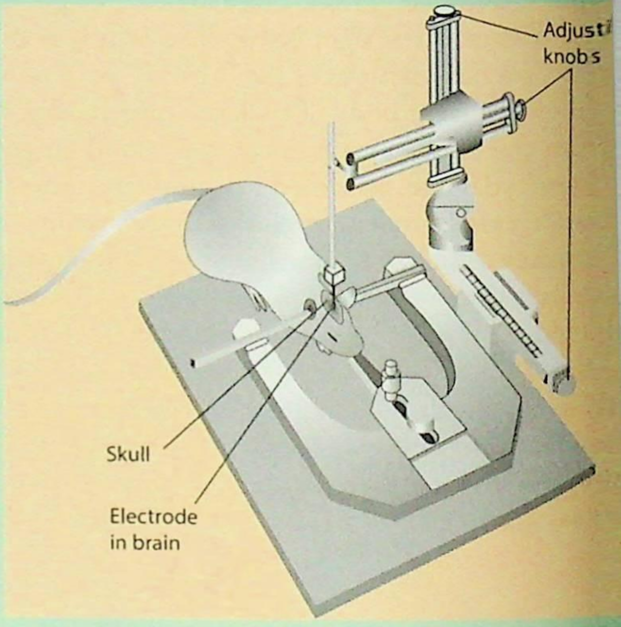
develop illnesses that damage their brains directly, or that lead to medical procedures (e.g., surgery) that cause damage. While these events are tragic for the persons who experience them, they provide psychologists with invaluable research opportunities. By observing the symptoms or deficits shown by such persons, psychologists can sometimes determine what portions of their brains are involved in various forms of behavior. For instance, consider a woman who shows the following baffling set of symptoms. If one object is held in front of her, she can name it. If two objects are held in front of her, however, she will name one of them *but not the other*. In addition, she can recognize that one wooden block is larger than another; but when asked to pick one block up, she fails to adjust the distance between her fingers and thumb according to the size of the object. What is responsible for these strange symptoms? By studying a number of persons who show them, psychologists have determined that the symptoms stem from damage to an area of the brain on the border between the parietal and occipital lobes (e.g., Broussaud, di Pellegrino, & Wise, 1996; Goodale et al., 1994). In many instances, then, studying persons who have experienced damage to areas of their brains can provide valuable information.

Experimental Ablation: Observing the Effects of Damage

Where human beings are concerned, psychologists must wait for naturally occurring damage to see what effects this produces. But with laboratory animals, it is possible to damage the brain in order to study the effects produced. While this may sound cruel, it is, of course, done under highly humane conditions, and it causes no pain in subjects (the brain has no pain receptors). Usually, researchers damage specific areas of the brain (create brain lesions) by inserting tiny electrodes that emit very high-frequency alternating current. The current produces heat that destroys cells in the chosen area. Because electrodes can be placed with high accuracy, this experimental *ablation* can be a valuable tool for determining the functions of specific regions of the brain.

Figure 2.13
Apparatus for Studying the Brain
This device (known as *stereotaxic apparatus*) enables psychologists to place tiny electrodes within the brain of animals with great prevision.
(*Source*: Carlson, 1999.)



Recording and Stimulating Neural Activity

A third method for studying the brain involves recording the electrical activity that occurs within it. This can involve recording the activity of individual neurons (with tiny *microelectrodes* implanted into the brain) or of brain regions (with larger *macroelectrodes*). In both cases, changes in patterns of activity that occur in response to specific stimuli, or during various activities, are recorded. (Changes in response to specific stimuli or events are referred to as *event-related brain potentials,* or ERPs for short.) The results can often help researchers identify the specific functions of different regions of the brain. With humans, electrodes cannot generally be implanted in the brain; so recordings are made from

(*Continue*

the outside of the scalp, a procedure known as **electroencephalography** (EEG).

Images of the Living, Intact Brain

And now for the newer methods provided by advances in technology. One of these is **computerized tomography** (CT). This procedure uses X rays to scan the patient's head from many different angles. A computer then produces two-dimensional pictures; each picture is like a slice through a loaf of bread or an apple, and these are compared to determine where, for instance, damage to the brain exists. A second and even more valuable procedure for studying the functions of the brain is **magnetic resonance imaging**, or **MRI**. Here, images of the brain are obtained by means of a strong magnetic field. Hydrogen atoms, found in all living tissue, emit measurable waves of energy when exposed to such a field. In MRI, these waves are measured and combined to form images of the brain. These MRI images are impressively clear and therefore extremely useful in the diagnosis of many brain disorders. A recent development is *functional* MRI, in which images can be scanned much more quickly than in the past.

A third recently developed imaging device is called **SQUID**—short for **superconducting quantum interference device**. SQUID produces images based on its ability to detect tiny changes in magnetic fields in the brain. When neurons fire, they create an electric current. Electric currents, in turn, give rise to magnetic fields that the SQUID interprets as neural activity. Researchers have used SQUIDs to map various brain functions, including constructing a representation of the hearing part of the brain.

Finally, scientists use **positron emission tomography**, or **PET**, scans to see what's happening in the brain as it performs various functions. PET scans accomplish this by measuring blood flow in various neural areas, or by gauging the rate at which glucose, the brain's fuel, is metabolized. Individuals undergoing PET scans are injected with small amounts of harmless radioactive isotopes attached to either water or glucose molecules. Blood flow (containing the radioactive water molecules) is greatest in the most active areas of the brain. Similarly, glucose is absorbed by brain cells in proportion to their level of activity, with the most active cells taking in the greatest amount of glucose. As a result, PET scans allow scientists to map activity in various parts of a person's brain as she or he reads, listens to music, or engages in a mental activity such as solving math problems. For instance, look at the PET scans. The top row shows activity while a person is in a relaxed state; the lower scans show the same person's brain while he is clenching and unclenching his fist. Scans can be made while people perform almost any activity you can imagine, or in order to compare persons with various mental disorders with persons who do

Electroencephalography (EEG): A technique for measuring the electrical activity of the brain via electrodes placed at specified locations on the skull.

Computerized Tomography (CT): A method of brain scanning in which a series of x-ray images are synthesized and analyzed by computer.

Magnetic Resonance Imaging (MRI): A method for studying the intact brain in which technicians obtain images by exposing the brain to a strong magnetic field.

SQUID (Superconducting Quantum Interference Device): An imaging technique that captures images of the brain through its ability to detect tiny changes in magnetic fields in the brain.

Position Emission Tomography (PET): An imaging technique that detects the activity of the brain by measuring glucose utilization or blood flow.

not show such disorders. As you can guess, PET scans provide psychologists with an extremely valuable tool.

Now that I've described the basic methods used by psychologists to study the brain, let's see what recent research using such methods has revealed. These methods have definitely lived up to their promise; they have added tremendously to our knowledge of the intricate—and intimate—links between the brain and behavior.

REVIEW QUESTIONS

- Who are "split-brain" persons? What evidence do they provide for specialization of functions in the two cerebral hemispheres?
- What evidence from persons with intact brains supports such specialization?
- What methods are used by psychologists to study the brain and its role in behavior?

The Brain and Human Behavior:
Where Biology and Consciousness Meet

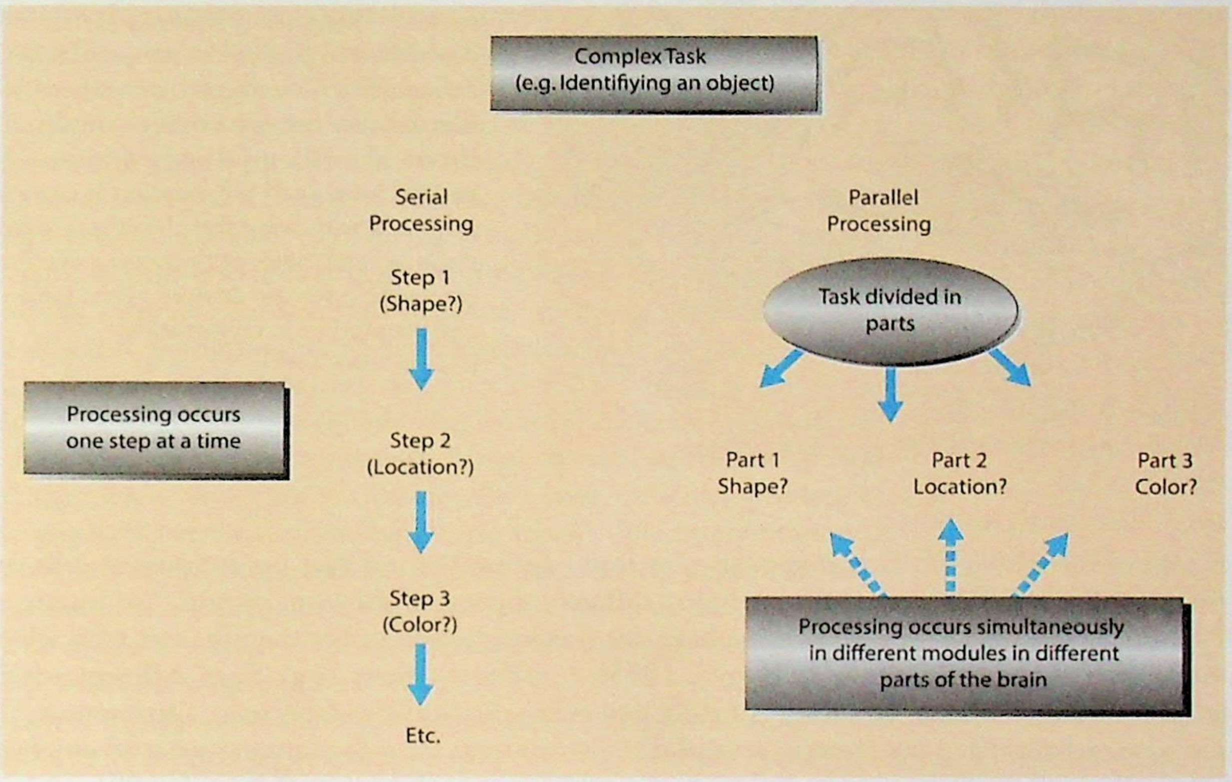
Armed with the new techniques and procedures described in the Research Methods section, psychologists and other scientists have begun to understand how the brain functions to produce human consciousness—our perceptions of the world around us, our thoughts and memories, our emotions. As you can probably guess, the findings of this research are complex; but they also tell a fascinating story. So read on for a look at one of the true cutting edges of modern science.

How the Brain Functions: An Example from Visual Perception

So far, we've taken the brain apart, examining its major parts and considering evidence that the two hemispheres are specialized for somewhat different tasks. Let's now try to put it back together by looking at how, according to modern research, the brain actually functions. We could illustrate this perspective in many ways; but our knowledge of visual perception—how we perceive the color, shape, and location of physical objects—is perhaps the most advanced, so it is a good place to begin.

Let's start with this question: Do modern computers provide a good model of how the brain works? As we'll see in Chapter 6, such a model has been useful in the study of memory, because our brains and computers do seem similar in certain respects. Both can receive information, enter it into storage (memory), and retrieve it at a later time. But, in fact, computers and the human brain are different in a fundamental way. Modern computers are *serial* devices: They work on information one step at a time. In contrast, our brains appear to process information in a parallel fashion; this means that many *modules*—collections of interconnected neurons—process information in different ways simultaneously. These modules may be scattered at widely different locations in the brain. Moreover each may work on a different aspect of a task. The more complex the task, the greater the number of modules that are called into operation. The result is that even very complex tasks can be handled very quickly, because different aspects of them are performed at the same time. In contrast, a computer proceeds in a serial manner, working on one step at a time, and this can result in slower performance, especially for complex tasks.

Figure 2.14
Serial versus Parallel Processing
In serial processing, tasks are performed one step at a time, in sequence. In parallel processing, in contrast, tasks are divided into subtasks, and all of these are performed simultaneously. Growing evidence suggests that our brains function through parallel processing, in which separate *modules* (collections of interconnected neurons) work on various parts of a task simultaneously.



As a concrete illustration of this difference, let's consider visual perception. We could readily program modern computers to differentiate between simple shapes such as triangles and squares. How would the computer do this? If we started with a drawing of, for instance, a triangle, this could be scanned by an input device (e.g., a scanner). The computer (really, its program) would then use this information to calculate the location of each line in the drawing, the angles between lines, and so on. It would then compare this information to definitions of "triangle" and "square" previously entered into its memory (or the program) and would classify each figure as a "triangle" or "square" depending on how closely it matched these definitions. So far so good. But what if we wanted the computer to recognize human faces? The program for *this* task would be truly immense, and step-by-step serial processing might take a long time indeed. In contrast, because our brains employ parallel processing by large numbers of modules, we can handle this task with ease. In fact, while computers take much longer to recognize complex patterns, human beings do not. So the fact that our brains act as parallel processors is a big advantage.

More direct evidence for this view of how the brain functions is provided by research on visual perception. As humans we are largely visual creatures, and this means that when we look around us, we can readily recognize vast numbers of objects, tell where they are in space, and use this information to react to them (e.g., pick them up or get out of their way!). How do we do this so quickly and effortlessly? Parallel processing

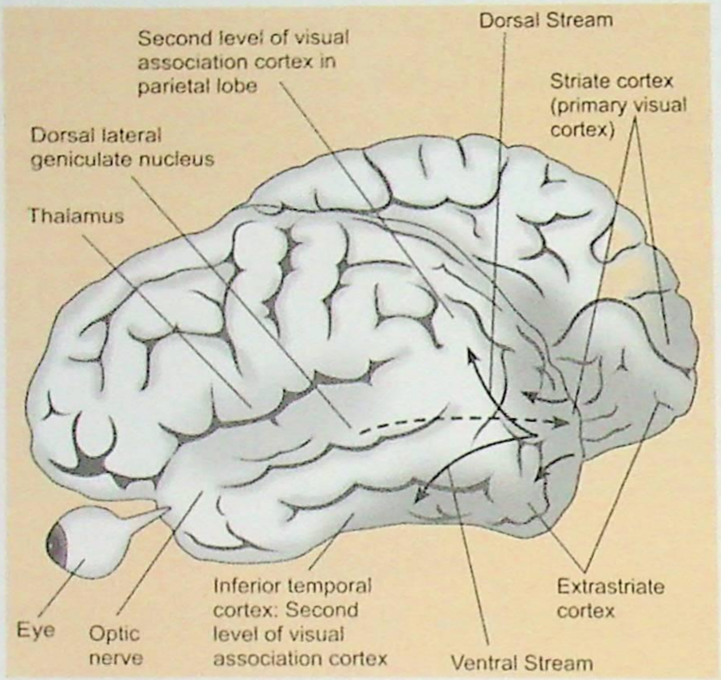


Figure 2.15
Parallel Processing in the Visual System
Information from our eyes arrives at the extrastriate cortex, where it divides into two separate streams. One stream (ventral) carries information downward to part of the temporal lobe; such information is concerned with where an object is or how we can react to it physically. The other stream (dorsal) moves upward to areas in the parietal lobe; such information is concerned primarily with what the object is—identifying it. Because both types of processing occur at once (in parallel) we can analyze visual information and respond to it very quickly.
(*Source:* Carlson, 1999.)

provides part of the answer. In fact, it appears that from the level of our eyes up, we possess cells specialized for performing different functions—for analyzing different aspects of the visual world. For instance, various cells (or modules) respond to new objects we have not previously seen rather than to ones with which we are very familiar (e.g., Logothetis, Pauls, & Poggio, 1995); to different views (e.g., from different angles) of the same stimulus (Wange, Tanaka, & Tanifjui, 1996); and even specifically to faces (e.g., Desimone et al., 1984) Perhaps even more surprising, we seem to possess different systems for responding to *what* an object is and fo determining *where* it is and how we can deal with it (reach for or touch it) (Goodale et al., 1994; Ungerleider & Mishkin, 1982). Research findings indicate that information from our eyes arrives at the *extrastriate cortex* and from there divides into two separate streams. One stream (ventral) carries information downward to part of the temporal lobe; such information is concerned with where an object is or how we can react to it physically. The other stream (dorsal) moves upward to areas in the parietal lobe; such information is concerned primarily with identifying what the object is (see Figure 2.15).

A study by Haxby and his colleagues (1994) provides clear evidence for this difference. Participant were shown either a human face or a random pattern, and then a second face or pattern. In a *form discrimination* task, they had to indicate whether the second stimulus was the same as the first they had seen. I a *location* task, they had to indicate whether the second stimulus was shown in the same place as the firs (the location could vary). PET scans of participants' brains indicated that activity in the extrastriate corte increased for both tasks, but that the form discrimination task increased activity in the ventral stream while the location task increased activity in the dorsal stream. Under normal conditions, processing occur in both streams simultaneously—thus enabling us to recognize and react to objects very quickly. Suppose for instance, that someone throws something to you and shouts "Catch!" You have only a split second t recognize the object and react; yet the chances are good that you will reach out your hand if it is somethin safe and acceptable (e.g., a tennis ball) but will jump out of the way if it is something less desirable—a shar object or a messy one. Your ability to do this is a good illustration of the advantages of parallel processing such processing allows us to recognize objects, their location in space, their movement, and other features with amazing speed. This example of our ability to respond so quickly to the word "Catch!" also neatly sets the stage for the next brain–behavior link we will consider: our ability to understand and use speech.

The Brain and Human Speech

Our capacities to produce and understand speech are amazing. But these remarkable abilities aren't nearly as mysterious as they once were. In recent decades, psychologists and other scientists have gained a much clearer picture of the regions of our brains that play key roles in speech. We say "regions" because, in fact, several areas are important. It is the integrated functioning of all of them that allows us to produce and understand speech.

Let's start with speech production. Here, a region in the frontal lobe near the primary motor cortex, known as **Broca's area**, is crucial. Damage to this area disrupts the ability to speak, producing a condition known as *Broca's aphasia*. People with Broca's aphasia produce slow, laborious speech that is agrammatical in nature—it does not follow normal rules of grammar. For instance, on being asked to describe a picture of a girl giving flowers to her teacher, one patient said: "Girl ... wants to... flowers ... flowers and wants to.... The woman wants to ... The girls wants to ... the flowers and the women" (Saffran, Schwartz, & Marin, 1980). In addition, persons with Broca's aphasia can't seem to find the word they want; and even if they do, they have difficulty pronouncing these words. What do all these symptoms mean? One interpretation is that this portion of the brain, and the regions immediately around it, contain memories of the sequences of muscular movements in the mouth and tongue that produce words. When Broca's area is damaged, therefore, the ability to produce coherent speech is impaired.

Broca's Area: A region in the prefrontal cortex that plays a role in the production of speech.

Wernicke's Area: An area in the temporal lobe that, through its connection with other brain areas, plays a role in the comprehension of speech.

The task of speech comprehension—understanding what others say—seems to be focused largely in another region of the brain located in the temporal lobe. Damage to this region—known as **Wernicke's area**—produces three major symptoms: inability to recognize spoken words (i.e., to tell one word from another), inability to understand the meaning of these words, and inability to convert thoughts into words. Together, these symptoms are known as Wernicke's aphasia. Careful study of these symptoms has revealed that in fact they stem from somewhat different kinds of damage to the brain. If Wernicke's area alone is damaged, *pure word deafness* occurs—individuals can't understand what is said to them and can't repeat words they hear; that's the first major symptom listed above. They aren't deaf, however; they can recognize the emotion expressed by the tone of another person's speech (e.g., that the person is angry or sad) and can hear other sounds, such as doorbells or the barking of a dog. Further, they can understand what other people say by reading their lips.

If an area behind Wernicke's area (sometimes known as the posterior language area) is damaged but Wernicke's area itself is spared, persons can repeat words they hear but have no understanding of their meaning—that's the second major symptom listed above. The fact that such persons can repeat words they hear suggests that there is a direct link between Wernicke's area and Broca's area; and, in fact, such a connection has been found to exist. If injury to the posterior language area completely isolates it from Wernicke's area, the third symptom listed above occurs: Affected persons can no longer produce meaningful speech on their own—something that patients with damage to Wernicke's area alone can do. Finally, if both Wernicke's area and the posterior language area are damaged, then all three symptoms of Wernicke's aphasia result: Persons with such injuries can't recognize spoken words, understand their meaning, or convert their ideas and thoughts into words.

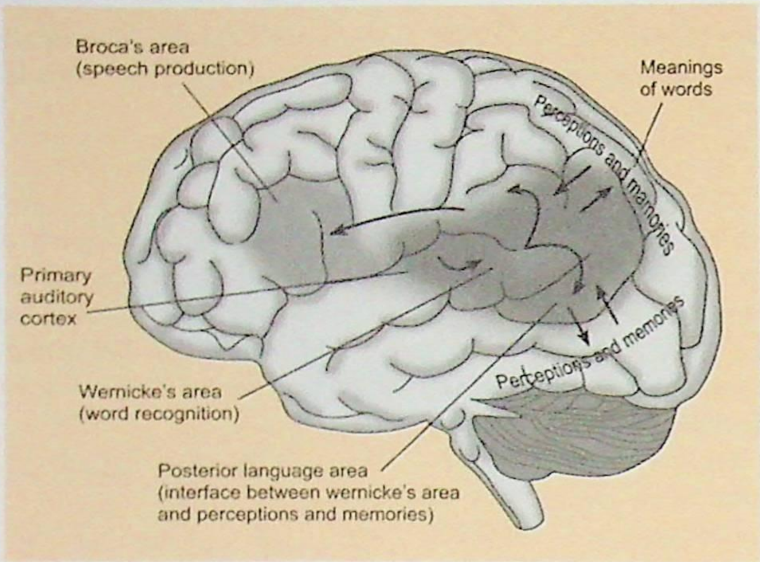


Figure 2.16
The Neural Basis of Human Speech: One Model
Existing research suggests that comprehension of speech involves the flow of information from Wernicke's area to the posterior language area and then to sensory association areas and back again. (The meanings of words may be stored in sensory association areas.) Speech production involves the flow of information from sensory association areas to the posterior language area and then to Broca's area.

(*Source:* Carlson, 1999.)

Putting all of these findings together, psychologists have developed the following model of human speech. The meanings of words involve our memories for them—what the words represent (objects, actions)—and such memories are stored in sensory association areas outside Broca's and Wernicke's areas. *Comprehension* of speech involves a flow of information from Wernicke's area to the posterior language area and then to sensory association areas and back again. Speech *production* involves the flow of information from sensory association areas to the posterior language area and then to Broca's area. This is probably an oversimplification of a highly complex process, but it is consistent with current knowledge about the role of the brain in speech. Figure 2.15 summarizes this emerging model.

The Brain and Higher Mental Processes

Try this simple problem: Sandra has longer hair than Shalana. Shalana has longer hair than Marielena. Does Sandra have longer hair than Marielena? The answer is obvious, but how do you obtain it so effortlessly? How, in short, do you know that if Sandra's hair is longer than Shalana's, and Shalana's is longer than Marielena's, then Sandra's hair must also be longer than Marielena's? Remember our basic theme: Everything psychological is ultimately biological. So reasoning, problem solving, planning, and all of our *higher mental processes* must involve events occurring in our brains. But what parts of our brains? And what kind of events? These are among the questions currently being investigated by psychologists in their efforts to understand the role of the brain in all aspects of human behavior. We can get only a glimpse of this work here, but I'm confident that even that will start you thinking about the complexities—and rewards—of investigating brain–behavior links.

Relational Reasoning

Let's begin with reasoning, and specifically the kind of *relational reasoning* illustrated by the hair-length example above. In essence, reasoning depends on the ability to manipulate mental representations of relations between objects and events in our minds: You don't have to see Sandra, Shalana, and Marielena to know that Sandra's hair is longer—you can tell just from reasoning about them. But here's the crucial point: While you can tell that Sandra's hair is longer than Shalana's directly from the sentence "Sandra's hair is longer than Shalana's," there is no statement comparing Sandra and Marielena; so here you must mentally integrate multiple relations to attain the correct solution. This ability, many experts believe, may underlie several of our higher mental processes. For instance, take planning. To formulate effective plans, we must be able to arrange many goals and subgoals according to their importance. This, again, involves being able to integrate multiple relations so that we can see, for instance, that Goal C is more important than Goal D, which in turn is more important to us than Goal F (e.g., Delis et al., 1992).

Now for the key question: Does any part of the brain play a special role in such reasoning? A growing body of evidence suggests that the *prefrontal cortex*—part of the association areas of the brain—is a likely candidate (e.g., Graham & Hodges, 1997).

REVIEW QUESTIONS

- What is the modern view of how the brain functions?
- What evidence suggests that processing of visual information occurs in a parallel fashion?
- What is the modern view of speech production and speech comprehension?
- What portions of the brain are involved in relational reasoning?
- What evidence suggests that the words and music in songs are processed by different modules within the brain?

Food for Thought

Do you think it will ever be possible to build computers that use true parallel rather than serial processing? If so, will such computers truly have a "mind"?

Heredity and Behavior:
Genetics and Evolutionary Psychology

By now, we hope, the basic theme of this chapter is clear: All aspects of behavior, including our consciousness, result from complex biological processes within our bodies. Given this basic fact, it makes a great deal of sense to consider the relationship of **heredity**—biologically determined characteristics—to behavior. After all, many aspects of our biological nature are inherited; so in an indirect manner, and always through the filter of our experience and environmental factors, heredity can indeed influence behavior (Rushton, 1989a, 1989b). In this final section we'll examine several aspects of heredity that appear to be relevant to an understanding of the biological bases of behavior.

Heredity: Biologically determined characteristics passed for parents to their offspring.

Chromosomes: Threadlike structures containing genetic material, found in nearly every cell of the body.

Genes: Segments of DNA that serve as biological blueprints, shaping development and all basic bodily process.

Genetics: Some Basic Principles

Every cell of your body contains a set of biological blueprints that enable it to perform its essential functions. This information is contained in **chromosomes**, threadlike structures found in the nuclei of nearly all cells (see Figure 2.17). Chromosomes are composed of a substance known as DNA, short for deoxyribonucleic acid. DNA, in turn, is made up of several simpler components arranged in the form of a double helix—something like the twisting water slides found by the sides of large swimming pools. Chromosomes contain thousands of **genes**—segments of DNA that serve as basic units of heredity. Our genes,