HUMAN MEMORY AND COGNITION
To the three who matter most:

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THE HUMAN INFORMATION PROCESSING SYSTEM

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Our theory of human thinking and problem solving postulates that the human operates as an information processing system (IPS). . . An IPS is a system consisting of a memory containing symbol structures, a processor, effectors, and receptors. . . The smallest units of information held in the memories of the IPS are symbols. There is no evidence that the human LTM (long-term memory) is fillable in a lifetime, or that there is a limit on the number of distinguishable symbols it can store. Hence, we assume that the IPS has a potentially infinite vocabulary of symbols, and an essentially infinite capacity for symbol structures. (Newell & Simon, 1972, pp. 19–20, 792)

If you’re a typical reader, you probably had Intro Psych no more than two or three years ago. Your book probably discussed concepts such as sensory memory, rehearsal, search through long-term semantic memory, and problem solving. Compare that with the following. The Intro Psych book I studied was published in 1963, not that long ago (after all, it was “after the revolution”). The text claimed that apparently the most important principle of memory was retroactive inhibition. It didn’t mention the terms information processing, sensory memory, or comprehension, and the chapter on memory was called “Retention.” Symbols and symbol structures were not discussed in the book, and computer science, which furnished cognitive psychology with a fundamentally important way of thinking about mental processes, was absent to an equal degree.

I think we surely have to conclude that cognitive psychology is asking more interesting and important questions now than were asked 20 or 30 years ago, and is discovering solid answers to at least some of those questions. In 20 or 30 more years, we may look back and conclude that today’s cognitive psychology wore blinders in some respects, was ignorant of some fundamentally important issues, or even was misguided in some basic ways. Nonetheless, I still think future psychologists will applaud cognitive psychology for reintroducing the undeniably important topics of memory and thought to the science of psychology.

This chapter, like the first, contains largely introductory material. In chapter 1, you got a very general idea of what cognitive psychology is all about, and you read a bit of the history of this approach. The purpose of that material was to make cognitive psychology a living, breathing thing for you—no more some abstract, academic quest that only Ph.D.s can be interested in, but a dynamic and vibrant approach to questions of human memory and thought. I tried to give you some of the flavor of the field and a sense of the excitement that cognitive psychologists feel for their topic by describing some of the shouting matches that gave birth to cognitive psychology. A student of 20 years ago, fired with curiosity about how memory works, would have been sent off to study retroactive interference, paired-associate learning, and forgetting curves. The same student today would be sent off to study topics such as human reasoning, comprehension of paragraphs, metaphorical language, and the like. This certainly seems a more rewarding set of questions to study—there has been progress.

Nonetheless, it must be admitted that these newer questions and interests are often quite difficult to pin down in a scientific fashion. The practitioners of a science need more than just the questions to tell them what experiments ought to be done and how they ought to do them. If, in particular, scientists need some sort of general framework to guide them, a set of assumptions that tells them where to start, what to look for, what to beware of. This general framework is sometimes referred to as a metatheory, where meta means above or beyond. A metatheory is this set of assumptions and guiding principles, a kind of Michelin guide that helps us find our way through unknown territory.

To a large extent, cognitive psychology’s Michelin guide, our metatheory, has been the information processing approach. This broadly defined approach describes cognition as the coordinated operation of active mental processes within a multicomponent memory system. The human information processing system that is described is thus a general model of the human memory and cognitive systems, a model that goes hand in hand with the broad approach known as information processing. Notice that as it was originally used, however, the term information processing had a rather narrow connotation, one that emphasized a one-by-one sequence of mental operations where one operation was assumed to end before another could begin. You’ll read about this so-called strict information processing approach to learn how it came about, what it said, and how it generated some important discoveries and ideas. You’ll also read about the drawbacks and limitations in the narrowly defined approach and how these led to the broader, less restrictive information processing approach of contemporary cognitive psychology. Our aim, therefore, is first to present the original information processing model and then to elaborate and revise it to take more recent developments into account.

A second goal of this chapter is to alert you to some of the important themes and ideas that you will encounter in this book. Some of these are rather new ideas in cognitive psychology, and so are not reflected in the general information processing model of the early 1970s—automatic and conscious processing is probably the best example of this kind of theme. Some are perennial issues that continue to be important to our theories and research—attention is, without doubt, the best example of this kind of issue. And finally, some are overriding issues, not specific to any one theory or approach, but general questions that cognitive psychology must consider. A good example of this is the issue of “the representation of knowledge”; this is essentially the question of how we organize or structure the information that we store in the memory system. You won’t find

1 The term metatheory is probably not the same as Kuhn’s (1962) paradigm, although there are important similarities.
sections throughout this book with these titles, though. Instead, the themes are recurring issues, basic ideas that contribute to several areas of cognitive psychology. If you can read a chapter and identify and discuss the themes that pertain to it, then you probably have achieved a good understanding of the material.

▼ Getting Started

As you read in chapter 1, a growing number of psychologists in the Forties and Fifties seem to have become disenchanted with the behaviorist approach to psychology—too many, it seemed too limited, narrow, and rigid to cope with complex human behavior and performance. During this period, the seemingly unrelated fields of communications engineering and computer science supplied psychology with some particularly intriguing ideas, ideas that were instrumental in developing the human information processing approach. To highlight just one contribution from communications, psychologists became fascinated with the issue of “channel capacity.” In communications engineering, say, the design of a telephone communications system, one of the built-in limitations is that any channel—any physical device that transmits messages or information—has a limited capacity. To put it bluntly, one telephone wire can carry just so many messages at the same time and loses information if the capacity is exceeded. Clever engineers in communications were the ones who could design methods of getting around these built-in limitations, thereby increasing the overall capacity of a channel.

At some point, psychologists noticed that in several important ways, humans could be thought of as limited-capacity channels, transmitters of information with a “built-in” limitation in the amount of information that could be handled at one time. Notice what a new perspective this insight lent to human experimental psychology. If we conceive of humans as limited-capacity channels, then a whole set of new questions arises, important questions that were not obvious under a different perspective. Suddenly it made sense to ask questions such as “How many sources of information can humans pay attention to at one time, What information is lost if we overload the human system, What information is not lost when overloading occurs, and How can we overcome this limitation?” Of supreme interest, of course, were the implications of a capacity limitation. Where is the limitation? Does it characterize the whole human system, or just one part of it? We will describe some of this research and thinking in this chapter and the next two, since much of the impact of the capacity limitation idea was on the areas of attention and both sensory and short-term memory. For now, notice how this pollination of some significant ideas from communications engineering helped the budding cognitive psychology determine its new approaches and directions.

More influential than the “message” that psychology received from communications engineering, however, was the “input” from computer science. While the limited-capacity channel idea is important, it is just one part of the general information processing approach to human performance. Computer science, on the other hand, had a machine that in many ways reflected the very essence of the human mental system. This machine, in its own way, did many of the things that humans do, things that cognitive psychologists very much wanted to understand. Further, a fair amount of cognitive psychology’s research and theorizing has appealed to the computer as an explanatory device, as a physical apparatus that can serve as a model for the human system we’re investigating.

Thus, it’s quite appropriate that we begin our study of human information processing by taking a short detour through computer science, for a discussion of the physical machine that has supplied cognitive psychology with one of its most fruitful analogies. Stated simply, this analogy says that in some very important ways we can consider human information processing as analogous or similar to information processing performed by a computer. By thinking of human mental processes as similar to the programmed sequence of steps and operations performed on a computer, we may understand better how humans process information and how humans learn and use the “mental programs” of reasoning, comprehension, and so forth.

▼ The Computer as an Information Processing System

Early in the development of high-speed electronic computers, scientists in that field needed a term to describe what it was that these computers did. Their term was data processing—computers take in data, and then “process” those data in some fashion or another. The term processing, of course, is pretty vague, but that level of abstraction was necessary because of the multiple kinds of processes one might want the data to be subjected to. For someone doing statistics, the processing would involve arithmetic and mathematical operations such as adding, squaring, and so forth. The computer on an airliner, on the other hand, performs different processes such as figuring flight paths, fuel reserves, and so on, while computers with engineering, military, or business applications need still other kinds of processes. Thus, processing was an appropriately general term to use.

It turns out that the data part of data processing was too restrictive. The word data usually implies numbers, but from the 50s on, developments in computer science rapidly outgrew the early “number crunching” limitations. All sorts of nonnumerical data are routinely processed by computers now, including words in word processing. Thus, the computer
1/1
will use for its computations. The translated patterns are then sent to the
counter's central processor, which retrieves the instructions for doing an
analysis of variance from its program library, retrieves the appropriate set
data from the data library, and then performs the sequence of calcula-
tions specified in the programmed instructions. Besides doing the
computations, the processor also has instructions and procedures—software—
for keeping track of where it is in the sequence of calculations, for recall-
ing quantities from earlier in the sequence, and so forth.

Eventually (an extremely brief “eventually” for the computer), the
analysis is finished. At this point, the computer generates for me a printed
copy of the outcome of the analysis, formatted in the fashion that I
requested. I know exactly what information was given to the computer—
it’s contained in the statements I typed on the terminal—and I know
exactly what the computer gave me as output—it’s printed on paper. I
can infer from the output that the computer indeed did what I asked. I
can also infer, again from the output, what operations the computer can
perform, what kinds of things it “knows how to do.” It doesn’t bother me
that I never see any of those operations as they happen. Literally watching
the physical hardware of the computer as it works would be of no help at
all in figuring out what it does. I can simply infer, based on the input I
supplied and the output it supplied, that computers can do analysis of
variance.

Right here, in a nutshell, is some important thinking in the information
processing approach to human memory and cognition. Of course we never
literally watch as the human mind processes information, for instance, as
it figures out the answer to a question. Yet, we know what the input was,
the question we gave to a human subject, and what output was given back,
the answer the subject gave to us. If I ask “What is 7 × 3,” and you answer
“21,” I can draw inferences and conclusions about your information pro-
cessing, just as a computer user can draw the same inferences about the
counter’s information processing. I infer from your response that you
know how to do multiplication, or at least that you know the answer to
that particular multiplication problem.

This focus on software in the computer analogy is particularly apt for
cognitive psychology. We are interested in the mental processes of
thought, how they happen, how they’re learned, how they’re modified by
experience. Assume for the sake of argument that human thought consists
of applying various operations and instructions to information held in
some “central processor,” much as this occurs in the computer. By
attempting to specify some of those operations, just as we would in writing
a computer program, we try to reach a better understanding of how
human mental processes occur. We understand how information “flows”
through the computer system by understanding the computer program,
the software that tells the system when to add, when to multiply, when to
retrieve data from the library, when to send the output to the printer. Can
we try to understand human cognition in a similar way, examining the
flow of information through the human information processing system?
Can we make progress in cognitive psychology by investigating the
“human software” of mental processes?

Measuring Information Processes

There is one remaining gap in this computer analogy. To understand
how the computer processes information, we merely sit down with a listing
of the computer program and follow step by step through the instructions
that it performs. But we have no equivalent listing for the operations and
steps that the human information processing system follows. We do have
a few strong hints, however, as to what those operations might be, and
how they might function. As was mentioned in the previous chapter, cog-
nitive psychology frequently relies on measures of time in order to infer
the underlying steps and operations. To continue the informal example
above, we might present the problem 7 × 3 = ? and the problem 9 × 7
= ? When this is done, it generally takes adults about 1300 msec (milli-
seconds) for the larger problem, but only about 1000 msec for the smaller
one (e.g., Stazzyk, Ashcraft, & Hamann, 1982). The nature of our inference
here should be clear—something about the human mental processes for
larger arithmetic problems takes longer than for smaller problems. Maybe
there are more steps involved, maybe the larger problem is more difficult
to find in memory—these are questions we can grapple with as we work
within the information processing approach.

While this time-based approach to cognition is very popular and useful,
other measures of behavior are also appropriate in our investigations.
Since human memory is fallible, even error-prone in some settings, it isn’t surprising that cognitive psychology continues to use the venerable accuracy measures that date from Ebbinghaus. In other words, correct recall from memory, errors, and incomplete memory performance are highly important indicators of mental processes. And especially in situations that require a great deal of time and active problem solving, the subjects’ spoken reports of their trains of thought can also be used as a way of studying cognition (Ericsson & Simon, 1980). In short, we measure any and all human behaviors that can provide glimpses of the mental processes and activities that are the “software” of human cognition.

In summary, the processing of information by computer involves a set of physical devices that seem analogous in function to the human information processing system. Further, information processing by computer involves an all-important “central processor,” a device that performs the instructions given to it in order to achieve some outcome or goal. The heart of the computer analogy involves the instructions and operations that are performed by the processor. If we think of human cognition as similar to a computer’s processing of information, then our task is to investigate the mental operations that occur in the human central processor. In broad terms, cognitive psychology’s understanding of human mental activity and processes often amounts to figuring out what the “human program” specifies: that is, what “software” we have up in our central processors that permits us to retrieve facts from memory, comprehend language, and so forth.

\[\text{The Human Information Processing System: An Overview}\]

Enough of computers for a while—it’s time to explore the human information processing system in more detail. We will examine both the original, rather narrowly defined strict information processing approach as well as the current, broader approach that most cognitive psychologists adopt. We are going to present the standard theory of human information processing, along with various examples of everyday experience that lend support to it. This is a general description of the human information processing system, the major outlines of which are still widely accepted. When we get to the section on process models later in the chapter, however, we’ll be discussing the strict information processing approach and how research was conducted within this framework. Process models were an important adjunct to the standard theory but turned out to be too dependent on some assumptions that proved to be unwarranted. So, as the story unfolds, you’ll read about more recent developments, ideas that don’t “fit” into the strict approach very well. Some of these ideas have led to a modification and elaboration of the standard theory and the process model approach. Others offer fresh insights or new perspectives and are useful because they are continual reminders of the complexity of the human information processing system.

By the end of this chapter, you should have a reasonably complete, intuitive idea of: (1) the current information processing approach is all about; (2) the architecture of the human IPS; (3) some of the general mental processes that have been investigated; and (4) the methods we use to investigate other, more specific processes. You’ll also be ready to go back to these issues from an empirical standpoint, studying the research results that give us the detailed information we need in cognitive psychology. The intuitive grasp you develop here, in other words, will provide a context for you, letting you see where the many different topics later in the book fit into the human information processing system.

\[\text{The Standard Theory}\]

Figure 2–2 illustrates the “standard theory” of human information processing, as it existed in the early 1970s. It is adapted from one of the first such models to receive widespread attention, the Atkinson and Shiffrin (1968; 1971) model of human memory. Notice first the hardware of the Atkinson and Shiffrin system. There are three general memory components, called sensory memory, short-term memory, and long-term memory. In computer systems, these correspond, respectively, to the receiving or input buffer device, the central processor, and the library of programs and data that are stored and available for use. At the input end of the human system, environmental stimuli flow into the system, each sense modality having its own sensory register or memory. At the output end, responses are assumed to come most directly from the short-term or working memory system, making the outcome of the internal processes observable.

Let’s briefly review the multiplication example from above, now tracing the flow of processing through Figure 2–2. I ask you “What is 7 × 3?” The sound wave patterns you hear are encoded into auditory sensory memory; the term encode means to take in information and convert it to a usable mental form. The auditory sensory register is the system that initially receives and holds auditory information for a brief period of time, the system that encodes the 7 × 3 question. Since you were paying atten-

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3 From now on, I will omit the quotation marks around hardware and software when speaking of the human information processing system. The terms should still be taken as metaphorical, however.

4 I certainly do not mean to elevate intuitive or introspective approaches above the empirical, scientific approach. On the other hand, an account of cognitive psychology that never makes contact with your own awareness and knowledge, or one that belittles the role of everyday, intuitive understanding as you learn about cognitive psychology, strikes me as both sterile and educationally misguided.
The Human Information Processing System

2 The Human Information Processing System

FIGURE 2-2  THE ATKINSON AND SHIFFRIN (1966; 1971) MODEL OF HUMAN MEMORY

The three memory components, sensory, short-term, and long-term memory, are illustrated along with the pathways of information flow, from sensory to short-term memory, from short-term to long-term memory, and from long-term to short-term memory. Notice that all responses are assumed to come mostly directly from short-term working memory.

**Explanation:**

In the context of this model, let's consider a scenario where the encoded stimulus is passed almost immediately to the short-term store or memory (STM). This STM is a working memory system where the information you are consciously aware of is held for further mental processing. For the multiplication example, the system determines that it needs to call on long-term memory (LTM) for the answer to the problem. One of the control processes in working memory initiates this search, while others maintain the problem until processing is completed. After the relevant memory search has occurred, long-term memory “sends” the 21 to short-term memory, where the final response can be prepared and sent to the appropriate device (the speech mechanism). Thus, the environmental input has been encoded into the human information processing system, a series of mental operations has occurred, and a final output has been generated.

In this example, we focused on how the hardware and software of the human information processing system enable us to retrieve already known information from long-term memory. To state the obvious, retrieval from long-term memory is one of the most fundamental processes that memory must be able to perform. A slightly different example will illustrate another aspect of the model in Figure 2-2: How do we learn new information, i.e., store something in long-term memory?

Consider a third-grade child who has learned only part of the “times tables” and is now trying to master the rest of the table. The teacher, or textbook, states to the child that $7 \times 3 = 21$. The same sensory and attentional processes operate as before, so the stimulus is in short-term memory. Some new process must operate now to store the problem in long-term memory. A likely candidate here is rehearsal—the child repeats over and over that $7 \times 3$ is 21, either silently or aloud as part of classroom drill (educational methods change, but surely everyone had to recite the “times tables” in grade school). The child may also practice a few of the other “seven times” facts, integrating $7 \times 3$ into a memorized sequence. Each repetition should do two things. First, the repetition maintains the item in short-term memory, temporarily preventing it from slipping away; Craik and Lockhart (1972) call this recycling kind of rehearsal **maintenance rehearsal**, a refreshing of the memory trace through repetition. Second, repetitions serve to promote transfer of the information into long-term memory. Of course, once it’s stored there, then the information can be recalled as needed, as in the preceding example.

Finally, other working memory processes may be employed here as well. One principle covered throughout the book concerns the influence of already known information and its (usually) positive effects on retrieval from memory. For now, assume that our third-grader compares the fact she’s trying to learn with related knowledge about arithmetic. She may recall or discover that adding 7 together three times, as in 7, 14, 21, is the same as multiplying $7 \times 3$. Or, if she already knows $3 \times 7$, she may use the inverse rule to help learn $7 \times 3$. Craik and Lockhart term this elaborative rehearsal, a more meaningful kind of rehearsal, using related knowledge from long-term memory.

While dozens of other examples could also be described, this is probably enough to reveal the usefulness of models like that in Figure 2-2. With these models, we have an idea of how to investigate mental activities such as learning, remembering, and so forth. By devising experiments that test the characteristics of the three different memory components, cognitive psychology has discovered much about the hidden mental processes of human cognition. Given the broad outlines of the human system, we know where to look for more particular processes and skills.
Having briefly considered the human information processing system, it's time to cycle back to the beginning of the remembering process and deal with the three memory systems separately and in greater depth. We will examine the three systems here from a somewhat structural perspective and will deal with relatively basic issues. For each memory component, we will consider three topics: the process of encoding, the issue of that component's size or capacity for holding information, and the question of duration of storage—how long information will remain in the memory component before forgetting takes place. We will discuss the more advanced topics, such as pattern recognition and retrieval from short- and long-term memory, in later chapters. In keeping with the introductory flavor of this chapter, this overview will focus more on intuitive demonstrations and everyday examples than on empirical evidence. After this introductory discussion, you'll be ready to plunge into the more detailed and specific topics that form the rest of the book.

**Sensory Memory**

The two varieties of sensory memory we will discuss are auditory and visual. So few investigations have been done on the other sense modes that there is little point in speculating about olfactory, kinesthetic, or other sensory memory systems. At this point, we merely assume that memory registers exist for these other senses, and that in important but unspecified ways they resemble auditory and visual sensory memories. In contrast, a great deal of research has been done on auditory and visual sensory memory, much of it at the very dawning of cognitive psychology. In addition to considering the sensory memory registers from the standpoint of encoding, capacity, and duration, we will also deal repeatedly with the role of attention in sensory memory processes. We'll begin with auditory sensory memory.

**Auditory Sensory Memory** As you talk with a friend in an airport, bus terminal, or other noisy place, you are bombarded with an enormous amount of auditory stimulation. While you can pay attention to that roar of sounds if you wish, it is certainly more common for you to continue your conversation with the friend and somehow ignore the auditory confusion around you. It is tempting to conclude from this that you really receive only the conversation message from your friend in this situation, and that the rest of the sensations are never even encoded in the first place. Of course, receiving the friend's message may be quite difficult, depending on factors such as the loudness of both the friend's voice and the background noise, as well as your intent or determination to follow what the friend is saying. Nonetheless, in routine situations we can generally overcome the nuisance of background noise and listen to the primary message we're trying to receive.

Yet, as we all know, if some nearby stranger happens to say your name, you typically do hear that message—your head jerks around as you try to hear that other conversation, and you miss what your friend was saying in the meantime. If you'll think about it for a moment, you'll have to agree that even the background messages surrounding you in the noisy place must be entering your memory system to some degree. If they weren't, how could you possibly have detected your name being spoken by someone you weren't listening to? What does an example like this tell us about auditory sensory memory?

**Auditory sensory memory, also termed echoic memory by Neisser (1967),** is the memory component that receives auditory stimulation from the external environment. Since even those messages we weren't paying attention to can cause a reaction, we must suppose that any and all auditory stimuli that are sufficiently loud will be entered or encoded into auditory sensory memory. This is not to say that we can identify or understand every speech message that gets encoded—this is clearly not the case. It simply means that at the very earliest stage of information processing, auditory messages or signals are all encoded into the memory system, where they are then available for further processing.

This input into auditory memory appears to be quite automatic. That is, deliberate attention is not required for receiving a message—if the message is loud enough, it will be received. Furthermore, we usually cannot avoid the wholesale encoding of everything audible around us. We've already covered our first two topics, then—encoding and capacity. Encoding into auditory sensory memory appears to be universal—any sound loud enough to be perceived gets encoded. Since any one of the encoded sounds might, in principle, prompt the redirection of attention that your name causes in the airport, we further conclude that the capacity of auditory sensory memory is probably very large.

Note another implication of this redirection of attention. There is some lag, however short, between the time the stranger nearby happened to say your name and the time you reacted to that sound. This means that the auditory sensory memory system is a true memory register or device—it holds information beyond the physical duration of the stimulus. In the case of sounds, this is especially sensible. An auditory stimulus such as spoken speech is inherently spread across time. We obviously need to remember the auditory message across some time period in order to have it available for further processing. Using Neisser's (1967, p. 201) example, only by holding and then comparing the two sounds in memory could a foreigner understand that his pronunciation was being corrected in "No, not real, real!"

The time period during which information in auditory sensory memory is available is probably no more than 2 or 3 seconds, at least for speech sounds. Nonetheless, even this short duration gives the memory system enough time to review the last few seconds' worth of auditory input, per-
mitting a virtual rehearing of those sounds. (Did you ever have a friend say “Huh?” to your question, then proceed to answer it before you’ve repeated yourself? Do you understand how this happens now?)

**Visual Sensory Memory** Whereas auditory messages are inherently spread out across time, visual stimulation is inherently spread out across space, across a huge array of spatial locations. Glance up from the book now, and focus on a single spot across the room (or on your fingertip, held at arm’s length). Then, without shifting your focus or attention, notice all the other information that is visible in your peripheral vision. To be sure, you can focus precisely only on the information that is projected onto the central region of the visual field. On the other hand, our peripheral vision is sufficiently sensitive to receive a great deal of visual information and to prompt a redirection of the eyes and/or visual attention when movement, light, and so forth are detected. We’re talking now about information received into **visual sensory memory**, also known as **iconic memory** (Neisser, 1967). Just as is the case for hearing, we have a brief-duration, sensory memory system specially designed to receive and hold visual stimulation—visual sensory memory. During the time that visual stimulation is being held in this memory, other cognitive processes, largely those related to attention, must act to process this visual information further, say by forwarding it to short-term memory.

So, in terms of our basic questions, it would seem that any and all visible stimulation can be registered or encoded into visual sensory memory, again by apparently automatic processes, while merely gazing upon a visual stimulus or scene. The capacity of the visual sensory memory, likewise, must be quite large, since there would be little point in receiving tremendous amounts of information, only to be unable to hold but a fraction in the actual memory system. This is not to say that the visual information is held a long time, however—it is not. Most estimates of the functional duration of information held in iconic memory are of about one quarter to one half of a second. That is, visual sensory memory holds information for no longer than one half of a second, during which time the other attentional and cognitive processes must act. Should attention not be devoted to the contents of visual sensory memory, then the information is lost very rapidly, just as unattended auditory messages are lost. In other words, when we attend to the contents of sensory memory, the contents are transferred via attention into short-term memory. When we fail to attend, the contents are lost or forgotten, quickly replaced by the new sensory messages being encoded into the system. (The verb attend simply means “pay attention to.” While the dictionary claims this sense of the word to be archaic, it is used almost universally in psychology to convey this meaning.)

A useful example of visual sensory memory is the perception of a flashlight swung in a circle in a darkened room (it’s not a precise example, since we obviously devote attention to the flashlight display). What you see in this situation is remarkably like a time-lapse photograph of ear traffic: i.e., a connected path of light. Since the flashlight is in only one physical location at a time, the visual experience of a path suggests that there is visual memory for the just-prevously locations. These memories are combined across time in some way to yield the perceived path of light. Think of visual sensory memory in this sense, a memory register that holds visual sensations for a very brief duration, combining them into something like a time-lapse photograph. The contents of this photograph, of course, will disappear quickly without attention, but at least the memory record is there long enough for attention to be shifted to it.

**Short-Term Memory/Working Memory**

Experiencing sensory memory in a conscious way is difficult, since its duration is so brief, and since the attention we devote to sensory stimuli automatically transfers them to the next memory component, short-term memory (STM). Experiencing the nature of short-term memory is much easier, however, since short-term memory can be loosely equated with consciousness. If you are paying attention right now, for instance, you may remember, without looking back, what the last word in the last sentence was—remember “consciousness”? And right now, you’re conscious of the experience of having just been asked what that last word was. You were aware of reflecting for a moment, then remembering what it was. And if you weren’t able to remember it, you’re probably conscious of the implication that you’re not attending carefully enough as you read. All of this—your recent thoughts and experiences, the information you have recently attended—is being held in your short-term memory system. So, short-term memory is the memory buffer or register that holds current and recently attended information.

Unlike the sensory memories, which receive information from the external world, short-term memory receives its information from the internal, mental world—it encodes information from sensory memory and from long-term memory. When a sight or sound is attended, then the mechanism of attention transfers the attended message into short-term memory almost instantly and automatically (and, please note, during that time the unattended information in sensory memory is being lost). Relying in short-term memory, the information is now available for conscious, deliberate processing. The nature of that deliberate processing, of course, depends entirely on what the stimulus was, what your task or intent is, and other such factors.

As indicated above, one of the control processes or mental events that can be triggered is a retrieval of information from long-term memory. When you hear “The first president of the United States was Lincoln,” your long-term memory search uncovers the information that it was Washington, not Lincoln. There is now a mismatch between the two names being held in short-term memory, so your conscious thought (or
spoken response) is “No he wasn’t, it was Washington.” In other situations, retrieval from long-term memory may not be successful, of which you’re also aware. For instance, a strange sound in a quiet room draws your attention away from studying. You turn toward the sound and try to figure out what caused it. A search of long-term memory doesn’t identify the noise, so you finally decide to get up and investigate.

A different control process operates to preserve the short-term memory record, because you know how fragile such records can be. As an example, directory assistance gives you a phone number, and since you don’t have a pencil, you concentrate intently on repeating the number over and over until you can dial it. Once it’s dialed, you can now breathe a sigh of relief and think of other things while waiting for the call to go through. Of course, if the number is busy, the newer things you’ve been mulling over may have destroyed your short-term memory record of the phone number.

A traditional view of short-term memory claims that it is a relatively small memory buffer or register, with the capacity to hold up to 7 plus or minus 2 units of information (Miller, 1956). Notice what a small amount this is—the sensory memories can encode a great deal of information, although they can hold on to it only for very brief durations. Short-term memory, on the other hand, has a disappointingly small capacity; only about 7 units of information can be held at a time. This limitation in capacity (recall the “channel capacity” idea from communications engineering) has been likened to a bottleneck. Just as traffic across a bridge is slowed because of a construction bottleneck that permits only a few cars to pass at a time, the bottleneck in processing capacity permits only a relatively few items or units of information to be held in short-term memory.

The term units here is intentionally nonspecific, because the person and the situation determine what a unit is, how big it is, and how much information it contains. A phone number, encoded or recalled one digit at a time (six-eight-seven-two-five-four-five) essentially uses up the 7 ± 2 capacity. A powerful device for overcoming this limitation in capacity is called recoding, grouping or chunking together some of the information into larger units. Your memory for phone numbers will improve if you merely group the last four digits into two (six-eight-seven, twenty-five, forty-five). Two and five were separate units before, but are now grouped into just one unit, thus saving capacity and avoiding possible overload. If the exchange portion of the number is familiar enough (687 is my university’s exchange), it may be retrieved from long-term memory as a single unit, further reducing the drain on short-term memory capacity.

A newer conception of short-term memory uses the term working memory as a rough synonym. This newer view is in keeping with the shift away from an emphasis on memory components and toward an emphasis on the dynamic processes or activities of the memory system. Under this newer connotation, working memory is the “scratch pad” of the memory system, the dynamic place where intermediate results of the memory processes are “scribbled down” so they’ll be available for later processing. While this scratch pad is also assumed to have limitations in its capacity, the newer view asserts that this limitation is not due to the size of working memory per se. Instead, the limitation is viewed as due to the total amount of processing capacity available to the entire memory system. If we make the reasonable assumption that the total amount of mental resources for cognitive processing is limited, then there is an upper limit on the number of processes that can occur simultaneously, or on the accuracy of processes that occur simultaneously.

Consider a couple of examples. Solve the following:

\[
\frac{4}{3} = 3 \\
((4 + 5) \times 2) + (3 + (12 + 4)) = 3
\]

Now of course you solved this problem by figuring the separate quantities, remembering the intermediate answers while you solved other portions. Then you returned to the final step of combining the intermediate solutions into an answer. On the working memory view, your mental processing involved an intricate series of steps, retrieving some facts (12 + 4) while holding others (the numerator 18, for instance) on the scratch pad of working memory.

An even more compelling example of working memory at work involves understanding a particularly complex sentence or idea, for instance “I know that you are not unaware of my inability to speak German.” Your attempt at understanding probably went something like this: “I know, . . . not unaware is ‘aware’, . . . inability is ‘can’t speak German’, . . . aha, I know you’re aware that I can’t speak German.” Naturally, this simplifying translation misses something from the original—speakers usually don’t generate such syntactically complex sentences without a reason. Regardless, you’ve now understood the basic idea of the sentence. As that happened, you were at least aware at an intuitive level of a drain on your comprehension resources, of a limitation in how much you could handle mentally at one time (following complicated instructions can often demonstrate this point as well). This kind of example captures the central idea behind the term working memory. It is a place where the mental work of putting ideas together happens, where retrieved bits and pieces of facts and meaning are combined.

Concluding with short-term/working memory, let’s mention a couple of facts you already know. As anyone who has had to call directory assistance again knows, information held in short-term memory isn’t there for very long. We mentioned earlier the idea of maintenance rehearsal, a recycling of the data in short-term memory. This is the repetition of the phone number until you dial it—refreshing the short-term memory trace to prevent it from being forgotten. Research suggests that the functional duration of short-term memory information is about 15 to 20 seconds—longer if you rehearse it, but no longer than that if you start attending to something else entirely.
A second fact you already know concerns the fate of short-term memory information when other things happen in the meantime. Which will be harder, recalling a phone number with music in the background, or recycling it when someone is asking you a question? The latter will be more difficult, of course, since attending to the question and answering it will consume some of those precious, limited mental resources. Which will be more difficult, rehearsing the phone number when someone asks your name, or when someone asks your social security number? Again, the latter—saying the numbers in your social security number will surely destroy the short-term memory trace more completely than responding fairly automatically with your name. So, interference from other sources, including other components of your memory, may depress your performance— interference may cause forgetting. This is particularly true if the interfering message is highly similar to the trace you’re rehearsing, or if the interfering message requires significant mental resources. Furthermore, you demonstrate your sensitivity to the threat of interference by engaging in rehearsal; your self-monitoring control processes alert you to the need to do something in order to avoid the interference.

Long-Term Memory

How do we encode information into long-term memory? We learn it! Well, what is learning, how does it happen? In some fashion, learning involves taking information that is currently being processed and attended and storing some version of it in long-term memory. Thus, long-term memory is the ultimate destination for information we want to learn and remember, the memory system responsible for storing information on a relatively permanent basis.

One method of accomplishing this storage into long-term memory has already been mentioned—rehearsal. Rehearsal is a deliberate mental process that can result in forming a long-term memory trace, a record or representation of the information. Another method, one that probably involves the essentials of straightforward rehearsal, might be comprehension. That is, if you’re listening to a fascinating speaker, interested in her lecture, and comprehending what she’s saying, you’re probably forming a long-term memory record of the lecture. You’re not “memorizing” her exact words, of course, unless you specifically rehearse that one sparkling figure of speech, or that one especially pertinent joke. Instead, you’re forming a long-term memory trace of the gist, the general idea that the speaker is talking about. With adequate attention, interest, and comprehension, we seem to be able to store information in long-term memory with minimal extra effort.

Who was that phone call from last night? You’d surely have to say that you didn’t deliberately rehearse that person’s name after the call was over (“I’m storing in memory the fact that Karen called just now”). On the other hand, the conversation took some amount of time, during which you were paying attention, understanding what was said, and contributing your point of view. All of this requires attention and comprehension, of course. Further, the topic of the conversation with Karen probably fits in with what you already know about Karen—in a sense, it merely continues the “Karen story” you already have stored in memory. The fact that you attended and comprehended, and that you already have a great deal of information about Karen stored in memory, suggests that storing the gist of last night’s conversation will not require that much additional effort. It will probably be integrated into your existing knowledge (depending on the situation, it may also become virtually indistinguishable from the other knowledge about Karen that’s already in memory).

Encoding into long-term memory, then, would seem to require some active attention on your part. Rehearsal certainly requires an active learner, not only to perform the rehearsal but also to realize that rehearsal is necessary in the first place. Deliberate attention or concentration also seemed necessary to store the gist of the lecture in long-term memory. For a fascinating lecture topic, or a phone call from a friend, the attention and concentration do not seem unpleasant or difficult. As you know only too well, however, a more ordinary lecture, on a less engaging topic, is harder to remember later—the necessary attention and concentration weren’t there to begin with, so surely you store less information in long-term memory in such situations.

Having answered the encoding question for long-term memory, we now turn to the questions of capacity and duration. The issue of capacity is an easy one. No serious theorist has ever suggested there is a limit on how much information can be stored in long-term memory. While the number of brain cells we have is certainly finite (but enormous), as is the number of interconnections among the neurons (even more enormous), we might as well admit that for practical purposes there is no limitation on long-term memory’s capacity. What limits us, of course, is our unwillingness to do the hard work of storing information there in the first place.

The duration and forgetting question is not answered so easily. One strong implication of the traditional research on interference theory was that any information stored in long-term memory is subject to loss, by virtue of competing, interfering information that is also stored there. More current theories suggest that no information is truly lost from long-term memory. Instead, it’s almost as if information gets lost in long-term memory—it’s still there, but it can’t be located or retrieved (for example, Who was the third president of the United States?). Other current research, focused on memory for real-world events, indicates that integrating new knowledge into existing information structures may set up a situation where old knowledge is replaced, revised, or updated by new information. In other words, old knowledge is altered, and therefore lost, as it is modified by new inputs.

In any event, the current debate over forgetting from long-term memory always involves a careful consideration of retrieval processes: Was the
item truly lost from memory; was the attempt at retrieving it unsuccessful possibly because the knowledge was stored too weakly to begin with; or was retrieval unsuccessful because the information had been altered or revised in the meantime? Thus, while we do truly lose information from sensory memory, by mere decay or replacement, and we do lose information from short-term memory, most probably by interference, it is questionable whether we truly lose information from long-term memory.

A Process Model

Say, for example, that I want to investigate how people read. In particular, I’m interested in how they “look up” words in memory when they see them on the printed page and how long this process takes. I might be interested in this for any of several reasons; for instance, maybe the speed of finding words in memory is centrally important in determining how rapidly a person can read or how high the person’s comprehension is during reading. Maybe the results on speed of retrieval will give me a new way to understand why some children have great difficulties in learning to read.

Regardless of my particular interests, I need something much more specific to guide my research than the illustration in Figure 2-2. That doesn’t look like a theory I might test when doing my research. It tells me only in very general terms what components are involved in reading. Frankly, it doesn’t help me, in any detailed way, to know that reading involves sensory, short-term, and long-term memory systems. I want to know how the process of reading takes place, how the various mental activities are accomplished. I need something that specifies the mental processes in much more detail than Figure 2-2, helping me to isolate the potentially difficult or time-consuming phases of the activity we call reading.

For this purpose, we need another illustration, a figure that depicts the sequence of mental processes in a task related to reading speed. Figure 2-3A shows such a model, a process model or hypothesis about the specific mental processes that take place when a particular task is performed. Part B of the diagram gives a rough indication as to which components and activities from Figure 2-2 go with which stages in the process model. Models such as this represent one way that cognitive psychologists apply the information processing approach to their research. Often as not, such process models also characterize the strict information processing approach mentioned earlier, because of two rather strong assumptions that usually accompany this kind of model.

A Process Model for the Lexical Decision Task Let’s pick a task that is quite typical of research in cognitive psychology, to explore the usefulness of process models. Along the way, you’ll begin to see what kinds of assumptions and decisions cognitive psychologists make when doing research, and how complex cognitive processes such as reading can be broken down into smaller, manageable pieces for scientific investigation. You’ll also start to see some of the limitations of the strict information processing approach, the rigid aspects that have now been abandoned in favor of the more broadly defined information processing approach.

The task we’re interested in here is called the lexical decision task, or sometimes simply the “word/nonword task”; (see Meyer, Schvaneveldt, & Ruddy, 1975). In this task, we show a series of stimuli, where each stimulus is a string of letters. On each trial, the subject must look at the letter string and decide if the letters form a word or not; that is, “Is this letter string in your ‘lexicon,’ your mental dictionary?” On any given trial, the letter string might either be a true word, e.g., MOTOR, or it might be a nonword (usually called a pseudoword), e.g., MANTY. The subject’s task is to decide if the letter string is a word or not, then press one key or button for a “yes” decision and a different one for a “no” decision. The performance measure is reaction time (RT), measured from the beginning of the stimulus display until the subject’s response.

Logically, what sequence of processes or events must happen in this task? We know from the general information processing model in Figure 2-2 that sensory memory will be the first memory component to act, followed by a transfer of the information to short-term memory via the pro-
What does the process model in Figure 2-3 tell us about the role of high-frequency words in reading? Our results suggest that the encoding of high-frequency words, such as 'the', 'of', and 'is', is influenced by the surrounding context. This is in contrast to low-frequency words, such as 'cat' and 'dog', which are less influenced by context and are accessed directly from long-term memory.

In the encoding stage, the model suggests that high-frequency words are more likely to be recalled accurately, even in the presence of distractors. This is because high-frequency words are more frequently encountered in the language and thus have stronger memory traces. On the other hand, low-frequency words are more susceptible to interference and may be forgotten more easily.

The model also predicts that the order of the word frequency in the sentence can affect the encoding process. For example, if a sentence begins with a low-frequency word, it may take longer for the reader to encode this word and subsequently the rest of the sentence.

In summary, the model provides a framework for understanding the role of word frequency in reading comprehension. It suggests that high-frequency words play a crucial role in encoding and retrieval processes, whereas low-frequency words require more effort and are more susceptible to interference.
affects the long-term memory search should influence the search stage of processing, and should produce a time or accuracy difference due to the altered operation of that stage. Using the numbers supplied earlier, then, we would conclude that the difference of 50 msec between high- and medium-frequency words and medium- and low-frequency words is evidence for a word frequency effect on the search stage of processing. The average time difference, in other words, would be attributed to the search stage of processing, as shown in Figure 2-3C, suggesting that the long-term memory search was influenced by word frequency.

The Two Strong Assumptions. It’s not appropriate now to develop a full-blown theory of long-term memory storage as a function of word frequency. Instead, you need to appreciate the nature of the process analysis or stage analysis that we just performed. Only when you understand this kind of analysis, and the assumptions embedded in this approach, will you then be able to understand the important criticisms of the strict information processing approach, and where the current information processing approach has relaxed or discarded some of the strong assumptions in the typical process model.

The first assumption in such process models is the assumption of sequential stages of processing. It is generally assumed under this approach that there is a sequence of stages or processes, such as those depicted in Figure 2–3, that occur on every trial. Importantly, the order of the stages is considered to be fixed, on the grounds that each stage provides a result that is necessary for the operation of the next stage. More to the point, this assumption of sequential stages usually implies that one and only one stage or process can be performed at any one time. In other words, sequential processing means not just that the sequence of stages is fixed, but also that mental processing is a sequence of one-by-one stages.

The influence of the computer analogy is especially clear here. Modern computers may have achieved extremely high speeds of operation, but they are still serial processors—they still perform operations one-by-one, in a sequential order. And yet, there is no a priori reason to expect that humans are limited to one-by-one processing in any and all situations. Thus, to foreshadow just a bit, this is the place where critics of the strict information processing approach tend to cluster, at the assumption of sequential, one-at-a-time stages of processing.

The second assumption, really an extension of the first, was that the stages were independent and nonoverlapping. That is, any single stage was assumed to finish its operation completely before the next stage in the sequence could begin, and the duration of any single stage had no bearing or influence on the other stages. Thus, at the beginning of a trial, the encoding process starts, completes its operations entirely, and then passes its result along to the next stage in sequence, the search stage. Then and only then could the search stage begin, followed after its completion by the decision and then the response stages. With these assumptions, the total time for any trial could be interpreted as the sum of the durations for each independent stage—since mental processes take time, and since each stage was a separate mental process, the total time for a trial could be viewed as the sum of the times for all the individual stages.

In our example from above, differences in overall time to judge ROBIN, MOTOR, and OFFICE (or more generally, to judge words that differ in word frequency) are attributed to the search stage—given our assumptions and logical analysis, it’s the only stage that could be influenced. Because of the assumed independence of the stages, we can interpret the differences in RT as being due to the search stage. Encoding, decision, and response all take constant amounts of time, leaving only the search stage to account for time differences in response to ROBIN, MOTOR, and OFFICE (see Figure 2–3C). The memory search for these words, then, is presumably slowed down when the words are of lower frequency. Notice, however, that slowing down one stage should only delay the beginning of subsequent stages, without altering the operations of those stages, according to the logic of this approach.

Beyond the Information Processed: Seven Current Themes

The information processing approach just described was a dominant way of “doing business” in cognitive psychology until the mid-1970s. Much of the research in cognitive psychology up to that point proposed process models such as the one in Figure 2–3, and often used a particular statistical and interpretive approach called “the additive factors technique” (Sternberg, 1969) which was based on such models. While this was, and occasionally still is, a very productive technique for studying cognitive processes, more recent developments have called into question some of the assumptions of the approach. As in any science, new questions and new discoveries have shown us some of the limitations of earlier conceptions and have broadened our awareness of the issues that need further study.

This final section of the chapter will discuss seven current themes found in cognitive psychology and emphasized in this book; Table 2–1 provides brief summaries of the seven themes. To differing degrees, each of these themes questions the generality, or at least the completeness, of models such as those presented in Figures 2–2 and 2–3. In my view, it is a mistake to conclude that these newer questions and discoveries support the cynical evaluation that there has been little if any progress in cognitive psychology (e.g., Neisser, 1976), however. Instead, it is likely that no one would have ever noticed the issues and questions if it hadn’t been for the earlier process models. Further, we do not throw out all of that earlier
### Table 2-1: Seven Current Themes in Cognitive Psychology

1. **Attention.** Attention is a topic of overriding concern in cognitive psychology. Attention is assumed to be responsible for the transfer of information from the sensory memories to short-term/working memory, and is also assumed to be a critical mental resource necessary for the operation of any conscious or partly conscious process. All theories that discuss attention assume that it is a limited mental resource and that the upper limits of this resource pool determine how many separate processes can occur simultaneously.

2. **Automatic and Conscious Processing.** Mental processes are assumed to fall on a kind of continuum, with “fully conscious” at one end, and “fully automatic” at the other end. Extensive practice and overlearning are generally viewed as the necessary means by which a conscious process becomes more automatic. Whereas conscious processes are assumed to require attentional resources, automatic processes are assumed to require little if any of those attentional resources for their operation. Detection of your name is presumed to be fully automatic; lengthy and difficult problem solving is presumably fully conscious.

3. **Serial and Parallel Processing.** In some situations, a series of mental operations may occur serially, one at a time, with one process ending before the next one can begin. In other situations, especially when we consider processes that are either partly or fully automatic, more than one process can occur in parallel, i.e., simultaneously.

4. **Data-Driven versus Conceptually Driven Processes.** A data-driven mental process is one that relies almost exclusively on the “data” — that is, the stimulus information being presented in the environment. Whereas data-driven processes are assisted very little, if at all, by already-known information, conceptually driven processes are those that rely heavily on such information. Thus, a conceptually driven process uses the information already in memory, and whatever expectations are present in the situation, to perform the task; data-driven processes use only the stimulus information.

5. **Representation of Knowledge.** Cognitive psychology is concerned with how information is represented or stored in memory; for instance, is long-term knowledge represented by the words in our language, represented or organized randomly in memory, or in some more orderly, systematic fashion? The issue also revolves around different kinds of knowledge, such as knowledge of how to do something, as well as how the different kinds of knowledge might be acquired in memory.

6. **Tact Knowledge and Inference.** When we comprehend a sentence, our understanding relies not only on the literal words in the sentence, but also on our background of information, stored in memory, that can be inferred from the sentence. This tacit knowledge, and inferences drawn on that knowledge, are an important part of comprehension, since every act of comprehension involves information that was not stated, as well as inferences drawn from memory.

7. **Metacognition.** The term metacognition refers to the awareness and monitoring of one’s own cognitive system and its functioning. Metacognitive awareness is thus a prompt that we need to rehearse information that we want to remember, is a checking mechanism by which we assess our level of comprehension or performance, and is a source of strategies and plans to be used for improving memory performance.

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**Research**

Research merely because there are newer ways of studying cognitive processes. We merely acknowledge that those conclusions pertain to certain kinds of mental processes and situations, and that other processes and situations require different conceptions of the human information processing system.

**Attention**

Turn back to Figure 2-2 on page 48 and study it very carefully. Now do the same for Figure 2-3 on page 59. What's missing from these two illustrations? Attention. Where is attention in the three-component memory model of Figure 2-2? It's not there, not explicitly anyway, since the figure shows the structure but not the processes of the memory system. We've said that attention, or at least consciousness, is more or less the same as short-term memory, yet there is nothing in the figure that hints at this. A slightly revised version of this model (Atkinson & Shiffrin, 1971) expanded the description of short-term memory by calling it temporary working memory. In this expansion, a list of control processes was supplied—rehearsal, coding, decision, and retrieval strategies. Again, there was nothing directly labeled as attention, and there was no component in the system that encompassed attention either.

The difficulty of course is that attention seems to be a process rather than a structural component of the memory system. **By rights, then, we might expect attention to show up in process models.** The fact that it isn't there, however, doesn't mean that cognitive psychology avoids using the concept of attention. Quite the contrary—the entire overview section you've just read discussed the process of attention repeatedly as a central and fundamental feature of human information processing. For process models, we usually assume that the subjects in our experiment had to maintain fairly high levels of attention in order to be accurate. If attention is constant across the subjects, then of course it pervades each subject's performance to the same degree and doesn't need to be explicitly mentioned (just as we don't mention that performance required a knowledge of English, normal vision, etc.).

What an unsatisfactory solution to the problem, you're probably saying to yourself. Page after page has attested to the overall importance of attention in normal cognitive processing, yet it's not showing up in the models because it can be assumed to be present. This doesn't sound like the all-important mental process that was described earlier. Furthermore, it begets a more fundamental question — what component of the memory system is in charge of attention, responsible for sending some of the limited attentional resources to this place or that? Isn't there some part of the cognitive apparatus that orchestrates the various components and processes of cognition? What causes us to redirect our sensory apparatus to other incoming information, and what prompts us to maintain information for later use? What triggers a long-term memory search, or an attempt to solve a knotty problem? What system is it that sets goals and then prods us along to reach these goals? Who’s in charge here?

One answer to this question is depicted in Figure 2-4, a substantially revised version of the traditional approach. In the figure, there are the same information flow pathways as in the Atkinson and Shiffrin model,
but several new ones have been added. The extra pathways essentially allow for each of the three components to influence each other: long-term memory can now influence sensory memory, as can short-term memory. Thus, the revised model eliminates the heavily sequential nature of the original information processing models, in that there is no inherent order of operation for the stages or components. Also eliminated here is the notion of strict independence of stages and components. Within the structure diagrammed in Figure 2-4, it is easy to see how one component might enter into the activities of another, how the components can continually interact and influence each other.

Further, there is an added component in the figure called the executive controller. This component has the responsibility of parceling out the mental resources of attention, in reaction to the three memory components' changing demands for processing resources. Recalling the figure of speech used earlier, the conductor cedes the various instruments in the orchestra, directing the separate groups through to the completion of the piece. Likewise, the executive orchestrates the processing activities or steps, directing the various components in the system toward some eventual goal or behavior. In computer science terms, the executive controller here is the "executive routine" in a computer program, that part of the program that keeps an eye on what has already happened and what still needs to be performed, deciding what activity or process should come next.

In psychological terms, proposing an executive control mechanism or process is often viewed as highly suspect. To suggest that: there is a mechanism in the memory system that directs and controls activity strikes some people as highly unscientific, or at least evasive. The gist of the criticism goes like this. Our original goal was to explain how people think, how cognition takes place. We propose separate memory components, separate stages of processing, and a variety of control processes, but still haven't quite explained how the whole system works. In desperation, we propose an executive, endowed with the mental powers of making decisions and causing mental activities to happen. Haven't we just reinvented the mental system we were originally trying to explain—haven't we merely put "a little thinking person" inside the "thinking person" we started out to understand?

The classic term for the little thinking person is homunculus—the little mental person who is responsible for making the whole thing work. In terms of attention, we were asking what part of the memory system takes care of the attentional needs of the various components, shifting resources around the system? The unsatisfactory answer is that the homunculus takes care of the needs, doing exactly what needs to be done to orchestrate the system, direct the mental traffic, and get the job done.

The executive controller need not be endowed with such majestic powers. In part, the executive control mechanism proposed here is highly similar to the central executive component of Baddeley's (1986) system called Working Memory. In that system, the central executive was thought to be a limited-capacity attentional system that could call on a variety of other working memory components to accomplish a task. For instance, one of the other components available to the central executive was Baddeley's articulatory loop, the subsystem responsible for verbal rehearsal. Rehearsal, not surprisingly, uses some of the executive's processing capacity, that is, attention. An earlier discussion of executive control by Greeno and Bjork (1973) is also quite similar to the present proposal: in these authors' view, the existence of an executive control component could not be doubted, given "the importance of attention and decision processes in the storage, rehearsal, and retrieval of information" (p. 54; see Kahneman, 1973, for a similar consideration of attentional capacity and central control mechanisms).

For this discussion of attention, then, consider the executive controller to be the component of the information processing system that does or attention for the completion of various tasks. In response to some z state, say, remembering the phone number that directory assistance ha just given you, the executive calls a verbal rehearsal process and devote some of the conscious, attentional resources to that rehearsal.

**Automatic and Conscious Processing**

In chapter 1, we mentioned several mental processes that seem to occur without any conscious awareness or involvement. For skilled readers, or such automatic process is the identification of words. You don't have to decide consciously to identify a word you see printed on the page in f
of you—indeed, you usually can’t avoid identifying it, can’t avoid becoming aware of its meaning as an automatic by-product of perceiving it (e.g., Stroop, 1935). Just as obviously, many mental activities, such as long division, writing a term paper, learning a foreign language, or even understanding a textbook, depend quite heavily on conscious decisions and processes. What causes some processes to become automated while others remain conscious? Can any process eventually become automatic, or are some so complex or lengthy that they will always require conscious effort?

The details of “diagnosing” automaticity, of determining whether or not a process is performed automatically, need not bother us yet. For now, it seems useful to propose a general rule about automatic and conscious processing. If we ignore innate reflexes, it seems that most mental processes begin at a conscious level. That is, they require conscious attention and processing resources at the outset. With extensive practice, however, it also appears that at least some of these mental processes can migrate toward the automatic end of the continuum. Thereafter, the mental activity can routinely happen at a very automatic, effortless level under normal circumstances, requiring little if any attention. If the situation changes dramatically, however, then some greater involvement of conscious processing may be required temporarily.

Consider a motor control example to clarify these remarks. When a baby begins to take her first steps, it requires intense concentration—conscious processing, in other words. Even with this conscious involvement, however, errors and inefficiencies in performance still happen. If you call the baby’s name out, she’s likely to look toward you, lose her balance, and keel over onto the floor. The distraction of hearing her name took away attentional resources that were being devoted to the job of walking. With practice, however, the baby begins to manage some of the balance and motor movements more automatically. In time, and with enough practice of the necessary components, the baby can walk with little or no conscious effort involved. Calling the baby now doesn’t result in a fall—the redirection of attention when you call doesn’t capture attentional resources that are being used for walking, since walking now happens at an automatic level. The same baby, however, must revert back to more conscious control of walking under unusual circumstances, such as walking on the uneven surface of the backyard or climbing stairs, for instance.

Notice that the information processing models that have been covered seem quite neutral with respect to the issue of automatic versus conscious processing. In the standard theory of Figure 2–2, the pathways leading from one memory to another stand for various mental processes, such as attention or rehearsal, but don’t indicate whether those processes should be considered automatic or conscious. It wouldn’t seem too damaging for such theories to add the notion that processes come in these two varieties, or, more accurately, that a process can evolve from the conscious end to the automatic end of the scale.

On the other hand, consider one of the assumptions of the process model shown in Figure 2–3, the assumption of a fixed series of discrete, independent processing stages. This assumption clearly implies that only one information process is occurring at a time, and that when it is completed the next one can begin. Think of this now in terms of automatic and conscious control. Under conscious control, it seems true that only one highly resource-consuming process can occur at a time—the baby must concentrate on those early steps and falls if her attention is diverted. Under automatic control, however, when few if any mental resources are necessary for a process to occur, then presumably other processes are free to occur. After all, adults routinely walk and talk at the same time, walking being so automatic that it requires none of the talking resources for efficient performance (for that matter, most of us know people who talk without benefit of conscious processing as well). Thus, it seems a bit unreasonable to assert, as the process model approach does, that mental processes must be occurring serially, one at a time, with no overlap whatsoever. Instead, doesn’t it seem that two or more mental processes can occur simultaneously if they require no shared or common conscious resources, or if together they do not exhaust the available resources of working memory?

This question, in fact, hints at the method for diagnosing automaticity: if one task interferes with another, then the two presumably have need of some of the same common processing resources. Stated simply, if turning toward a parent who calls her name interferes with the baby’s walking, then walking and attending to the parent must share common attentional resources. If the baby can walk and shift attention at the same time, then walking must be under automatic control, using none of those attentional resources anymore.

What about purely cognitive tasks, where two or more mental processes must occur? It seems safe to conclude that virtually any cognitive task, except the very simplest ones, will involve some balance of automatic and conscious processing. The faster the performance in the task, the more exclusively it uses automatic processes. Slower performance is the product of both kinds of processes, with conscious processing taking the dominant role. The examples in chapter 1—“Does a robin have wings?” and “How many hands did Aristotle have?”—illustrate this balance or proportion idea fairly clearly. Processing is largely automatic for the robin question. Part of the processing for the Aristotle question was also quite automatic, the perceptual/reading part, for example. Other aspects of processing were quite conscious for this question, however (for instance, when you asked yourself “Why would he ask such an obvious question?”).

As Eysenck (1982) has noted, subjects typically have little or no conscious awareness of the nature of their mental processes during so-called fast process tasks, tasks that typically last no more than one or two seconds. Such tasks tend to ask for more elementary information, often require only yes/no decisions, and generally involve fewer, somewhat simpler, and highly practiced mental processes. For the most part, it is these tasks that have been studied within the process-model framework of information processing—the lexical decision task is an excellent example
of a fast process task, for instance. It is also these fast process tasks that permit the careful separation of automatic and conscious mental activities (e.g., Posner, 1978). One unfortunate consequence of automaticity, however, is that people generally lose whatever introspective awareness they have of a process as it evolves toward the automatic end of the scale. Automatic processes are simply too fast and too highly overlearned and practiced to be accessible to conscious awareness. You can probably introspect quite accurately on how you remember the French word for house. Maison looks and sounds like mansion, a kind of house. You probably cannot introspect at all about how you remember the meaning of the word house itself, on the other hand.

**Slow process tasks** take from several seconds up to several minutes or more to be completed. These tasks generally rely very heavily on conscious processes, and often are of a problem-solving nature, either literally or figuratively. Since conscious processing is required, the subject is more able to introspect about those activities during the actual performance. Naturally, the accompanying automatic processes will remain out of awareness in slow process tasks. They will be masked by the more time-consuming, effortless conscious activities that capture our awareness.

**Serial and Parallel Processing**

Another perspective on the theme of automatic and conscious processing is in terms of the distinction between **serial** and **parallel processes**. A fundamental assumption of the process-model approach, you will recall, was that the stages of mental processing occur in a fixed order, sequentially or serially, with one stage finishing before the next one begins. For the specific processes investigated, say, the lexical search process, this assumption clearly implies that no other relevant mental process can occur at the same time. This is the **essence of serial processing**, in which a **series of processes will occur at one time, with no overlap**.

Our discussion of automatic and conscious processing, however, just yielded a very different conclusion: if a process is automatic, and therefore does not exhaust the pool of available mental resources, then in principle it can occur at the same time as some other mental process, or in parallel with other processes. **Parallel processing** simply means **two or more processes occurring simultaneously**. By extension, any number of processes might occur in parallel, as long as their total demand on mental resources does not exceed the available supply. As an example, Salthouse (1984) has analyzed skilled typing and found evidence for four separate processes, all of which occur in parallel during normal, rapid typing.

It's relatively easy to decide what's going on when we're dealing with completely conscious mental operations. By most accounts, conscious mental processes require a large amount of processing capacity. As such, we clearly wouldn't expect two completely conscious processes to be performed simultaneously—there wouldn't be enough processing capacity to go around. On the other hand, couldn't an automatic process occur at the same time as a slow, conscious one, since the automatic process will not drain off much processing capacity? Couldn't two relatively conscious processes co-occur, as long as their total demand was within the limits of available resources? The serious difficulty for process models, obviously, is that they assume that processing occurs serially. By this and the other assumptions, process models truly seem incapable of investigating mental operations that occur in parallel.

Another difficulty, discussed by Anderson (1976) among others, involves the interpretation of results obtained under some process model assumptions. It has been suggested that virtually any set of results that illustrates serial processing can also be accounted for by a parallel model of processing, and vice versa. Given these uncertainties, some have argued that the entire information processing approach, or at least the kind of sequential process model that we've called the "strict information processing approach," is invalid, and ought to be rejected.

To resolve this issue for now, we will fall back on a simplifying assumption, then consider the specific evidence for and against the various positions later on. Assume for now that automatic processes generally perform fairly simple mental operations, whereas the more complex mental feats we can accomplish tend to rely heavily on conscious processing. Two or more automatic processes may occur simultaneously, but only one highly conscious process will generally be possible at any point in time. Except in situations where skills have been highly overlearned, for instance the typing skills of a practiced secretary (Salthouse, 1984), we will look for conscious process explanations of complex cognitive performance. Thus comprehending what you read will still rely heavily on conscious processing, even though several of the components of this skill—letter and word identification, eye movements, and so forth—may be occurring in parallel with your comprehension processes.

**Data-Driven Versus Conceptually Driven Processes**

Neisser's (1967) landmark book, considered by many to have signalled the coming of age of cognitive psychology, popularized a progressive and compelling theoretical notion about the everyday operation of the human information processing system. This notion was called **analysis by synthesis**, a concept borrowed from work in speech perception: As Turvey (1978) put it, however, "Analysis by synthesis was to become, in the hands of Neisser (1967), a provocative account of many visual phenomena, both common and exotic" (p. 101). The specific term has fallen by the wayside but the idea is still forceful throughout cognitive psychology. Ignoring many of Neisser's detailed remarks, the analysis by synthesis phrase suggested largely the same division of mental labor as the more current terminology, data-driven versus conceptually driven mental processes. A completely synonymous set of terms is bottom-up and top-down processing. A revered example of these distinctions is illustrated in Figure 2-5.
If you've never seen this photograph before, your attempt at figuring out what is depicted is probably an excellent example of data-driven, or bottom-up, processing. You're confronted with an odd collection of black and white splotches. Since it's an illustration in a textbook, your general knowledge of these things tells you it has to be an illustration of something—it's probably not just random splotches—but beyond that, you haven't got a clue. As you slowly study the picture, you eventually start to perceive some distinguishable forms. In a manner of speaking, you begin to "try on" some interpretations of the picture, much as you would try on several pairs of shoes to see which pair fits the best. Eventually—it usually strikes people quite suddenly—something in the picture "fits," and you realize you're looking at a rather unusual picture of a dalmatian dog, his nose down to the ground, standing in a shady, mottled patch of ground. Your shifts of gaze back and forth to different portions of the picture, your very conscious puzzling over the picture, and the final identification of the pattern, were rather unusual, in the sense that so much effort is usually not necessary to process ordinary pictures.

What happened here was largely **data-driven processing**. You were working from the bottom up, using only the features and clues in the stimulus to identify the pattern. Little of your existing knowledge was of any use as you looked at the picture, so you had to rely almost exclusively on just the stimulus itself, just the data afforded you by the picture. With only a little help from your "higher" conceptual knowledge, you slowly pieced together some ideas about the picture. Rarely in our everyday world are we confronted with so isolated a situation, with data so lacking in helpful context and familiarity. But data-driven processing is just that—attempting to process a stimulus with none of the supporting context and knowledge that we usually bring to bear on the data around us. (Listening to fluent speakers of another language is a good example of data-driven processing—our mental processes have only the unfamiliar sounds of those strange data to drive them towards understanding.)

If you had seen the dalmatian photograph before, then you probably only glanced at the figure briefly. You realized "Ah, it's that strange dalmatian picture again." This abbreviated set of mental processes comes very close to illustrating purely **conceptually driven processing**, where your understanding is guided by means of the "top" level of knowledge stored in memory. In this case the top level of knowledge exerted an influence "down" toward the actual perceptual processes of scanning the picture. You needed only a bare minimum of information or data from the illustration, just enough to trigger the relevant knowledge in memory. From this point, your conceptual processes took over and likely did not even call for any more perceptual processing of the figure. You relied almost exclusively on the context supplied to you by your knowledge of the picture, a clear case of the mental processes being driven by conceptual knowledge. (Failing to notice typographical errors, such as the one you just passed over, is another good illustration of top-down processing.)

Standard information processing approaches, such as those illustrated in Figures 2–2 and 2–3, generally imply bottom-up processing. That is, a sequence of mental processes, triggered by the stimulus, is driven or "powered" by the features and characteristics of that stimulus. In a sense, the human information processing system suggested by such approaches merely sits around, waiting to be affected by incoming stimuli. It reacts to such stimuli by entering them into the system and processing them up to some level of identification and understanding. A symptom of this data-driven emphasis is that the majority of pathways in such figures point inward, from out there in the environment into the memory system.

A serious shortcoming of this approach is that it neglects mental processing that is triggered or assisted by **internal events**. If you were already familiar with the dalmatian example, only a small bit of processing of the data, the picture, was necessary before you recognized the pattern. In other words, you do not repeat the slow, effortful understanding of the pattern each time you see it. Once you've identified the pattern, then your next encounter with it benefits from that previous experience—your long-term memory knowledge assists you with subsequent encounters. Significantly, once you're familiar with the pattern, it's quite difficult to avoid seeing the dalmatian when you view the picture again. Even consciously trying to see it again "from the bottom up" fails, because you know where to look for the dalmatian, and you can't help but see it there.

In terms of the standard information processing approach, this conceptually driven processing seems unexplainable. The model in Figure 2–2 would need a pathway from long-term memory to sensory memory in...
order to account for this conceptually driven identification of the pattern. Yet that pathway is not included in the model. Of course, many examples illustrate the need for a pathway from long-term to short-term memory: for example when retrieval from long-term memory places information in short-term memory in order for further processing to continue. On the other hand, the dalmatian example suggests that long-term memory information is actually influencing the sensory processing that occurs as you perceive the picture.

This direction of influence, long-term memory to sensory memory, is present in the revised model of Figure 2-4. In this revised approach, each of the three memory components can both receive and send information to each of the other components. Sometimes this information transfer will help a component finish a sequence of operations, as when long-term memory supplies an answer to a question held in short-term memory. At other times, the information transfer will alter the nature of the operations occurring in a component, sometimes quite radically. In the normal course of events, any significant mental task will involve both data-driven and conceptually driven processing. Elements of the data will be identified in long-term memory, prompting a change in the ongoing activities of sensory and short-term memory, with these changes resulting in new cycles of retrieval, and so forth. (In many ways, this pattern of mutual and continuously changing influence is similar in spirit to Neisser’s “perceptual cycle” notion; 1976)

Representation of Knowledge

An important theme in cognitive psychology, especially since the early 70s, has been an interest in the different information types that must be stored in long-term memory. For instance, the Atkinson and Shiffrin model suggested that certain physical characteristics of an input would be recorded in long-term memory, whether the input was visual, linguistic, kinesthetic, etc. On the other hand, the model did not distinguish among other kinds of long-term memory records. As an example, all of the following are probably stored in the “A-V-L” (auditory-verbal-linguistic) mode: your mother’s maiden name, your street address, your concept of a robin, your knowledge that people generally have two hands. These kinds of knowledge are relatively undifferentiated in the Atkinson and Shiffrin model—all of them are simply A-V-L memories. Yet they seem quite different, ranging from very personal and specific to very cultural and generic. Further, our generic knowledge itself varies from rather simple and limited concepts, such as the name of a letter in the alphabet or the meaning of a single word, all the way up to very global knowledge, such as the typical sequence of events when you eat at a restaurant or travel by airplane. The issue, then, is the kind of information that is stored.

This question, in turn, raises another question: How are different types of information stored? In other words, how are the various kinds of long-term memory information organized and structured in the storage system? How is long-term memory information represented in the memory system? Is there a different representation for different kinds of information, or are all kinds represented in some common format?

One of the basic distinctions that has been proposed is the distinction between semantic and episodic knowledge (Tulving, 1972). In this dichotomy, semantic memory contains a person’s general world knowledge, including knowledge of language. Semantic memory is conceived to be the all-purpose, permanent repository of generic information that is typically similar across individuals. Thus, your concept of a robin is largely the same as mine, and the same as anyone else’s in the culture and society we all share. On the other hand, episodic memory is characterized as an autobiographical memory storehouse, containing all of the personally experienced and stored information that is particular to the individual. Thus, while the concept of a maiden name is common to all of us, that is, a semantic memory, your own mother’s maiden name is an episodic memory, specific to you and your experiences.

A great concern of cognitive psychologists over the last 15 years or so has been to explore this distinction between episodic and semantic knowledge. In particular, the question of knowledge representation has been very important in this work: For instance, are episodic memories stored in the same kind of memory structure as semantic memories? Are the two sorts of information stored according to the same rules? Are they retrieved from memory in the same fashion?

Another distinction that has begun to attract attention is the distinction between declarative and procedural knowledge (e.g., Anderson, 1976, 1982).6 According to this dichotomy, basic facts and conceptually knowledge are stored in a declarative long-term memory system, whereas knowledge of how to do something is part of one’s procedural knowledge base. Procedural knowledge, in this sense, contains not only various mental procedures that are used for thought but also other kinds of “how to” knowledge, such as the nonverbal knowledge of how to ride a bicycle, how to shift gears in a car, and so forth. Anderson (1982) has provided a useful example of this dichotomy in his analysis of problem solving. Say that you had to add 845 + 629. Your declarative knowledge structure would supply you with the intermediate answers as you work through the problem. Your procedural knowledge, on the other hand, contains the “how to” knowledge of what column to begin with, when to carry, when to write down a number, when to shift columns, etc. In Anderson’s scheme, the two kinds of knowledge are stored in quite different formats. That is, the mental representation of the two kinds of knowledge is

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6 The term declarative, I suspect, is borrowed from computer programming, where a variable may be “declared” at the beginning of the program. This sets up an initial state of the system that contains (or will contain) certain information. Anderson’s declarative knowledge (e.g., 1983) is similarly set up as the basic factual memory that will be used by various procedures in different problem-solving situations.
very different: the mental processes that use the two kinds of knowledge are rather different as well.

One attractive aspect of this scheme is that it permits a careful examination of complex learning, such as the learning that eventually enables us to do arithmetic, solve physics problems, or perform any other complex skill (e.g., Anderson, 1982; Salthouse, 1984). To repeat the idea from above, nothing in the older models of information processing suggested questions about how complex ideas and skills might be learned or stored in memory. Newer approaches to human information processing have inquired about these more complex issues and have helped revise the older models to provide a more complete account of human cognitive processes.

**Tacit Knowledge and Inference**

Especially when we turn to more complex kinds of mental processing—the topic of language and comprehension, for instance—we must concern ourselves with the theme of *tacit knowledge and inference*. The idea here is that any act of comprehension involves far more than just the string of words being comprehended. In particular, when we comprehend, we use not only the words actually spoken in a sentence, but also the *unspoken but implied knowledge that can be inferred* from our storehouse of general knowledge. If we were limited to dealing only with the literal message that we hear or read, we would never truly understand. But we are not so limited. Conceptually driven processing, in particular, *inference* based on extensive general knowledge, serves to flesh out the message and enables us to comprehend.7

Since several chapters examine this theme in some depth, we’ll only consider a quick example here. Read the following vignette, then think for a moment about the knowledge that goes into full comprehension of the story (adapted from Schank & Abelson, 1977):

Billy was excited to have been invited to his friend’s birthday party. But when he went to his piggy bank and shook it, it didn’t make a sound. Billy thought to himself, “Maybe I can borrow some from Mom.”

How do you understand this story? Is your comprehension limited to just the words on the page? Certainly not. In order to make sense of the second sentence, you must understand what a piggy bank is, and what it has to do with a birthday party. The fact that this is not stated in the story is of small consequence, since it’s “common knowledge” that children take gifts to birthday parties and that gifts cost money and that children keep their money in piggy banks. Thus, the connection between piggy banks and birthday parties is “obvious.” The central idea in the theme of tacit (or implicit) knowledge and inference is that the “obvious” connection comes from your general knowledge of the world—you suppress the necessary connections from memory as you comprehend the story. In a very literal sense, although quite automatically, you make the rather straightforward inference that Billy wanted to get money from his piggy bank in order to buy a gift.

If *anything* characterizes our comprehension of language, it is this kind of *inference based on tacit knowledge*. You usually have no conscious awareness of the process, because it happens so rapidly and effortlessly. A complex or more remote connection between concepts, however, makes the role of tacit knowledge and inference very clear, since you must work harder at finding the connection that the storyteller (writer, painter in a conversation) has in mind. A simple revision to the “birthday party” story illustrates this final point:

Billy was excited to have been invited to his friend’s birthday party. *Even when he went to the dock, he couldn’t find any gas. How was he going to cross the lake without gas for the boat?*

**Metacognition**

One of the more significant contributions to cognitive psychology comes from research on the development of children’s memory and cognitive processes. This contribution is usually labeled metacognition, a term that refers to an awareness and monitoring of one’s own cognitive state. Our ability to reflect on our own cognitive condition, to assess how successfully our own memory and thought processes are operating, is a metacognitive skill. A simple example of metacognition involves rehearsal. Earlier discoveries, for example, show a fairly high degree of memory awareness on the part of adults—we know we have to rely on the phone number in short-term memory until we dial it.

Interestingly, small children show very little sensitivity to the need for rehearsal. They act as though they are unaware of the need to rehearse the phone number, or more generally that it requires some deliberate effort to store information in memory. Their predictions about their memory performance are sometimes wildly optimistic; when confronted with their poor performance, they sometimes are genuinely puzzled. Short, small children seem quite unaware of how their own memory system works, of how to assess the difficulty of a task and respond appropriately to that assessment. This research implies quite clearly that a significant part of cognitive development involves growth in one’s metacognitive skills. In a very real sense, we have to learn how our memories work and what has to be done to ensure successful remembering.

This increasing awareness of the cognitive system, this self-examining aspect of thought, is an important influence on mainstream cognitive psychology. It is represented in Figure 2-4 as the component labeled *executive controller*. Some component or aspect of the cognitive system needs to be in charge, reflecting our awareness, our goal-directed mental activity, our mental system’s sensitivity to changing circumstances. Something...
there learns to realize when things need to be done and instigates mental processing to achieve that goal. Notice that the actual processes we use to ensure remembering are easily considered part of our procedural knowledge base. That is, the mental software of rehearsal, the knowledge of how to do it, is a procedural memory. There is a fair amount of research on such knowledge, showing how various procedures are learned and what consequences result from their use. Realizing that you need to rehearse, however, implies awareness, a self-monitoring act of the cognitive system. What component does this self-monitoring? What component is “aware,” responding to the awareness by prompting this or that mental process to occur? For our purposes, it is the executive controller of Figure 2–4.

My purpose in this chapter was to give you a broad overview of the human information processing system and approach in cognitive psychology, painting an intuitive, nontechnical picture of the field with the broad brush strokes of everyday examples and demonstrations. I intended to whet your appetite for the more informative, careful detail that follows. One of the major drawbacks of the informal, example-oriented presentation is its vagueness, its lack of specificity and precision. This is probably best exemplified in the present chapter by the treatment of attention. Attention is a slippery concept in cognitive psychology—it’s a process that can be captured by external events, yet it can be deliberately directed by some internal goal, force, or mechanism. It is a limited-supply commodity, yet it is absolutely essential for normal cognitive processing. It’s now time to abandon the informal approach, with its vaguely contradictory implications, and get our hands dirty in the empirical results that give cognitive psychology its substance. We will begin in chapter 3 with attention.

CHAPTER SUMMARY

1. The information processing approach has been the dominant metatheory in cognitive psychology. The original “strict” information processing approach was responsible for some important developments and insights. This strict approach has now been largely rejected in favor of a more broadly conceived approach, which describes cognition as the coordinated operation of active mental processes within a multicomponent memory system.

2. The computer has provided cognitive psychology with its richest analogy for understanding human cognition. There is a rough analogy between human and computer systems at the level of hardware, the physical devices and mechanisms, but this is far less important than the analogy based on the software of the two systems, the actual processes and activities that occur within the human and computer information processing systems.

3. The human information processing system consists of three major memory components: the sensory memories, short-term or working memory, and long-term memory. The three basic issues of encoding, information capacity, and the duration of storage are discussed for each memory component; the processes of attention, rehearsal, and retrieval, for the most part, account for the transfer of information among these three components.

4. To understand performance in some information processing task, we often devise a process model, a step-by-step breakdown of the entire task into separate processing components. As an example, the lexical decision task is analyzed in terms of a process model, and a result known as the word frequency effect is interpreted as being due to the operation of a long-term memory search stage. This process analysis reveals the strong assumptions that characterized the strict information processing approach and that forced cognitive psychology to revise and elaborate that approach.

5. Seven overriding themes are described, issues and ideas that reappear frequently throughout cognitive psychology. The seven themes us beyond the strict information processing approach and reveal some of the fascinating complexity and flexibility of the broadly conceived human information processing system. The seven themes are:

- attention;
- automatic and conscious processing;
- serial and parallel processing;
- data-driven versus conceptually driven processes;
- representation of knowledge;
- tacit knowledge and inference; and
- metacognition.

SUGGESTED READINGS


A more detailed presentation of the elements of the information processing approach is chapter 5 in Lachman et al. (1979). Palermo (1985) retells the story of the cognitive revolution in a very approachable fashion, and Newell and Simon’s (1972) “Historical Addendum” provides a personal account of the development of the general information processing framework and discusses the connections between psychology, computer science, and information theory.