus happiness, for example. Neuroimaging methods, introduced later in this chapter, have been used to try to capture the patterns of neural activation in the brain corresponding to each basic emotion. To illustrate, when an animal freezes when confronted with a threatening, fear-inducing stimulus, a group of neurons in a brain region called the amygdala become active (LeDoux, 2000). It has been proposed that the amygdala is part of a neural circuit that mediates the emotional state of fear in humans as well. Specifically, the amygdala seems to be involved in a fast, unconscious reaction to the fearful stimulus. Human beings may then follow this with a slower, deliberate, and conscious appraisal of the situation. This is one example of dual process theory applied to our understanding of human emotional responses.

An alternative theoretical framework suggests that categories such as fear, sadness, happiness, and so on are not the way nature carves up emotional life at all. Instead, these psychological categories are elaborate constructions from biologically simpler, more fundamental dimensions of affective valence (pleasure/displeasure) and arousal (high activation/low activation). From this affective dimension perspective, it may not be possible to identify a specific neural circuit for, say, fear. The response of freezing and the activation in the amygdala associated with it could be part of more than one emotional state. Researchers are currently looking to discover whether the brain circuitry of fear is distinct from the circuitry involved in, say, anger (Barrett & Wager, 2006). These emotions are similar in valence and arousal and, in fact, have brain regions in common. Of interest, then, is whether each emotional category has a specific "brain marker" that can be disentangled from others that share some, but not all, brain regions in common.

THE BRAIN

Cognition is assumed to be a function of the brain, just as breathing is a function of the lungs or blood circulation is a function of the heart. The human brain may well be the most complex structure in the known universe. Consider just a few of the brain's properties to understand this point (Sejnowski & Churchland, 1989). A neuron is one of about 200 different types of cells that make up the 100 trillion (10^{14}) cells of the human body. As shown in Figure 1.5, a neuron includes dendrites for receiving signals from other neurons, a cell body, and an axon for transmitting a signal to other neurons via a synaptic connection. This is an idealized illustration of one of several classes of neurons that vary in the size, shape, number, and arrangements of their dendrites and axons. The dendrites of a single neuron may receive as many as 10,000 synaptic connections from other neurons. The central nervous system is composed of 1 trillion (10^{12}) neurons of all kinds and about 1,000 trillion (10^{15}) synaptic connections among these neurons.

Cerebral Cortex

The outer neural covering or "bark" of the brain is called the cerebral cortex. It is the most recently evolved part of the brain and is, therefore, referred

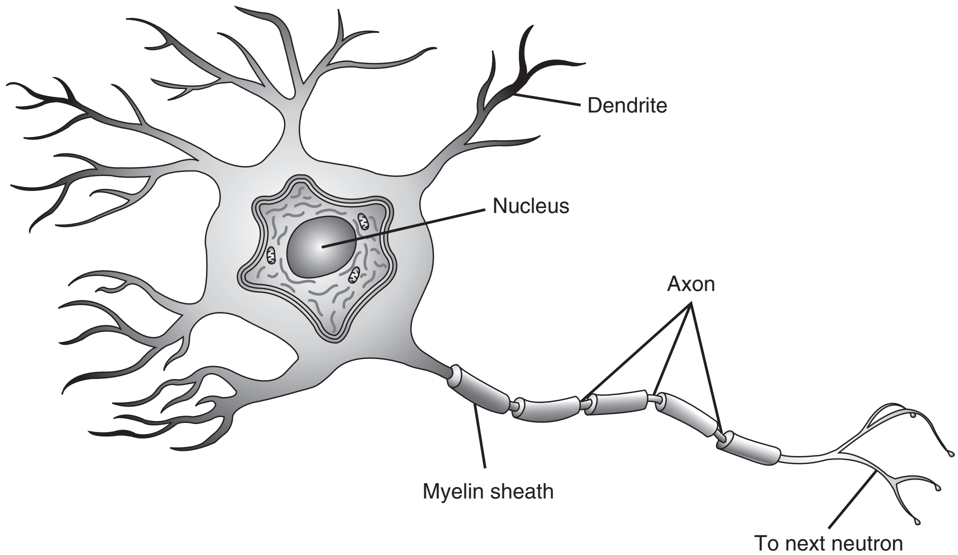

Figure 1.5 The basic components of a neuron.

to as **neocortex** to differentiate it from the more primitive, ancient types of cortex (e.g., the **limbic system**). The cerebral cortex is especially well-developed in primates, including human beings, and cetaceans, including dolphins and whales. The total surface area of the human cerebral cortex is 2,200 to 2,400 square centimeters, but most of this is buried in the depths of the *sulci* (Gazzaniga, Ivry, & Mangun, 1998). To pack that much neural tissue in the small space of the human cranium is no small challenge. The evolutionary solution to this problem was to fold the cortex, creating the convoluted surface seen in Figure 1.6. Each enfolded region is a *sulcus.* Cortical regions within these lobes have been mapped extensively based on the structure of the neurons in those regions and how they are arranged with respect to each other. The surface area of the cerebral cortex is made of gray matter, which consists of densely interconnected, unmyelinated neurons. Regions below the surface appear white in color because of the fatty myelinated fibers that insulate the axons of the neurons to speed their signal transmission (see Figure 1.5).

Shown in Figure 1.6 are the four lobes of the cerebral cortex from (a) a lateral view, (b) a medial view, (c) a dorsal view, and (d) a ventral view. These regions are separated, in part, by anatomical markers called the central sulcus, lateral fissure, and longitudinal fissure. The lobes of the cerebral cortex are divided into a left and right hemisphere by the longitudinal fissure. Large folds

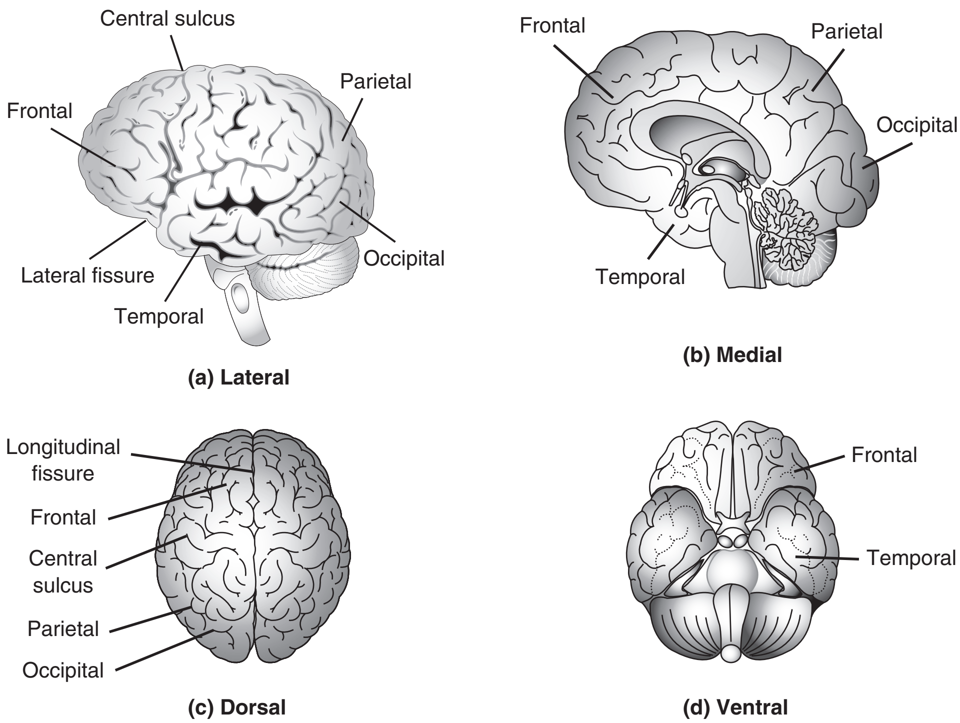

Figure 1.6 Four views of the lobes of the cerebral cortex.

in the cortex identify the boundaries of the four lobes of the brain. The **frontal lobe** extends from the anterior of the brain back to the central sulcus. The **temporal lobe** lies on the side of the brain, beginning below the lateral fissure. The **parietal lobe** extends toward the rear of the brain, beginning at the central sulcus. The **occipital lobe** lies at the rear base of the brain.

The two hemispheres look like similar structures, but they do not perform exactly the same functions. Instead, the left and right hemispheres have evolved to specialize to a degree in particular cognitive functions (Ornstein, 1997). For example, the left hemisphere specializes in producing and comprehending language. For its part, the right hemisphere specializes in recognizing faces and processing the spatial relationships among objects.

Underneath the lobes of the neocortex lies the limbic lobe, an evolutionarily old portion of cortex that mediates emotionally driven behaviors fundamental to survival, such as approach, attack, mate, and flee. These basic responses are found in primitive reptilian species such as the crocodile, where the limbic lobe analyzes olfactory or smell stimuli that are linked to these survival responses (Thompson, 2000). The limbic system consists of the limbic lobe and subcortical structures including the cingulate gyrus, fornix, **hippocampus**, and amygdala. Many of the components involved in emotion are shown in Figure 1.7. These regions are highly developed in mammals, so much so that the limbic system is sometimes referred to as the "mammalian brain" (MacLean, 1973). The primary function of the limbic system is regulation of motivational and emotional states. These range from rudimentary states of pleasure (reward) versus pain (punishment) to more complex motivational drives, such as hunger, thirst, and sex. The basic emotions of fear, sadness, anger, and happiness are also mediated by the limbic system, as perhaps are still more complex blends of emotions, such as jealousy.

Because the limbic system is so well-developed in mammals, animal models have been extremely useful for understanding the neural substrates of emotion and their role in cognitive functioning (LeDoux, 2000). For example, the hippocampus plays a critical role in learning and memory storage as well as in emotion.

The most primitive or ancient parts of the brain in terms of evolution are the brain stem and the spinal cord. The **brainstem** consists of the midbrain and the hindbrain, which includes structures called the medulla oblongata, pons, and **cerebellum**. Together these provide the basic life support

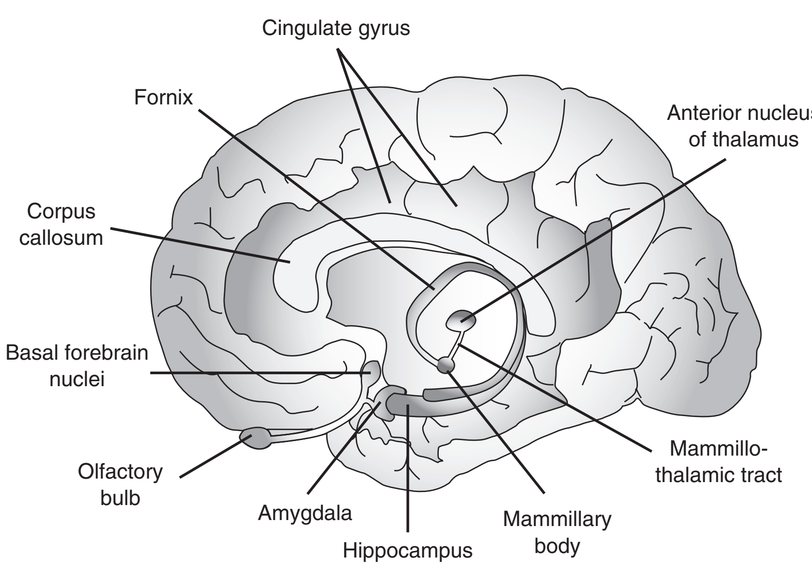

Figure 1.7 Brain structures involved in emotions.

SOURCE: From Beatty, J. (2001). *The human brain: Essentials of behavioral neuroscience*. Reprinted with permission of Sage Publications, Inc.

mechanisms of the body, such as regulating respiration, heart rate, and blood pressure. In primitive animals such as fish and amphibians, the hindbrain and midbrain are about the end of the story. The forebrain is hardly developed at all, totally unlike mammals, whose forebrain evolved into the large, complex structures of the limbic system and neocortex. The life support structures of the spinal cord, hindbrain, and midbrain, together with other ancient regions immediately surrounding the midbrain, are sometimes called the “reptilian brain” (MacLean, 1973). The human brain, therefore, evolved as a composite structure with the reptilian brain at its core, the mammalian limbic system surrounding this core, and the neocortex, in turn, surrounding the limbic system.

Parallel Processing

Another way the brain supports cognitive function is parallel processing. Many separate streams of data are processed to support a single cognitive function. Each parallel stream involves a series of stages of processing. Consequently, it is misleading to think of a cognitive function, such as recognizing your friend across a crowded room, as dependent on just one cortical region. Although it is known that certain regions in the temporal cortex of the brain are necessary for face and other object recognition, in a parallel data stream in the parietal lobe, the location of your friend in the room is computed simultaneously (Gazzaniga et al., 1998). As shown in Figure 1.8, a ventral or side pathway projects from the occipital lobe to the temporal lobe—the so-called “what” pathway. The dorsal or top pathway projects from the occipital lobe to the parietal lobe—the “where” pathway.

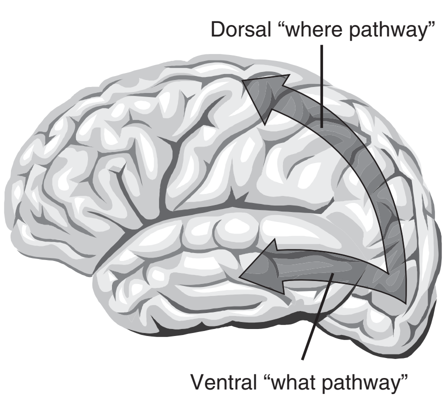

Figure 1.8 The ventral “what” pathway versus the dorsal “where” pathway.

Shown in Color Plate 2 in the section of color plates are the results of a functional magnetic resonance imaging study in which the participants attended to the identity of a face (by matching it to another face) or attended to its location in a different matching condition. The red arrow marks the ventral pathway, and the green arrow marks the dorsal pathway. As may be seen, there was greater activation in the ventral pathway in the face matching condition and greater dorsal activation in the location matching condition (Haxby, Clark, & Courtney, 1997).

Although the brain uses parallel processing extensively, serial processing is also involved. For example, the streams of data corresponding to facial recognition and to identifying location both depend on an earlier serial stage of processing in the visual cortex of the occipital lobe. The occipital, parietal, and temporal lobes all are necessary for recognizing your friend. No one region is sufficient by itself, and both parallel and serial processing are necessary.

> Some functions are known to be localized in the neocortex, such as preliminary visual processing in the occipital lobe. However, visual perception depends on multiple regions of the brain carrying out processes in parallel, such as identifying an object using the temporal lobe while spatially locating it using the parietal lobe.

RESEARCH METHODS

Laboratory experiments that measure behavior form the methodological backbone of cognitive psychology. Measuring behaviors can inform us about cognitive processes. For example, counting the number of words correctly recalled from the list shown in Figure 1.1 would shed light on memory processes. Cognitive psychologists and neuroscientists also measure physiological indicators of brain activity. The neuroimaging methods, for example, are increasingly being used to understand brain structures that support a particular cognitive function. Cognitive psychologists typically try to isolate a particular component of cognitive functioning, such as working memory. They design a laboratory task that allows them to study the characteristics of this component by manipulating independent variables. For example, the digit span task calls for a research participant to recall a list of digits, such as 1-6-4-8-3-9-2, immediately after their presentation. The number of digits presented is an independent variable.

The independent variable causes changes in a dependent variable or measurement of performance in the chosen task. By manipulating the independent variable and measuring its effects, clear causal relationships may be established. In our example, the percentage of digits correctly recalled is the dependent variable. The percentage correctly recalled decreases once the number of digits exceeds about seven. Studies of this type are considered in

Chapter 4. Researchers commonly manipulate more than one independent variable at a time. For example, a researcher might vary both the number of digits presented and whether they are heard or seen by the participant.

Behavioral Measures

Typical dependent variables in cognitive psychology measure the speed and accuracy of human performance. Some tasks are so easy and automatic that few errors occur. For example, are these letter strings the same or different: WAQ, WAO? Now, try again with this pair: WAQ, BEC. **Reaction time,** the number of milliseconds to perform a task, provides a sensitive measure of the cognitive processes required. The participant is provided with two buttons and presses the one on the right if the letter strings are the "same" and the one on the left if they are "different." The first pair of letter strings in the example above requires identifying a single distinctive feature to make the correct "different" response, and the additional search time for this feature is easily detectable in reaction times measured with millisecond accuracy. Reaction times might range from 400 to 500 milliseconds in same-different judgment tasks, depending on the stimuli compared. Such times are much larger than the neural transmission time for inputting information from the eye to the brain and for outputting a motor response from the brain to skeletal muscles. Furthermore, reaction times vary in systematic ways as stages of processing are added to or subtracted from tasks (S. Sternberg, 1995).

The proportion of correct responses, or conversely the **proportion of errors,** provides another widely employed measure. For example, in a memory experiment such as the one demonstrated in Figure 1.1, the researcher might measure only the proportion of errors made in recalling the words or nonsense syllables. Suppose that instead of asking the participant to recall the words, a recognition test was given. Which of these two words appeared in Figure 1.1: PIG, DOG? Here, the researcher could readily measure not only the errors but also the time taken to reach a decision. Typically, the faster the reaction time in a task, the higher the proportion of errors. This relationship is called a speed-accuracy trade-off.

Lastly, **verbal protocols** or tape-recordings of people thinking aloud while they carry out a task provide a rich record of conscious processing. For example, suppose that you are presented with an arithmetic problem to solve. As you solve the problem, verbalize aloud your thinking. Remember to vocalize each thought you have as you solve the problem: 482 + 341 = ?

Ideally, the research participant introspects and reports all that passes through consciousness without omitting any thoughts. Equally important, the process of thinking aloud ought not to change the processes used to perform the task. If providing verbal protocols distorts the processes normally used when thinking silently, then the validity of the method is compromised. Problem solving, reasoning, writing, and related tasks have been investigated extensively using verbal protocols. In such tasks, it is possible to identify many of the steps individuals work through in arriving at final solutions. The use of verbal protocols is justified so long as the processes required by a task are mentally represented in a verbal format or can be readily translated into words, phrases, or sentences (Ericsson & Simon, 1980). It is also necessary to demonstrate that thinking aloud is inert and does not react with and alter the processes that the researcher is trying to reveal (Russo, Johnson, & Stephens, 1989).

Physiological Measures

Besides behavioral measures, physiological measurements of bodily systems, including the brain, are also collected in experiments. These include continuous monitoring of eye movements and other muscular activity or changes in the autonomic nervous system such as heart rate, blood pressure, respiration rate, and skin conductance. Direct measurements of brain activity are also examined. The electroencephalogram (EEG) is a multichannel recording of the continuous electrical activity of the brain. It is measured with a multichannel recorder that detects voltage changes generated by large numbers of neurons below each of many electrodes placed on the scalp. The frequency and amplitude of these voltage fluctuations depend on whether the brain is awake and alert, drowsy and relaxed, or at various stages of sleep, including the well-known phase of rapid eye movement sleep.

An EEG signal that reflects the brain's response to the onset of a specific stimulus is called an **event-related potential** (**ERP**) or simply an evoked potential. To illustrate ERPs, consider the response of the brain to the presentation of a novel stimulus. An ERP called the P300 component (also known as the P3a) is the positive peak in the EEG signal that occurs 300 milliseconds after onset of an attention-getting stimulus, as shown in Figure 1.9. This component arises from an individual orienting to a novel stimulus and can be readily observed when recording from regions in the frontal lobe (Knight, 1996). Researchers use an "odd ball" task in which participants attend to and count an infrequent stimulus (e.g., red dot) while ignoring the frequent occurrences of another stimulus (e.g., green dot). In normal individuals, a novel red dot elicits a P3 ERP associated with detecting and remembering its occurrence. It turns out that this response is absent in alcoholics, however, even when they have quit drinking. Abstinent alcoholics display a diminished or delayed ERP in the odd ball task, reflecting a long-term impairment in the processing of novel information (Rodriguez, Porjesz, Chorlian, Polich, & Begleiter, 1999). The effect does not reflect alcohol intoxication per se because the participant is sober when tested.

An ERP measures the activation of large numbers of neurons in a cortical region by detecting positive and negative voltage fluctuations on the scalp in response to a stimulus event. Multiple ERPs occur as time passes after the event is first registered.

Moreover, the novelty deficit indexed by a P300 response might not even be related to the effects of chronic alcohol consumption per se. The children of alcoholics who have not yet consumed alcohol also show the same deficit in the odd ball task. Thus, this cognitive deficit may reflect a genetic predisposition to ignore novel stimuli rather than an alcohol-produced deficit. Of great importance, the ERP deficit can, in theory, be used as a marker of the genetic disorder. Children and adolescents who display this ERP deficit

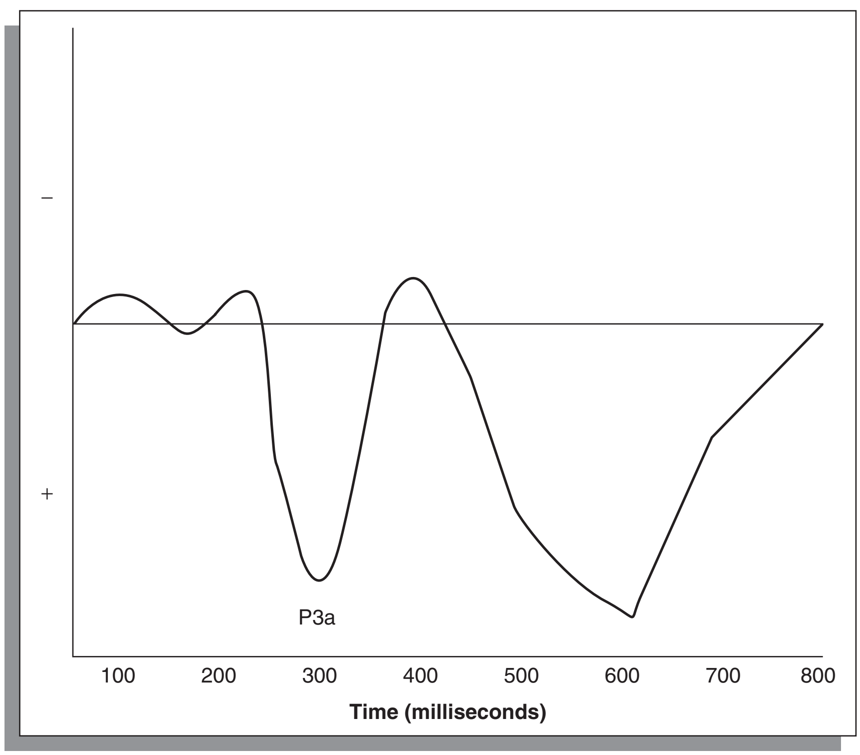

Figure 1.9 An idealized P3a ERP elicited 300 milliseconds after the presentation of a novel unexpected visual event. By convention, positive voltage changes are plotted below the *x* axis.

SOURCE: Adapted from Knight (1996).

are vulnerable to alcohol dependence and should avoid ever starting to drink.

Neurometric profiles can be developed that show how various stimuli and tasks evoke activities in different regions of the brain. Posner and his colleagues have developed a geodesic sensor net containing 128 electrodes for obtaining such profiles (Posner & Raichle, 1994). Each electrode, in the form of a tube containing saline solution, rests on a small sponge that makes contact with a carefully calibrated spot on the person's head. By averaging together the voltage changes that occur following the presentation of a stimulus, a waveform can be plotted at each of the locations.

EEG and ERP provide information about the temporal dynamics of neural activation in the millisecond range. Such electrophysiological measures of brain activity show excellent temporal resolution (see Figure 1.10). But it is not possible to identify the specific location, within a few millimeters, of the neuronal networks that generate the evoked potentials and fields. To pinpoint the location of neuronal activity, other methods are required.

Neuroimaging. Methods of neuroimaging measure the location of neural activation generated during a cognitive task. Two techniques now in wide use

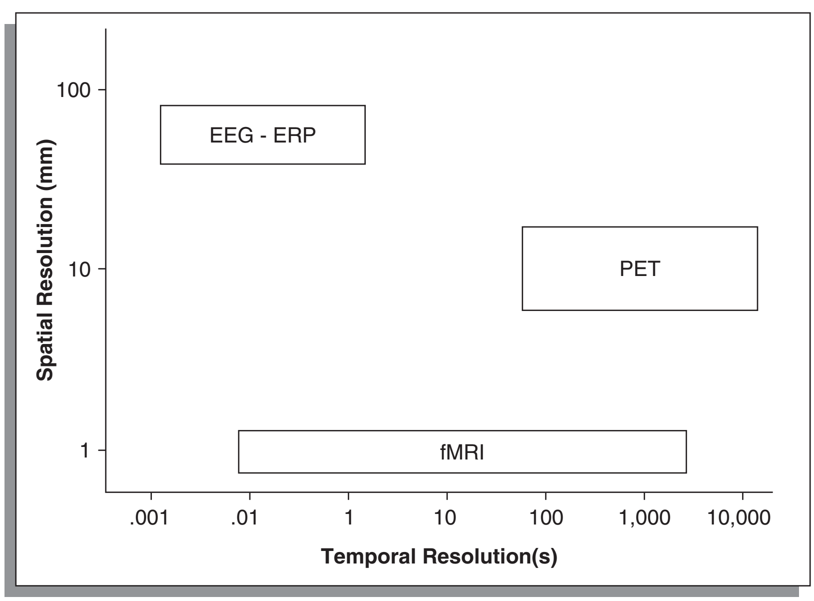

Figure 1.10 The spatial (*y* axis) and temporal (*x* axis) sensitivity of different neuroimaging techniques.

provide an indirect measure of more localized brain activity as compared with electrical scalp recordings. The first of these is **positron emission tomography (PET).** PET uses injections of radioactively labeled water (hydrogen and oxygen 15) to detect areas of high metabolic activity in the brain before the radioactive substance decays completely and is no longer radioactive (about 10 minutes). PET images require multiple scans and allow the reconstruction of a three-dimensional picture of activated regions.

The second technique is called **functional magnetic resonance imaging (fMRI).** With fMRI, a powerful magnetic field is passed through the head to reveal detailed images of neuronal tissue and metabolic changes reflecting the brain's cognitive activity. This technique extends the method of structural MRI that simply shows a detailed static image of the brain's structure. Both PET and fMRI are based on the principle that as areas of the brain increase their activity, a series of local physiological changes accompanies the activity and provides a way to measure it (Buckner & Petersen, 2000). PET works by detecting increases in blood flow in the vascular network that supplies a population of neurons; fMRI works by detecting changes in the concentration of oxygen in the blood—this is often referred to as the BOLD signal in fMRI studies, an acronym for blood oxygenation level–dependent. Thus, both PET and fMRI reveal how the brain supports behavior in a cognitive task by measuring local changes in blood properties. Because changes in blood flow and oxygenation take a few seconds to occur, the neuroimaging methods do not provide the temporal resolution found with evoked potentials (see Figure 1.10). The color plate section of the book includes several examples of PET and fMRI images. A person undergoing an fMRI scan is shown in Figure 1.11.

> PET and fMRI provide neuroimages of the living brain as it processes information in a cognitive task. An increase in brain activity in a region is detected by increases in blood flow with PET and by increases in blood oxygenation with fMRI.

A high degree of neural activation in one region of the brain provides evidence that it is necessary for the cognitive process under investigation. It does not mean that the region is sufficient, all by itself, for the process in question. The brain processes multiple streams of data in parallel, and multiple structures are typically activated in any task. How are the regions of interest identified for a particular cognitive process?

The **method of subtraction** is used to isolate the properties of a single stage of cognitive processing. The method assumes that stages of processing used in a simple task are not modified in some way when a choice is added to the task. This is called the assumption of pure insertion. If a control task requires Stages 1 and 2 of processing and an experimental task requires Stages 1, 2, and 3, then pure insertion holds when the experimental task does

Figure 1.11 An fMRI scanner at the Washington University laboratory in St. Louis, Missouri.

SOURCE: Courtesy of Steven E. Petersen, Washington University, St. Louis, MO.

not in any way alter the processes and time needed for Stages 1 and 2. In this way, the extra time required by the experimental task can be assigned to the demands of Stage 3 (S. Sternberg, 1969, 1995).

For example, suppose that researchers design two tasks for the participants that, in theory, demand exactly the same cognitive processes but for a single process of interest. The researcher then obtains neuroimages during both tasks and subtracts one from the other, leaving only the brain activity related to the process under study. A classic PET study on how word names are retrieved from long-term memory illustrates the method of subtraction (Posner, Peterson, Fox, & Raichle, 1988).

Participants in the study were presented with familiar nouns one at a time (e.g., *bottle*). The way the words were presented and the instructions regarding how to process the words were varied at different points during the experiment. The experiment was designed hierarchically, so that the processes engaged by one set of instructions provided a control condition for examining the brain regions activated by a condition higher in the hierarchy. The design is shown in Figure 1.12. In the fixation point only or control condition, brain activity associated with focusing attention on the task is measured. The activation pattern obtained in the "perceive fixation" condition is then subtracted from the activation levels found when words are perceived as the experimental condition. This subtraction isolates the processes involved in "word recognition." In the next experimental condition, participants repeated each word aloud. Now, the "perceive word" condition is used as a control, and its activation is subtracted from the "repeat word" activation. In so doing, the activation associated with "speech production" is isolated. Finally, the "repeat word" or experimental condition serves as the control for the task of generating functional uses of the words. For example, if presented with the word *bottle,* the participant might respond with *drink.* The "generate use" task requires that the meaning or semantic features of each word be processed, and the activation associated with this semantic processing is thus isolated.

The results are shown in Color Plate 1 in the section of color plates. Following convention, the relative degree of blood flow in a region is depicted in a different color. The highest to lowest levels of activation are coded by white, red, orange, green, blue, and purple, respectively. These show activation patterns resulting after subtracting the appropriate control activation patterns for each of the four tasks in the left hemisphere only. In the upper left scan, participants visually perceived each word. As shown,

Control	*Experimental*	*Experimental-Control*
Perceive fixation	Perceive word	Word recognition
Perceive word	Repeat word	Speech production
Repeat word	Generate use	Semantic processing

Figure 1.12 The method of subtraction used in neuroimaging studies of cognitive processes.

regions in the occipital cortex at the rear of the brain were activated in this condition. In the upper right scan, a similar passive perception condition is shown, except in this case the words were heard rather than seen. As a result, the auditory cortex in the temporal lobe was recruited into action. When participants repeated the words, PET revealed activation in the frontal motor areas of both hemispheres. Finally, generating a verb related to each word recruited extensive regions in the left prefrontal cortex, including Broca's area. This semantic processing also recruited regions in the temporal cortex that other research has suggested are involved in representing meaningful categories.

Brain Lesions. The oldest method of studying the function of the brain is to examine individuals who have suffered damage to brain tissue through accidents, strokes, and diseases of the brain such as Alzheimer's and Parkinson's disease. For example, in the nineteenth century, Paul Broca reported a case study of "Tan," a man with brain damage whose speech ability was reduced to saying the word "tan" repeatedly. Such tragic circumstances have provided the data for the field of clinical neuropsychology, which seeks to correlate specific lesions in the brain with specific kinds of behavioral and cognitive deficits. Lesions have also been experimentally created in rats, rabbits, monkeys, and other mammals to determine the function of the damaged area. With the exception of psychosurgery performed on psychiatric patients, for ethical reasons lesions have not been created in humans. Indeed, many have questioned the ethics of treating even severely disturbed psychiatric patients with lesions in the frontal lobe and limbic system.

Until recently, clinical neuropsychology was limited to verifying the exact location of a lesion only after the death of a patient through postmortem examination of the brain. For example, Broca discovered that Tan's brain was damaged in the left frontal lobe. This became known as Broca's area when it was discovered that additional patients with speech disorders also suffered from lesions there. Today, the use of structural as opposed to functional MRI scans allows identification of the brain regions injured by a stroke, aiding the process of using lesion case studies to understand how the brain supports cognition.

> The case study method of research is a valuable tool in cognitive neuroscience. The behavior of a patient is related to the specific areas of the brain known to be damaged by a tumor, accident, or stroke.

In using single cases or group studies, the investigator attempts to find two tasks that discriminate between the performance of normal controls and patients with lesions in a particular region of the brain (Gazzaniga et al., 1998). The objective is to find evidence that one cognitive function is served by one brain region, whereas a different function is served by another brain region. To reach this conclusion, the investigator seeks double dissociations, in which the specific type of brain injury affects performance in two tasks in different ways.

In general terms, a **double dissociation** refers to situations in which an independent variable affects Task A but not Task B, and a different variable affects Task B but not Task A. One independent variable might be a lesion in the parietal cortex as compared with normal controls. A second independent variable might be a lesion in the frontal lobe as compared with normal controls. To illustrate, suppose that Task A measures planning in problem solving and Task B measures locating objects in space. If it can be shown that frontal lobe damage disrupts planning performance relative to normal controls but has no effect on locating objects in space, then a single dissociation has been demonstrated (see Figure 1.13). If, in addition, it can be shown that the parietal damage affects locating objects in space but not planning in problem solving, then a double dissociation has been established. The double dissociation isolates planning as a function of the frontal lobe and locating objects in space in the parietal lobe.

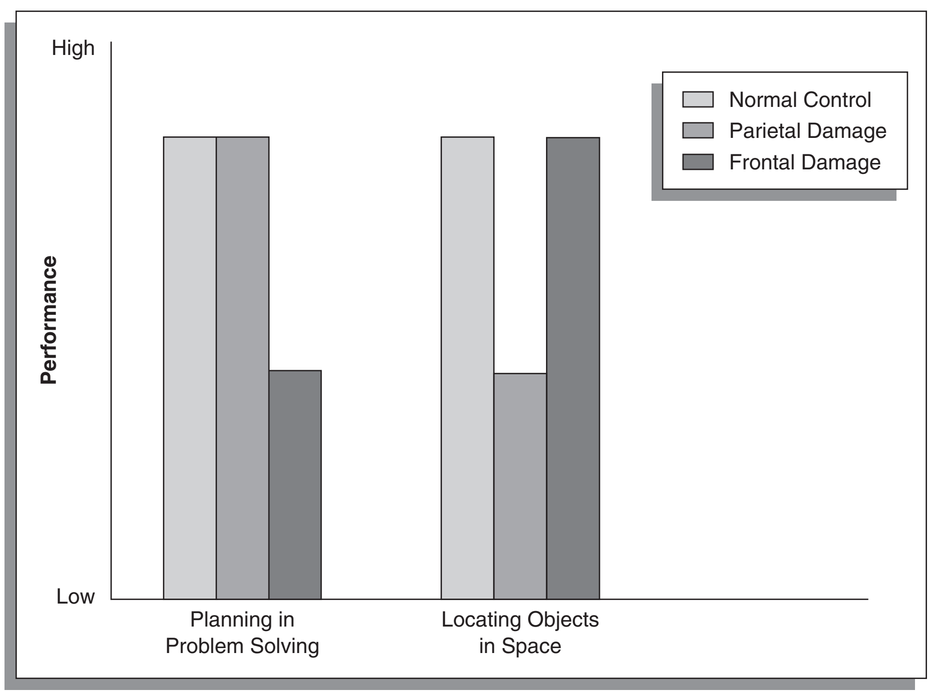

Figure 1.13 Hypothetical results of studies illustrating a single dissociation and a double dissociation.

SUMMARY

1. The beginnings of a scientific understanding of the human mind are taking shape in the fields of cognitive psychology and cognitive science. These fields connect with numerous areas of inquiry, as one would expect of a science of mental life. Cognitive psychology is the study of human mental processes and their role in thinking, feeling, and behaving. Cognitive science takes a mathematical perspective of the mind or brain as a computational device and draws insights and methods from psychology, biology, anthropology, linguistics, philosophy, and computer science.

2. Information must be mentally represented to be involved in perception, memory, or any other cognitive activity. It is through our mental representations that we know anything and everything. Mental representations are processed in stages such as encoding the information, storing it in memory, retrieving it when needed, and manipulating the information to arrive at a decision. Cognitive operations needed to, say, retrieve an item from memory may, in theory, occur in a series of steps or in parallel. Symbolic models and connectionist models are two alternative ways to describe the architecture of the information processing system.

3. Consciousness is another core concept of cognitive psychology that does not stem from information processing theory. It is necessary to distinguish between unconscious cognitive operations and those that give rise to the subjective qualities of consciousness. There are three senses in which the term *consciousness* is used in cognitive psychology. Self-knowledge means the capacity to represent the self mentally in addition to the objects, events, and ideas represented. Information access means being aware of and able to report on mental representations and cognitive processes. Finally, sentience means the capacity for feelings and other subjective experiences.

4. The human brain may well be the most complex structure in the known universe. The central nervous system contains on the order of 1 trillion neurons and about 1,000 trillion synaptic connections among these neurons. The outer layer of the brain—the cerebral cortex—is symmetrically divided into two hemispheres. Within each hemisphere, the frontal, temporal, parietal, and occipital lobes are distinguished. Regions within these anatomical structures support specific cognitive functions, such as speech or face recognition. The limbic system lies beneath the cerebral cortex and is important in emotion, learning, and memory. The organization of the brain is highly parallel, with many separate streams of data being processed to support a single function, such as the recognition of an object in a spatial location.

5. Cognitive psychologists measure behavior that provides information about cognitive processes (e.g., verbal protocols of thinking aloud). They also measure physiological indicators of brain activity, such as event-related potentials (ERP) and neuroimages (PET and fMRI). Lesions provide another way to study the cognitive functions served by the brain. A double dissociation refers to a lesion that disrupts performance on Task A but spares performance on Task B, whereas a different kind of lesion disrupts Task B but spares Task A. Double dissociation suggests that the two brain regions damaged by the lesions support different cognitive functions, as measured by Tasks A and B.

KEY TERMS

cognitive science

mental representation

stages of processing

serial processing

parallel processing

cognitive architecture

module

symbolic models

connectionist models

self-knowledge

informational access

sentience

neocortex

limbic system

frontal lobe

temporal lobe

parietal lobe

occipital lobe

hippocampus

brainstem

cerebellum

reaction time

proportion of errors

verbal protocols

event-related potential (ERP)

positron emission tomography (PET)

functional magnetic resonance imaging (fMRI)

method of subtraction

double dissociation