M O D U L E 18

Information Processing

Information processing enables memory, a cognitive skill so important that it's virtually impossible even to imagine life without it. Before leaving for school this morning, I need to remember to let the dog out. I also need to remember to put the student papers I read last night into my briefcase and bring some ground beef up from the freezer in preparation for tonight's dinner. As I sit here working, I can remember details from my recently completed weekend. The football game I saw on television was close enough to hold my attention all the way to the end. My wife and I went to a pretty good movie on Saturday. On Friday, my recreational league volleyball team won two of three games in a hotly contested match. I actually got both feet off the ground at once to spike the ball a couple times!

We rely on memory all the time, and not just for the details of our daily lives. I need to remember who I am and what I stand for. I need to remember the norms our society has developed—the "proper" rules for behavior: what to do with my trash, how to answer the phone, which side of the hall to walk on, and a thousand other guidelines that let us coexist in a complex society. I also need to remember how to cook, how to balance my checkbook, how to wash my clothes, and how to program the VCR. And, though I am not consciously aware of it, I even need to remember the meanings of words in my language, and the processes necessary for walking or standing upright.

In this module, we will focus on memory, using an information-processing model (Atkinson & Schiffrin, 1968).

The Information-Processing Model

What's the Point? 1. What are the three basic steps in the information processing model?

There are certainly differences between how a human brain works and how a computer works, but they both process information in three basic steps (Figure 18.1):

1. **Encoding,** or getting information into the memory system.
2. **Storage,** or retaining information over time.
3. **Retrieval,** or getting information out of storage.

Let's see how these three steps work as computers process information.

To begin with, nothing happens unless you can *encode* information or get it into the computer. There are various options for doing this, but two common devices for encoding information are keyboards and modems. Once encoded, the information must be retained in *storage.* Computers offer two kinds of storage, one temporary and the other more permanent. Temporary storage takes place in the active memory of the computer that keeps the various applications open on your desktop. You know how temporary this memory is if you've ever briefly lost power while working on a project. More permanent storage is available on the computer's hard drive. This storage can even survive the computer's "loss

▸ **encoding** The process of getting information into the memory system. The first stage of the information processing model of memory.

▸ **storage** The retention of encoded information over time. The second stage of the information processing model of memory.

▸ **retrieval** The process of getting information out of memory storage. The third and final stage of the information processing model of memory.

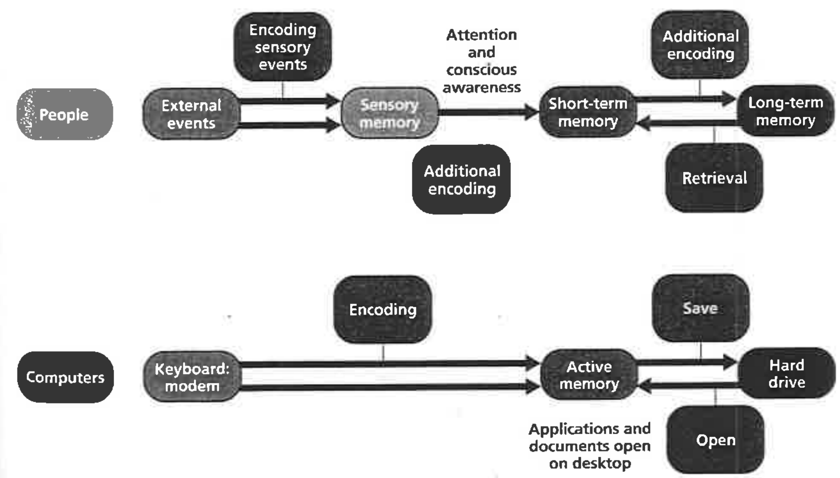


Figure 18.1 Memory as Information Processing Computer memory and human memory differ in many ways, but they share three basic steps: encoding information, storing information for later use, and retrieving information.

► **automatic processing** The unconscious encoding of some information, such as space, time, and frequency, without effort.

► **effortful processing** Encoding that requires attention and conscious effort.

► **rehearsal** The conscious repetition of information.

► **Hermann Ebbinghaus** (1850–1909) German philosopher who conducted pioneering memory studies.

► **overlearning** Rehearsal of information beyond the point where it has been learned. Overlearning is an effective strategy for improving memory.

of consciousness" when it's turned off! But all this encoding and storage would be useless if you couldn't *retrieve* information from storage. If you're careful about setting up folders and subfolders, this can be a snap. If you're not careful, you can lose documents. You may know you've stored a project, but if you can't recall its name or the folder where you placed it, you won't be able to retrieve it easily.

Human beings also encode information. Instead of a modem or a keyboard, we use our senses to gather information. Then we must store the information, either temporarily or permanently. Finally, we must gain access to the memories we have permanently stored. Let's take a more detailed look at these three steps in the human system.

Encoding

Encoding is the process in which you move information—the raw material, the "stuff" that you will ultimately remember—into your memory system. Good students are invariably good encoders of information. Fortunately, we can control some of the factors that influence how well we encode information.

Automatic and Effortful Processing

2. How do automatic and effortful processing differ, and how do we use them to encode school-related information?

Automatic processing is an unconscious process of capturing, or encoding, information. Have you ever had the experience of taking a test and being able to remember exactly *where* in your textbook the information is, but not being able to remember *what* the information is? That's because we encode place information automatically (probably because it provides an evolutionary advantage—it's important to remember where threats in the environment came from, for example). We also tend to encode information about time and frequency automatically.

Unfortunately, you can't automatically capture *what* you've written in your notes. To master that information, you must pay attention and work hard, because it requires **effortful processing** (Figure 18.2). Research indicates that some processing strategies are more effective than others, and the most important one seems to be **rehearsal**, or practice.

Hermann Ebbinghaus taught us much of what we know about the importance of rehearsal. Ebbinghaus, a nineteenth-century German philosopher, wanted data to support his ideas about memory. To get those data, he spent a considerable amount of time committing to

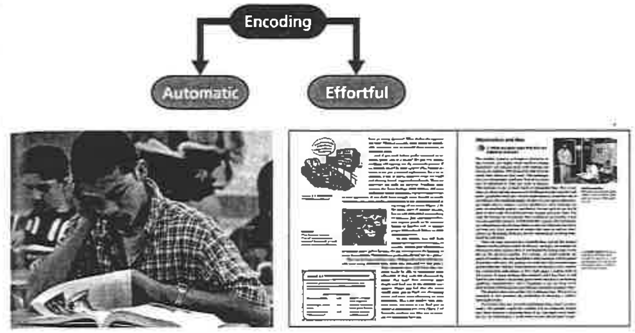


Figure 18.2 Automatic and Effortful Processing Thanks to automatic processing, this student will be able to remember where he studied his textbook with no effort at all. But he will have to pay attention and use effortful processing to encode the information he's trying to learn from the book!

memory lists of three-letter nonsense syllables. If this sounds like nonsense to you, keep in mind that Ebbinghaus wanted to memorize only unfamiliar items. His major conclusion? The more you rehearse, the more you retain (Figure 18.3). Practice, indeed, does make perfect. Here's your first tip for becoming a good encoder: *The more time you invest in rehearsing, the more effective your memory is going to be.*

Another effective processing strategy is **overlearning**—continuing to rehearse even after you have committed something to memory. Students who play musical instruments know they should continue to practice pieces that they can already play without error. And gymnasts

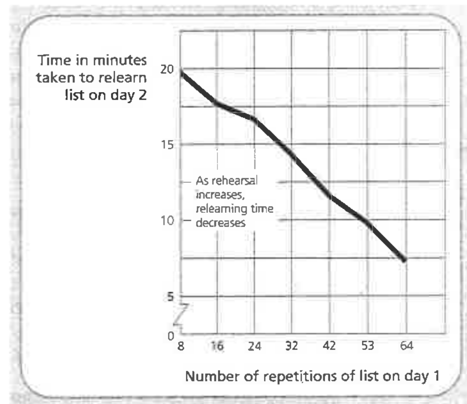


Figure 18.3 Rehearsal and Retention Hermann Ebbinghaus discovered that the more times he rehearsed a list on the first day, the less time it took to be able to repeat the list with no errors on the second day. (From Baddeley, 1982.)

know that they must continue to rehearse mistake-free routines in order to give their best performances. Overlearning is just as important for school-related information. So here's your second tip: *Continue to rehearse academic information even after you think you have it mastered.* This is one of the best ways to make sure the information is available under stressful test conditions.

Practice Makes Perfect! Whether in sports, music, or academics, more rehearsal leads to better performance.

Serial Position Effect

3. How does an item's position in a list influence our memory of that item?

How many times have you taken a test in which you had to remember a list of items? Probably a lot. At such times, the **serial position effect**—the tendency to recall the first and last items on the list more easily—comes into play. Chances are good that you struggled most with recalling the middle items (Figure 18.4). You may also have experienced the serial position effect if you were introduced to a dozen new people at a party. By the end of the evening, which ones were you most likely to remember? The folks you met first and last. Each of these conditions has its own term:

- The *primacy effect* enhances our ability to recall items near the beginning of a list. We have more opportunities to rehearse those first items. Memory researchers who want to minimize the primacy effect may present the list of items quickly, thus eliminating the opportunity to rehearse between items.
- The *recency effect* enhances our ability to recall items near the end of a list. The most recent items are freshest in memory. Memory researchers who want to eliminate the recency effect will delay recall or distract the memorizer by asking several unrelated questions (What is your zip code?) between presenting the final items and asking people to recall the list (from Craik & Watkins, 1973).

Here is your third tip: *Devote extra rehearsal time to the middle of lists you must memorize.*

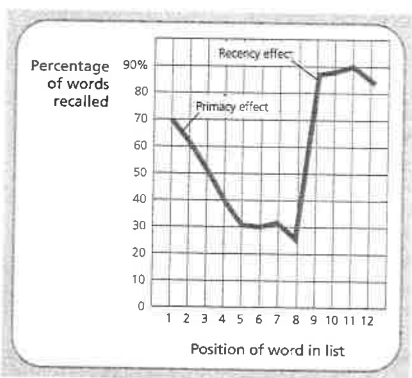


Figure 18.4 The Serial Position Curve People given a list of items and later asked to recall the items had little trouble remembering the first few items (the primacy effect) and the last few items (the recency effect). The hardest items to recall are those in the middle. (From Craik & Watkins, 1973.)

Spacing Effect

4. Why is distributed rehearsal more effective than massed rehearsal?

Rehearsal can be more or less effective, depending on when you do it. Research on the **spacing effect** (Dempster, 1988) shows **distributed rehearsal**—or spread-out sessions—works better than **massed rehearsal**, rehearsal packed together into longer sessions (cramming). Consider the way performers practice. Do actors or musicians mass all their rehearsals for the week into a single, day-long session? No, because as the performers tire, additional rehearsal becomes less and less valuable. So here's your fourth tip: *If you cram all your studying into one long session the night before an exam, you will not encode the information as effectively as you would if you space your study time fairly evenly throughout the unit.* You may put in as many hours, but you won't learn as much per hour. In fact, the spacing effect is one of the most powerful arguments for the use of comprehensive semester final exams—reviewing the material from a course throughout the semester will actually enhance *lifelong* retention of the material (Bahrick & others, 1993)!

Encoding Meaning

5. How does semantic encoding improve our memories?

If rehearsal is central to encoding, so is meaningfulness. In fact, you might well think of rehearsal and meaningfulness as the twin pillars of encoding. If you're interested in cutting down the amount of time you spend in rehearsal (and what student isn't?), your most effective option is to make the material meaningful, a process known as **semantic encoding**.

Research shows that when we encode according to meaning, we remember more effectively than when we encode either sounds (*acoustic encoding*) or images (*visual encoding*). In one experiment, researchers flashed words to participants and then followed with questions that led to semantic, acoustic, or visual processing of information (Figure 18.5, p. 340). For example, to get participants to process acoustically, the researchers might ask whether the flashed word rhymed with another word. To promote semantic encoding, researchers would ask whether the flashed word would fit in a particular sentence. The participants remembered much better when they had encoded the material semantically (Craik & Tulvig, 1975).

Ebbinghaus himself estimated that it was *10 times* harder to learn nonsense syllables than meaningful material. To search for meaning is therefore a wise investment of your time, but where do you find it? If you're ready for your fifth tip, I'll tell you: *One good way to add meaning to material is to use the* ***self-reference effect*** *by relating it to your own life.*

► **serial position effect** Our tendency to recall best the first and last items in a list.

► **spacing effect** The tendency for distributed practice to yield better retention than is achieved through massed practice.

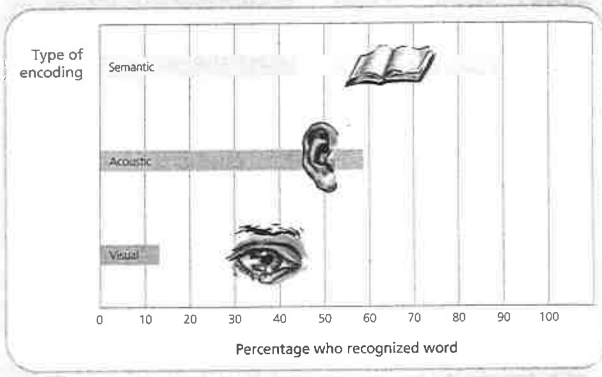
► **distributed rehearsal** Spreading rehearsal out in several sessions separated by periods of time.

► **massed rehearsal** Putting all rehearsal time together in one long session (cramming).

► **semantic encoding** The encoding of meaning.

► **self-reference effect** The enhanced semantic encoding of information that is personally relevant.

Figure 18.5 **The Advantage of Semantic Encoding** This graph shows the results of a study in which researchers flashed words and caused people to process the words according to their meaning (*semantic encoding*), sound (*acoustic encoding*), or image (*visual encoding*). They found that people were more likely to remember the words if they had considered their meaning. (From Craik & Tulving, 1975.)



Search for such connections and you will encode, and remember, the material more effectively (Symons & Johnson, 1997). Meaningful connections are particularly easy to find in a psychology course because the subject matter—behavior and mental processes—relates to *you*.

Encoding Imagery

6. How does encoding imagery aid our memory?

Encoding visual images is relatively easy. Our mental pictures tend to stick, as you well know if you've ever struggled to rid your mind of the image of an unpleasant event. The videos of the collapse of the World Trade Center towers will surely remain with us for the rest of our lives. Images of positive events also tend to stick in our minds. Do you have positive images of your elementary school days? For many of us, these happy snapshots overwhelm the less pleasant aspects of grade school. The third-grade roller skating party remains, but the day you suffered through class with a stomach ache does not. This tendency to encode images of the high points while letting the tedious or less joyous moments pass causes us to recall events—like elementary school—more positively than we actually felt about them at the time. Just think, this *rosy retrospection* (Mitchell & others, 1997) will probably apply one day to your high school memories! The tests, relationship hassles, and scheduling difficulties will likely be overwhelmed by more pleasant images.

The Power of Images None of us will forget the horrible images of September 11, 2001.

Mnemonic Devices

7. How do mnemonic devices help us encode memories for storage and easy retrieval?

Which way do you set your clock for daylight savings time? I remember "spring forward." When using a screwdriver, it's "righty-tighty, lefty-loosey." I do well naming the Great Lakes, too, because of the acronym HOMES—Huron, Ontario, Michigan, Erie, and Superior. These are examples of **mnemonic devices** (pronounced nih-MON-ik), a formal term for memory tricks. If you recall that we encode visual images fairly easily, you'll understand why so many of these tricks rely heavily on imagery. The method of loci and the peg-word system are two of the best-known image-based mnemonic devices.

Have you ever heard a speaker preface major points of a talk with phrases like "In the first place I'd like to discuss . . . " or "In the second place let's shift our attention to . . . "? Where are these "places" the speaker is referring to? They are in the imagination, and they relate to an old speaker's technique for remembering major points in the days before Teleprompters. The technique, the **method of loci**, associates items to be remembered with specific locations in the imagination. Let's say I want to remember to remind my classes of an upcoming assignment on a day I'll have to miss class because of a conference. To use the method of loci, I might imagine my living room, with student papers strewn all over my couch, waiting to be corrected. I could "see" myself trying to enter the room and tripping over a suitcase sitting by the door. Later, in school, I would return to this scene in my mind. The couch would remind me of the assignment, and the suitcase would remind me of the trip.

Another mnemonic device that depends on imagery is the **peg-word system**. To use this memory trick, you would learn a set of peg words—words or phrases on which you can "hang" items you want to remember (Figure 18.6). The more striking and unusual the image,

▶ **mnemonic device** A memory trick or technique.

▶ **method of loci** A mnemonic device in which you associate items you want to remember with imaginary places.

▶ **peg-word system** A mnemonic device in which you associate items you want to remember with a list of peg words you have already memorized.

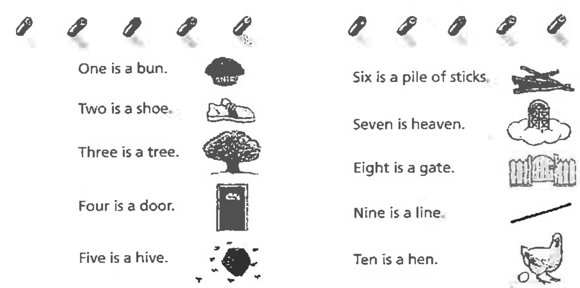


Figure 18.6 **A Simple Peg-Word System** Learn these 10 "pegs" and you can use them to remember any list of 10 items by creating vivid associations between the items and the pegs. Research shows a list learned this way can be remembered in any order with few errors (Bugelski & others, 1968). Notice that the pegs (*bun, shoe,* and so on) rhyme with the numbers (*one, two,* and so on)—a mnemonic device in its own right.

► **chunking** Organizing information into meaningful units.

the less likely you are to forget the item. For example, assume that my first item is carrots, and my peg for item one is *bun*. To come up with a vivid image linking carrots and buns, I could imagine a steaming hot carrot in a hot dog bun and see myself adding ketchup, mustard, onions, and relish before taking a big, delicious bite. Then I'd associate my second item with the peg *shoe*, and so on. You are right if you're thinking this is a lot of effort, but memories encoded with the peg-word system can last a long time. When I use it to teach a 10-item list to my students, they can usually recall the list perfectly more than a month later. So here's your encoding tip on using mnemonics: *Memory tricks like the method of loci and the peg-word system can create vivid images that you won't easily forget.*

Organizing Information

8. What are two ways of organizing information, and how do they help us encode large amounts of information?

I happened to stumble across a NASCAR race on television the other day and was amazed by the efficiency of the pit crews. They were able to accomplish more in a few seconds than my local mechanic can do in an hour. Many factors help explain this, not the least of which is organization. Each member of the pit crew plays a meaningful role in a highly organized structure designed to produce maximum efficiency.

Another tip on becoming a successful encoder: *You can encode more efficiently if you take a few moments to organize your information first.* Organizing information into meaningful units is called **chunking**. You can encode many more letters if they are organized into meaningful words and sentences than you can if they are just randomly grouped (Figure 18.7).

Organizing information into a *hierarchy* is another effective encoding technique. Hierarchies are organizational systems that focus on the relationships between pieces of information. The most familiar example of a hierarchical organization is an outline, which you've probably done for papers or other assignments. By indenting subpoints beneath main points, you get a sense of how each piece of information relates to the rest of the information. Chemistry's periodic table of elements is another example of hierarchical organization. It is so central to the field that it hangs on the wall of every chemistry classroom and is printed inside the cover of every chemistry textbook. Each row and column provides specific meaning to help the user know how the elements relate to one another.

ROW 1	RNN TYW KTYU ACDF OAHNSOO RTA UO UCR OYO
ROW 2	ASK NOT WHAT YOUR COUNTRY CAN DO FOR YOU

Figure 18.7 Effectiveness of Chunking Give yourself 10 seconds to learn the letters in Row 1. How well did you do? Now try Row 2. Did you do any better? The identical letters appear in both rows, but they are easier to encode if they are chunked, or organized into meaningful units—in this case, into words, and then into a meaningful sentence.

TABLE 18.1 TIPS FOR BECOMING A BETTER ENCODER

1. ***Rehearse.*** The more time you invest in rehearsing, the more effective your memory is going to be.
2. ***Overlearn.*** Continue to rehearse academic information even after you think you have it mastered.
3. ***Overcome the serial position effect.*** Devote extra rehearsal time to the middle of lists you must memorize.
4. ***Benefit from the spacing effect.*** If you cram all your studying into one long session the night before an exam, you will not encode the information as effectively as you would if you space your study time fairly evenly throughout the unit.
5. ***Take advantage of the self-reference effect.*** One good way to add meaning to material is to relate it to your own life.
6. ***Use mnemonic devices.*** Memory tricks like the method of loci and the peg-word system can create vivid images that you won't easily forget.
7. ***Chunk material or arrange it in a hierarchy.*** You can encode more efficiently if you take a few moments to organize your information first.

So, did you encode all those tips we gave you on becoming a better encoder? If you need to rehearse them, read through the list in Table 18.1.

Storage

Storage is retention of information, the very core of memory. Humans have three distinct storage systems, each with a different degree of permanence. We will deal with them in order from least to most permanent: *sensory memory*, *short-term memory* (which includes *working memory*), and *long-term memory*.

Sensory Memory

9. What are the two types of sensory memory?

Our senses are constantly bombarded with sensory input. Consider how many objects are in view right now. If you're in a classroom, there are undoubtedly displays on the wall, scenes visible through windows (if you're lucky enough to have windows in your room!), and people to look at. Each of those people offers much to see—facial features, hairstyle, items of clothing, jewelry, and so forth. And that's just visual input. What can you hear right now? Is anyone talking? Is there machinery operating? Is there music in your environment? Even a quiet environment might include the rustling of papers or the gentle sound of someone breathing. Add to this the smells, tastes, touches, and internal feedback on balance and positions that you receive from your body, and it becomes obvious that we gather much more information at any instant in time than we can possibly cope with or hope to use. **Sensory memory** is a way of encoding this sensory input just long enough to make a decision about its importance.

We can hold visual information in sensory memory for less than half a second, in the *iconic store* (Sperling, 1960). It is the iconic store (think of the little pictures that constitute computer icons to remember that *iconic* is visual) that helps us to hold one image in our visual field until another image replaces it. We hold auditory, or sound, information in sensory memory for perhaps three or four seconds, in the *echoic store* (Cowan, 1988; Lu & others, 1992). Have you ever been spacing off in class and had a teacher ask, with an irritated tone, "What did I just say?" Did you notice that you can generally retrieve that information, even though you truly weren't paying attention? Thank your echoic (from the word "echo") store for this ability.

Short-Term Memory

10. What techniques can we use to increase the limited capacity and duration of our short-term memory?

Your **short-term memory** is more permanent than sensory memory. This part of your memory system contains information you are consciously aware of at any point in time. Sometimes, short-term memory is referred to as *working memory* to emphasize the active processing that occurs there. In this way, it is similar to the active memory on your computer that allows you to manipulate and use several applications at once.

Sensory memory is brief but huge. Short-term memory is far more limited because our consciousness itself is limited—we can attend to only a few things at one time. How many? George Miller (1956) established that short-term memory can maintain roughly seven chunks of information, or—as his classic article put it in the title—*The Magical Number Seven, Plus or Minus Two.* In other words, most people can handle somewhere between five and nine chunks of information at one time. When my co-author spells his name for other people, he can run it all together: E-r-n-s-t. With a five-letter name, people have no problem maintaining the whole thing in their short-term memory at once. When I spell my name for others, however, I can't just run the letters together. *Blair-Broeker* contains 13 characters, including the hyphen, and that is enough to overwhelm short-term memory. I have to pause a couple times

► **sensory memory** The brief, initial coding of sensory information in the memory system.

► **short-term memory** Conscious, activated memory that holds about seven chunks of information briefly before the information is stored more permanently or forgotten. Also called *working memory.*

► **long-term memory** The relatively permanent and limitless storehouse of the memory system.

as I spell it if there is to be any hope of the other person getting it down correctly. Notice that the capacity of short-term memory is seven *chunks*. You can hold seven chunks almost as easily as seven individual items. Holding seven words in short-term memory, for example, means that you are actually holding more than seven syllables and a lot more than seven letters. Chunking is an effective technique not only for encoding but also for increasing the capacity of short-term memory.

What about the duration of short-term memory—how *long* can we retain information in this portion of our memory? About as long as you keep rehearsing it. If you meet a new and interesting person at a party, you will retain the person's name as long as you keep repeating it to yourself. But what if you get distracted? How long will the name stay? To answer this question, researchers (Peterson & Peterson, 1959) presented participants with short, three-consonant groups to remember. They then distracted the participants by giving them an arithmetic task that prevented rehearsal. As the results show (Figure 18.8), short-term memory is indeed short term. Even though people had to remember only three consonants, these items disappeared from memory in less than 20 seconds when rehearsal was prevented.

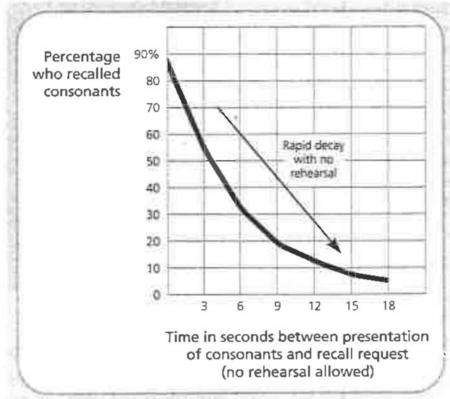


Figure 18.8 How Long Does Short-Term Memory Last? As this graph shows, when people are not allowed to rehearse, short-term memory decays rapidly. Within a few seconds, most people are unable to recall three consonants. (From Peterson & Peterson, 1959.)

Short-term memory, with its limited capacity and short duration, is like a stovetop on which you're preparing your dinner. Having only four burners limits the number of dishes and volume of food you can cook. You also must pay active attention to the food you're preparing if you're going to avoid ruining the meal or burning down the house. All of the rest of the food stored in your cupboards, refrigerator, and freezer—the food you don't need to pay attention to—represents our next topic: long-term memory.

Long-Term Memory

11. What are the capacity and the duration of long-term memory?

Long-term memory represents the vast, amazing memory storehouse that can hold memories without conscious effort. Remember our computer analogy here. Short-term memory is like the active memory on your computer that allows you to deal with the various projects open on your desktop at any moment. Constant power (attention) is necessary to maintain

Clark's Nutcracker Do you ever have trouble remembering where you left your psychology book or your wallet? Compare your memory to that of the Clark's Nutcracker. It can remember the location of up to 6000 places where it has stored seeds for the winter (Shettleworth, 1993).

this memory. What happens to your work if the power blinks off? It's gone! As a result, most of us have learned to save our work frequently. This means we make a copy of the project on the computer's hard drive, a device that will retain the information even when the machine is turned off.

Similarly, we can file information away in our long-term memory and have it stay there without paying attention to it. It's available (we hope!) when we want it. Although until I mention it, you probably have not been thinking about these bits of information, but I'll bet you could retrieve with ease your zip code, the name of your English teacher, how you spent last New Year's Eve, and countless other events that you encoded and stored at some point in the past. Note that you effectively encoded these pieces of information either because you rehearsed them frequently or because they held personal meaning for you—two of the factors we identified as crucial when we discussed encoding. And now they are permanent residents in your long-term memory storehouse.

Long-term memory is as expansive as short-term memory is limited. What is its duration? Nobody knows for sure, but it's clear that humans can maintain memories for about a century. (Are you willing to trust your computer's hard drive to last that long?) Short-term memory can hold about seven chunks. What's the capacity of long-term memory? Again, nobody knows. Like a sponge with unlimited capacity, your long-term memory can always absorb more, even on days when you feel you can't possibly take in even one more piece of information.

One especially interesting kind of long-term memory is **flashbulb memory**, a clear, vivid memory of significant, emotional events. I have lived long enough to pick up lots of these: driving home in my first car (a used, powder blue 1965 Mustang GT); the sunshine briefly breaking through in the middle of our outdoor wedding; being left in the hallway as they wheeled my wife in for an emergency C-section on the night our son Carl was born. Sometimes flashbulb memories center around a shared event. People in your grandparents' generation may recall with amazing detail what they were doing when they heard the news of the attack on Pearl Harbor. Your parents may have flashbulb memories of President Kennedy's assassination or the explosion of the space shuttle *Challenger*. Your vivid memories of the September 11 terrorist attacks on the World Trade Center will last a lifetime.

► **flashbulb memory** A vivid, clear memory of an emotionally significant moment or event.

► **long-term potentiation** An increase in a synapse's firing efficiency. Believed to be the neural basis of learning and memory.

Memory and the Brain

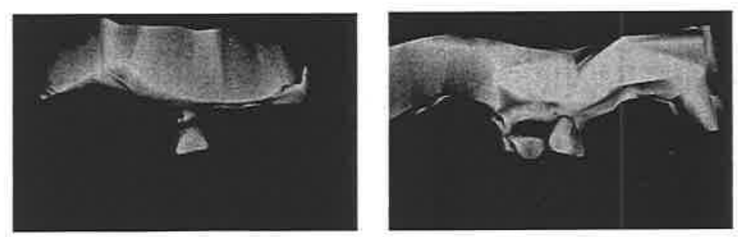
12. How do we get information into long-term memory?

How, exactly, does the brain go about storing long-term memories? This mystery has occupied scientists for decades, but in the last several years, researchers have uncovered some important clues. We now know that our brain does not function like a tape recorder, holding permanent, accurate records of every experience, ready to be played back if the right button is pushed. Current memory research indicates that memories are constructed from myriad bits and pieces of information. Our brain *builds* our memories, just as you would assemble a jigsaw puzzle. When pieces are missing, we invent new ones to fill in the spaces. Because of this, some of our memories are accurate, and others are way off.

Another important clue to how memories are stored is that each memory appears to activate a particular, specific pattern of firing in brain cells—neurons. The key to the process lies in the synapses that form the connecting points between the neurons. As the sequence of neurons that represents a particular memory fires over and over, the synapses between these neurons actually become more efficient, a process known as **long-term potentiation** (Figure 18.9). Learning and memory stimulate the neurons to release chemicals (primarily the neurotransmitter serotonin) at the synapses, making it easier for the neurons to fire again in the future (Kandel & Schwartz, 1982). The tracks formed in your brain are almost like a trail blazed through deep snow from a cabin to the woodpile. With repeated trips, the trail becomes easier and easier to follow.

The concept of long-term potentiation helps explain several other memory phenomena. A variety of things, including a blow to the head, can disrupt neural function and the formation of new memories. This is why football players who have suffered concussions may have trouble remembering the play when the injury occurred (Yarnell & Lynch, 1970). Drugs can also disrupt memories, by interfering with

Figure 18.9 Growing a Memory These two electron microscope images show one way that long-term potentiation makes a synapse more efficient. The left image, before long-term potentiation, shows only one receptor site (gray shows the receiving neuron). The right image shows two receptor sites. This dual target increases the likelihood that a message from the sending neuron will make it across the synapse to the receiving neuron. The growth of the second site is an indication that something may have been learned and remembered.



Stress and Memory Stressful events, such as this car accident, stimulate the release of stress hormones that enhance the formation of memories. These drivers are not likely to forget this day. Such memories may help encourage defensive driving in the future.

the neurotransmitters necessary for long-term potentiation. Alcohol is one such a drug, which accounts for the alcohol-induced memory "black-out" that often accompanies a night of heavy drinking (Weingartner & others, 1983).

Stress hormones also affect memory. Do you think they disrupt or enhance the ability to form long-term memories? Here's a hint: Stress is often the body's response to danger. It is important that we retain details of dangerous situations so we can protect ourselves in the future. It's not surprising, then, that stress enhances memories. The hormones tell your body that something significant is happening, and they trigger biological changes that stimulate the formation of memories. People given a drug to block the effect of hormones in a stressful situation tend to remember fewer details of an upsetting story than their counterparts who did not receive the drug (Cahill, 1994).

Explicit and Implicit Memories

13. What are explicit and implicit memories, and what parts of the brain process each of these types of memory?

Let's examine one last aspect of long-term memory. There are many types of memories, but one major division separates explicit from implicit memory (Figure 18.10). **Explicit memory** is what we normally think of when we think of memory: the recall of facts and experiences. At what temperature does water freeze? Where did you eat dinner last night? What is your mother's middle name? Answering all of these questions requires a conscious effort to retrieve and state information. **Implicit memory** requires no such conscious effort. Implicit memory lets us retrieve our knowledge of procedures and skills, such as walking. You don't have to think about how to ride a bicycle before peddling off. Nor do you have to think about how to read or how to button your shirt. Your ability to perform all these tasks depends on memory, but it is implicit, not explicit.

▸ **explicit memory** Memory of facts and experiences that one must consciously retrieve and declare.

▸ **implicit memory** Memory of skills and procedures, like how to walk, that are retrieved without conscious recollection.

Explicit and implicit memory appear to be entirely different systems, controlled by different brain parts. Explicit memories are processed through the *hippocampus,* a small structure located in the central region of the brain. Implicit memories are processed through the *cerebellum,* the rounded structure at the bottom rear of the brain (see Figure 18.10). Odd things can happen because of this split. A man who experienced damage to the hippocampus, for example, would be unable to form new explicit memories, but his ability to form implicit memories would remain intact. What would happen if he went to play golf on the same course each day? He would have no explicit memory of the course—it would seem like a brand new place every time. But his scores would gradually improve over time, because his implicit memories would allow him to get better with practice.

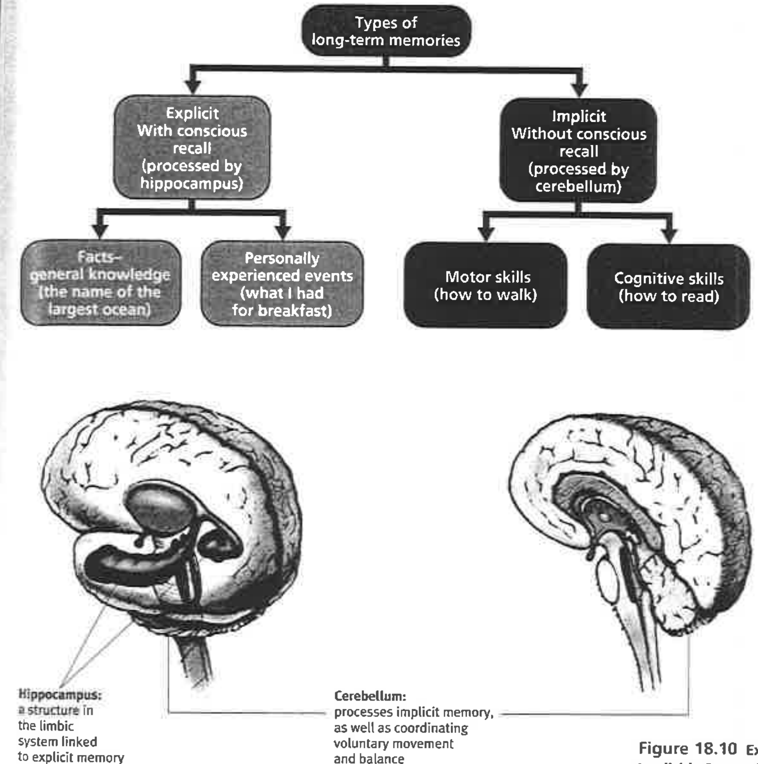


Figure 18.10 Explicitly or Implicitly Remembered? Long-term memories can be classified as either explicit or implicit. These two types of memories are processed by different parts of the brain. Explicit memories of facts and experiences are processed through the hippocampus, a part of the limbic system deep in the center of the brain. Implicit memories for procedures and skills, however, are processed by the cerebellum, a structure at the bottom rear of the brain.

▸ recall A measure of memory in which you must retrieve information you learned earlier, as on a fill-in-the-blank test.

▸ recognition A measure of memory in which you must *identify* items you learned earlier, as on a multiple-choice test.

▸ context effect The enhanced ability to retrieve information when you are in an environment similar to the one in which you encoded the information.

Retrieval

14. What are two forms of memory retrieval?

The final step in the information processing model of memory is *retrieval,* the process of getting information out of memory storage. Two forms of retrieval are recall and recognition.

- **Recall** is the kind of retrieval we usually think of as "memory"—searching for information that was previously stored, and calling it back into conscious awareness. This is the literal meaning of the word *re-call.* Test makers use fill-in-the-blank, short-answer, and essay questions to tap recall.
- **Recognition** is also retrieval, but it is an easier process than recall, because you need only identify information. You may struggle to describe an individual you witnessed committing a crime (recall) yet have little trouble picking the person out of a police line-up (recognition). Multiple-choice and matching questions test recognition.

How do we get to the memories we need to retrieve? We follow pathways, often multiple pathways, that lead to the memory. When I need to contact a friend, I can do so by hopping in the car and driving to his house. If I'm feeling relaxed, I can walk over. I can also e-mail him, or call him on the phone, or send a message with a mutual friend I know will see him before I do. The point is, I have lots of ways to reach him. Likewise, there are many pathways I can follow to retrieve a memory. I can "connect" to a memory of, say, Mount Rushmore by remembering a family trip, by thinking of a TV show I might have seen, or by seeing a photo in a magazine. In each case, my memory of Mount Rushmore is *primed,* or triggered, by a memory *retrieval cue* (Figure 18.11).

Memories weave a web of neural pathways inside the brain, and retrieval cues send us down one pathway or another in our search for memories. Have you ever noticed that the more you know about a subject, the easier it is to learn even more about it? Learning and retrieval build on each other. If you know only one or two isolated facts about how the federal government works, you don't have much of a framework upon which to hang new information. But if you already know about the Constitution, the three branches, the role of the civil service, significant Supreme Court decisions, and close presidential elections, it becomes relatively

High School Days Here is how my co-author and I looked when we were your age! Our present students might have difficulty identifying us, but our high school classmates would probably have no trouble at all.

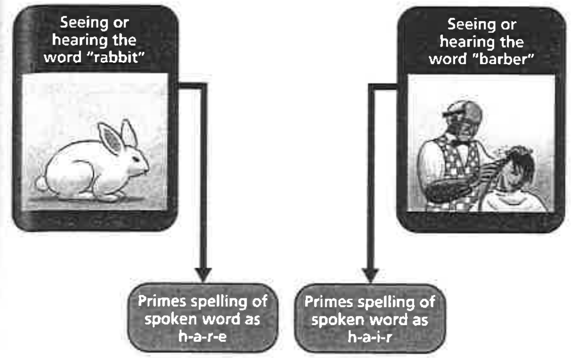


Figure 18.11 A Hare-Raising Experience If you show people a picture, you can activate certain associations in their memory pathways—a process known as *priming.* When you later ask them to spell a word that can be spelled in two different ways (*hare* or *hair*), their response may reflect the content of the picture. Thus, a picture of a rabbit is likely to activate the spelling h-a-r-e. A picture of a barber at work is likely to activate the spelling h-a-i-r. (Adapted from Bower, 1986.)

easy to integrate new information. This interrelated web of association allows for easy priming of memory, and thus more effective retrieval.

Context

15. How does context affect our ability to retrieve memories?

Context is the environment in which you encode or retrieve information. When these environments are the same, you may experience the **context effect**—an enhanced ability to retrieve information more effectively. This happened when my wife and I visited a little town in Oregon where her family vacationed many years before. When we arrived, her memories began flooding back, and she was able to direct me to several landmarks around town. Returning to the context where she had encoded the memories primed the retrieval of those memories years later. One experiment carried this idea even further. The researchers divided scuba divers into groups and read each group a list of words. One group heard the list on shore; the other, under water (Figure 18.12).

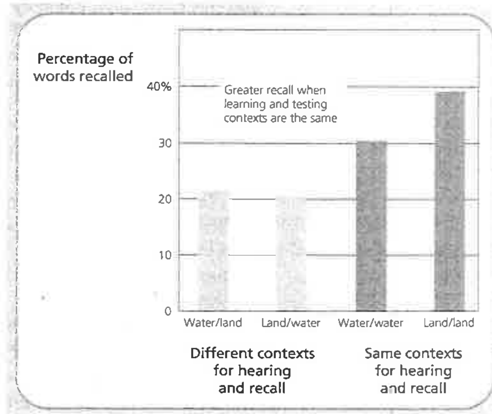


Figure 18.12 Context and Memory As this rather odd experiment demonstrated, retrieval is best when it occurs in the same environment where encoding took place. In this case, the two contexts were under 10 feet of water (while scuba diving!) or sitting on the shore. (Adapted from Godden & Baddeley, 1975.)

Later, those who heard the words on shore recalled more of the words when they were on shore, and those who heard the list under water recalled the words best under water (Godden & Baddeley, 1975). Any environment provides countless cues that can later function to prime the retrieval of memories.

State Dependency

16. How do our physical condition and mood affect our ability to retrieve memories?

Our ability to retrieve memories also depends on the physical or mental state we were in at the time we encoded an event. **State-dependent memory** means that retrieval is best when the retrieval state is *congruent* with (that is, the same as) the encoding state. Strangely enough, if you were tired when encoding, retrieval will also be better when you are tired. Note, however, that you will neither encode nor retrieve as well when you are tired as you would if you were not tired. Do you drink caffeinated drinks, like cola, when you study? Chances are you'll retrieve better under the influence of caffeine. This even extends to drugs which normally disrupt learning, like alcohol (Lowe, 1987). Despite its overall negative effects, if you were under the influence of alcohol when encoding, you'll retrieve somewhat better (although not well) with alcohol in your system.

Memories are also *mood-congruent*. If you're happy when you encode, you'll retrieve better when you're happy. On the other hand, if you've been somewhat depressed as you worked your way through a particular unit in a class, you'll probably test better when depressed. Odd, isn't it? Perhaps even more significant is the way our moods bias our memories. If you think back to first grade when you're in a good mood, the mood is likely to prime positive memories. But if you're depressed when you try to remember, your mood is likely to function as a retrieval cue for negative memories (Eich, 1995).

Lose your memories, and you've lost your sense of self. Without the past, both joy and sadness would be fleeting and our world would be shallow indeed. We would have no way to connect events, and we would be unable to learn anything. Our waking hours are a constant progression of encoding important information, storing countless pieces of information on both a short-term and long-term basis, and retrieving needed information from long-term storage. If you remember nothing else about this topic, remember the remarkable, amazing role memory plays in our daily lives.

► **state-dependent memory** The enhanced ability to retrieve information where you are in the same physical and emotional state you were in when you encoded the information.