Memory is a topic of central interest to psychologists, and it is not difficult to see why. Without memory, there would be no recollection of previous events, and so no possibility of reflecting on our experiences or telling others about our lives. Without memory, we would have no knowledge, because, after all, if we know that up is the opposite of down, that people are nicer to their friends than to their enemies, and that Elvis Presley was a famous singer, then we have to draw this information from somewhere—and that somewhere, of course, is memory.

Memory is also crucial for other reasons. Are you proud of who you are? If so, it is partly because you recall your past achievements. Are you embarrassed about who you are? If so, it is because you recall your shortcomings. Likewise, if you feel happy about your life, or sad, you are probably being influenced by your memory of positive things you have experienced, or negative. In these ways, your perception of yourself and of
your life—and, with that, your mood and your self-esteem—is dependent on memory.

It is no wonder, then, that psychologists regard the study of memory as a topic of enormous importance, and there are many questions about memory that need to be addressed: How accurate and complete are our memories? Does everything we experience get stored in memory, or is memory somehow selective? Why do we forget? Are there things we can do to help ourselves remember? Let us look at what psychologists have learned about these crucial questions.

**Acquisition, Storage, Retrieval**

Each of us has a huge number of memories. We can recall what we did yesterday, or last summer. We can remember what the capital of France is, or what the chemical formula is for water. We remember how to ride a bicycle, how to tie our shoes, and how to throw a baseball. It turns out that these various examples—remembering episodes, remembering general facts, and remembering skills or procedures—all draw on different memory systems; but it also turns out that these various types of memory all have some things in common, and it will be useful for us to begin with those common elements.

Any act of remembering requires success at three aspects of the memory process. First, in order to remember, you must learn something—that is, you must put some information into your memory. This seems an obvious point, but it deserves emphasis because many failures of memory are, in fact, failures in this initial stage of acquisition. For example, imagine meeting someone at a party, being told his name, and moments later realizing that you no longer know it! This common (but embarrassing) experience is probably not the result of ultrarapid forgetting. Instead, it is likely to stem from a failure in acquisition. You were exposed to the name but barely paid attention to it and, as a result, never learned it in the first place.

The next aspect of remembering is storage. To be remembered, an experience must leave some record in the nervous system (the memory trace); it must be squirreled away and held in some enduring form for later use. One question to be asked here is how permanent this storage is. Once information is in storage, does it stay there forever? Or does information in storage gradually fade away? We will tackle these questions later in this chapter.

The final aspect of remembering is retrieval, the process through which you draw information from storage and use it in some fashion. Retrieval can actually take many forms. For example, recall is a task in which you draw information from memory in response to some cue or question. Trying to answer a question like “What is Sue's boyfriend’s name?” or “Can you remember the last time you were in California?” requires recall. A different way to retrieve information is through recognition. In this kind of retrieval, you are presented with a name, fact, or situation and are asked if you have encountered it before. “Is this the man you saw at the bank robbery?” or “Was the movie you saw called Memento?” are questions requiring recognition. Recognition can also be tested with multiple items: “Which of these pictures is the one you saw earlier?” This latter format obviously resembles a multiple-choice exam, and, in fact, multiple-choice testing in the classroom probes your ability to recognize previously learned material. In contrast, exams that rely on essays or short answers emphasize recall.
People commonly speak of “memorizing” new facts or, more broadly, of “learning” new material. However, psychologists prefer the term memory acquisition, using it to include cases of deliberate memorization (intentional learning) and also cases of incidental learning, learning that takes place without any intention to learn and often without the awareness that learning is actually occurring. (You know that grass is green and the sky is blue, and you probably can easily recall what you had for dinner yesterday, but you did not set out to memorize these facts; the learning, therefore, was incidental.)

As we will see, memory acquisition is not a simple matter of “copying” an event or a fact into memory, the way a camera copies an image onto film. Instead, acquisition requires some attention to the to-be-remembered material, and some intellectual engagement with the material—thinking about it in some way. It is the product of this engagement—what you thought about during the to-be-remembered event—that is stored in memory. In a sense, then, memory acquisition involves a translation process, translating the raw input into some intellectual record of the input. Investigators call this process memory encoding; thus, we acquire memories by placing encoded information into storage.

The Stage Theory of Memory

How does memory acquisition proceed? The stage theory of memory, developed roughly 50 years ago, provides an answer, proposing that, in fact, we have several types of memory, each with different properties, so that memory acquisition is a process of moving memories from one (temporary) store into another (more permanent) resting place (Atkinson & Shiffrin, 1968; Broadbent, 1958; Waugh & Norman, 1965).

Why would we need several kinds of memory? When we are actively working with information, we want the information to be immediately available to us. As an analogy, think about how you spread your notes out on your desktop when you are working on a paper or studying for an exam; that way, the information you need is instantly accessible. The mental equivalent of this is working memory (called short-term memory in the original theory), a memory that holds onto the information you are working with right now.

But, at the same time, you do not want to put too many things on your desktop. If you did (if, for example, you placed every book you owned out on the desk), then you would start losing track of what’s there, and that would destroy the advantage you were seeking—having instant access to the information you are now using. That is why you sensibly leave the books you are not using right now on your bookshelves. In that way, you give up instant access to what’s in the books, but you also won’t be distracted or overburdened by this extra information, and this allows you to focus on your more immediate tasks. The mental equivalent of your bookshelves is long-term memory—the huge repository that contains everything you know, a mostly “dormant” storage for information you are not using right now but may need later.

The Storage Capacity of Working and Long-Term Memory

Working memory and long-term memory differ in many important ways, including the storage capacity of each. The capacity of long-term memory is enormous. The average college student remembers the meanings of 80,000 words, thousands of autobiographical episodes, millions of facts, hundreds of skills, the taste of vanilla, and the smell of lemon. All of this and more are stored in long-term memory.

In contrast, the capacity of working memory is sharply limited. Traditionally, this capacity has been measured by a memory span task in which the individual hears a
series of items and must repeat them, in order, after just one presentation. If the items are randomly chosen letters or digits, adults can repeat seven items or so without error. With longer series, errors are likely. This has led to the assertion that working memory’s capacity is seven items, give or take one or two. In fact, many tasks, not just memory span, show this limit of seven plus-or-minus two items, leading psychologists to refer to it as the magic number (after Miller, 1956). Given the assumption that a wide range of tasks must rely on working memory, it is perhaps unsurprising that this limit—presumably, a reflection of the small size of this memory—sets a boundary on performance in a variety of settings. (We return to the issue of how working memory’s capacity should be measured—with some important updates—in Chapters 8 and 14.)

WORKING MEMORY AS A LOADING PLATFORM

What is the relation between working memory and long-term memory? The stage theory asserts that the road to long-term memory necessarily passes through working memory. Seen in this light, working memory could be regarded as a loading platform, sitting at the entrance to the huge long-term warehouse. But what is it, according to this view, that moves information off of the platform and into more permanent storage? One key factor, according to stage theory, is memory rehearsal, a process through which items are kept in working memory for an extended period of time, increasing the likelihood that these items will be transferred to long-term storage (Figure 7.1).

What is rehearsal? It involves several elements, and we will have more to say about it later in this chapter. In many cases, though, rehearsal literally involves saying the to-be-remembered items over and over, sometimes out loud, but more often silently. This silent rehearsal can be documented in various ways, including PET scans (see Chapter 3) that show considerable activation, when people are silently rehearsing, in brain areas typically involved in the production of speech (e.g., Jonides, 2000).

To see how rehearsal matters, consider how the stage model accounts for some classic results. In these studies, research participants hear a series of unrelated words, one word at a time. At the end of the list, the participants are asked to recall the items in any order they choose (this is why the participants’ task is called free recall). If the list contains just six or seven items, participants are likely to remember them all. But if the list is longer, the participants will not remember all the words and there is a clear pattern for which ones they recall and which ones they do not: Words presented at the beginning of the list are quite likely to be recalled; this is the primacy effect. Likewise, the last few words presented are also likely to be recalled; this is the recency effect. The likelihood of recall is appreciably poorer for words in the middle of the list (Figure 7.2).
What creates this pattern? As the to-be-remembered words are presented, the participant pays attention to them, and this ensures that a representation of each word is placed in working memory. Bear in mind, though, that working memory is limited in size, and so, as participants try to keep up with the list presentation, the newly arriving words will bump the previous words out of this memory. Therefore, as participants proceed through the list, their working memories will at each moment contain just the half-dozen words that arrived most recently.

On this account, the only words that do not get bumped out of working memory are the last few words on the list, because obviously no further input arrives to displace them. Hence when the list presentation ends, these few words are still in working memory and are easily retrieved. This is why participants remember the end of the list so accurately—the pattern we called the recency effect. The primacy effect comes from a different source. To put this in concrete terms, let us say that the first word on the list is camera. When research participants hear this word, they can focus their full attention on it, silently rehearsing “camera, camera, camera, . . . ” When the second word arrives, they will rehearse that one too, but they will now have to divide their attention between the first word and the second (“camera, boat, camera, boat, . . . ”). Attention will be divided still further after hearing the third word (“camera, boat, zebra, camera, boat, zebra, . . . ”), and so on through the list.

Notice, then, that earlier words get more attention than later ones. At the list’s start, participants can lavish attention on the few words they have heard so far. But as they hear more and more of the list, they must divide their attention more and more thinly, since they have more words to keep track of. This provides our account of the primacy effect: Earlier words receive more attention than later words and are rehearsed more often; as a result, they are more likely to make it into the long-term warehouse, and so more likely to be recalled later.

Support for these interpretations comes from various manipulations that affect the primacy and recency effects. For example, what happens if we require research participants to do some other task immediately after hearing the words but before recalling them? This other task will briefly require the use of working memory, and this should be enough to displace this memory’s current contents. Those contents, of course, are the hypothesized source of the recency effect, and so, according to our hypothesis, this other task, even if it lasts just a few seconds, should disrupt the recency effect. And indeed it does. If participants are required to count backward for just 30 seconds between hearing the words and recalling them, the recency effect is eliminated (Figure 7.3).

Other manipulations produce a different pattern—diminishing the primacy effect but having no effect on recency. For example, if we present the list items more quickly, participants have less time for rehearsal. As a result, there is less transfer to long-term storage. We therefore should expect a reduced primacy effect (since primacy depends on retrieval from long-term memory) but no change in the recency effect (because the recency items are not being retrieved from long-term memory). This is exactly what happens (Figure 7.4).

**RECodiNG TO EXPAND THE CAPACITY OF WORKING MEMORY**

As we have seen, working memory has a limited capacity: It can handle only a small number of packages at one time. However, what these packages contain is, to a large extent, up to us. If we can pack the input more efficiently, we can squeeze more information into the same number of memory units.

As an example, consider an individual who tries to recall a series of digits that she heard only once:

149162536496481
If she treats this as a series of 15 unrelated digits, she will almost surely fail. But if she recognizes that the digits form a pattern, specifically

\[149162536496481\]

this task becomes much easier. She only has to remember the underlying relationship, “the squares of the digits from 1 to 9,” and the 15 components of the series are easily recreated.

In this example, the person repackages the material to be remembered, recoding the input into larger units that are often called **chunks**. This is important, because, it turns out, working memory’s capacity is measured in chunks, rather than in bits of information.

Much of the recoding of memory items, or **chunking**, happens quite automatically. For example, consider memory for sentences. If we have to recall a list of random words (chair, line, smoke, page, ...), we are unlikely to remember more than six or seven of them. But we can often recall a fairly long sentence after only a single exposure. This fact holds even for sentences that make little sense, such as *The enemy submarine dove into the coffee pot, took fright, and silently flew away*. This dubious bit of naval intelligence consists of 14 words, but it clearly contains fewer than 14 memorial packages: *The enemy submarine* is essentially one unit, *took fright* is another, and so on. (For more on chunking, see Gobet et al., 2001.)

**A Changed Emphasis: Active Memory and Organization**

The stage theory describes the architecture of memory in roughly the right way. But, in order to understand how people learn, and how they remember what they have learned, we need to consider more than just the architecture. We also need to consider the learner’s activities—his strategies and goals, and the previous knowledge that he brings to the learning situation. This is evident in the process of chunking—in which the person relies on other knowledge (e.g., knowledge about the squares of the digits) to repackage memory’s contents. But other evidence makes it clear that the learner’s activity plays a far broader role than this.

**Working Memory as an Active Process**

Why is it that rehearsal helps to establish material in long-term storage? One possibility is that the transfer of information, from the short-term loading platform into the long-term warehouse, requires some amount of time—perhaps a second or so. If this is right, then rehearsal helps for a very simple reason: It holds the information in working memory, making it possible for the transfer to take place.

It turns out, however, that rehearsal provides much more than this, and that establishing material in long-term memory requires more than the passage of time. This is evident, for example, in studies of **maintenance rehearsal**, a strategy that keeps information in working memory but with little long-term effect. As an everyday example, consider what happens when you look up a telephone number. You need to retain the number long enough to complete the dialing, but you have no need to memorize the number for later use. In this circumstance, you are likely to employ maintenance rehearsal: You mechanically repeat the number to yourself while dialing, barely paying attention to the digits. This strategy is fine if the call goes through, but what if the line is busy? A moment later, you try to dial the number again but realize you have already forgotten it. Maintenance rehearsal kept the number in working memory long enough for you to dial it the first time, but utterly failed to establish it in long-term memory. As a result, the number is forgotten after just a few seconds.
Many studies confirm this observation and make it clear that, in general, you are unlikely to recall stimuli that you thought about only in a mindless, mechanical fashion. Likewise, if a stimulus was in front of your eyes (or presented to your ears) for many seconds, but you paid little attention to the stimulus, you probably will not be able to remember that stimulus later. Even if the stimulus was presented again and again and again, you probably will not be able to recall it unless you actively thought about the stimulus, actively paid attention to it.

As an illustration of these claims, consider people’s memory for ordinary coins. Adults in the United States have probably seen pennies, for example, tens of thousands of times; adults in other countries have seen their own coins just as often. If sheer exposure is what counts for memory, then people should remember perfectly what these coins look like. But, of course, most people have little reason to pay attention to the penny. Pennies are a different color and size from the other coins, so they can be identified at a fast glance, with no need for further scrutiny. And, if scrutiny is what matters for memory—or, more broadly, if we remember what we pay attention to and think about—then memory for the coin should be quite poor.

In one study, participants were asked whether Lincoln’s profile, shown on the heads side of the penny, faces to the right or to the left. (Which way does it face? Try to decide before looking at Figure 7.5 on p. 240.) Only half of the participants got this question right—exactly what we would expect if they were merely guessing. This result provides striking confirmation of the fact that memory requires mental engagement with a target and not mere exposure (Nickerson & Adams, 1979; Rinck, 1999; for a related demonstration, see Craik & Watkins, 1973).

**Processing and Organizing: The Royal Road into Memory**

It seems, then, that the transfer of information, from working memory into long-term storage, is not automatic. Instead, some sort of work is involved, so that, to put the matter simply, whether you will remember something or not depends on how, and how fully, you encoded that information when you first met it.

Many studies confirm this broad claim, including studies of brain activity during learning. The results from these studies show that greater levels of activity during the initial encoding are reliably associated with greater probabilities of retention later on. This is especially true for brain activity in the hippocampus and regions of the prefrontal cortex (Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; Wagner, Koutstaal, & Schacter, 1999; Wagner et al., 1998), but it may also include brain activity in the parietal cortex (Wagner, Shannon, Kahn, & Buckner, 2005) (Figure 7.6 on p. 240).

But what exactly is this brain activity accomplishing? One prominent hypothesis, offered 30 years ago, focuses on the “depth” of which the incoming information is processed (Craik & Lockhart, 1972). For verbal materials, shallow processing involves encoding that emphasizes the superficial characteristics of a stimulus, such as the font in which a word is printed. In contrast, deep processing involves encoding that emphasizes the meaning of the material.

Many experiments confirm that deep processing leads to much better recall. In one study, research participants were told that the researchers were studying perception and speed of reaction and then were shown 48 words. As each word was presented, the participants were asked a question about it. For some words, they were asked about the word’s physical appearance (“Is it printed in capital letters?”); this should produce shallow encoding. For others, they were asked about the word’s sound (“Does it rhyme with
train?"; this should encourage an intermediate level of encoding. For the remainder, they were asked about the word’s meaning (“Would it fit into the sentence: The girl placed the _______ on the table?”); this presumably would lead to deep encoding. After the participants had gone through the entire list of words, they were given an unexpected task: They were asked to write down as many of the words as they could remember. The results were in line with the depth-of-processing hypothesis. The participants recalled very few of the words that called for shallow processing (typeface); words that required an intermediary level (sound) were recalled a bit better; and words that demanded the deepest level (meaning) were recalled best of all (Craik & Tulving, 1975).

It seems, therefore, that, to create memories, you need to think about the to-be-remembered materials in some fashion. This engagement with the materials does not have to involve profound contemplation, and so, for example, merely paying attention to the sound of a word (What does it rhyme with?) is better than, say, a thoughtless echoing of the word’s syllables. This is evident, for example, in studies in which participants seem to be engaged in rote memorization. If participants merely repeat the words over and over without thinking about them, then subsequent memory is poor. If, in contrast, participants actually give some thought to the words’ sounds as they are repeating them, then memory performance later on is appreciably better. But how do we know which participants are paying attention to the words’ sound? This is revealed by fMRI scans (see Chapter 3) while the participants are rehearsing the words: Attention to a word’s sound properties is reliably associated with activation in a specific region of the prefrontal cortex, so, if this region is activated during the rehearsal, we know the participant was thinking about the sounds. And, crucially, activation in this area during rote rehearsal is predictive of better memory in subsequent tests (Davachi, Maril, & Wagner, 2001; Poldrak & Wagner, 2004).

Attention to a word’s sound, therefore, is better than thoughtless and mechanical rehearsal; but attention to a word’s meaning is better still, and attention to meaning is almost always associated with a greater likelihood of subsequent recall. And it is not just the search for meaning that helps memory. Instead, memory is promoted by finding the meaning—that is, by finding an understanding of the to-be-remembered materials. Support for
this claim comes from many sources. In some studies, experimenters gave participants material to read that was difficult to understand, and then, immediately after, they probed the participants to see whether (or how well) they understood the material. Some time later, the experimenters tested the participants’ memory for this material. The result was straightforward: the better the understanding, the better the memory later on.

Other studies manipulated whether the to-be-remembered material was understandable or not. For example, in one experiment the following tape-recorded passage was presented:

The procedure is actually quite simple. First you arrange things into different groups depending on their makeup. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step; otherwise you are pretty well set. It is important not to overdo any particular endeavor. That is, it is better to do too few things at once than too many. In the short run this may not seem important, but complications from doing too many can easily arise. A mistake can be expensive as well. The manipulation of the appropriate mechanisms should be self-explanatory, and we need not dwell on it here. At first, the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then one never can tell. (Bransford & Johnson, 1972, p. 722)

Half of the people heard this passage without any further information as to what it was about, and, when tested later, their memory for the passage was poor. The other participants, though, were given a clue that helped them to understand the passage—they were told, “The paragraph you will hear will be about washing clothes.” This clue, allowing them to make sense of the material, dramatically improved later recall (Bransford & Johnson, 1972; for a related example, with a nonverbal stimulus, see Figure 7.7).

There is a powerful message here for anyone hoping to remember some body of material—for example, a student trying to learn material for the next quiz. Study techniques that emphasize the meaning of the to-be-remembered material, and that involve efforts toward understanding the material, are likely to pay off with good memory later on. Memory strategies that do not emphasize meaning will provide much more limited effects.

7.7 Nonverbal stimulus   In general, we easily remember things that are meaningful but do not remember things that seem to have no meaning. This picture can be used to document this point with a nonverbal stimulus. Initially, the picture looks like a collection of meaningless blotches and as such, is immensely difficult to remember. However, if viewers discover the pattern in the picture, the picture becomes meaningful and then it is effortlessly remembered.
Let us also note that these data demand some revisions in how we think about working memory. Early theories conceptualized this memory as just a temporary storage spot—the loading platform, we said, for the long-term memory warehouse. But, as we have now seen, working memory is far more dynamic than this description implies. After all, it is in working memory that the memorizer assembles the incoming information into larger memory chunks. Likewise, when someone is trying to understand a story or a picture, this effort is focused on information currently in working memory. For these reasons, working memory seems less like a loading platform and more like an active workbench on which various items of experience can be sorted, manipulated, and organized.

**MEMORY CONNECTIONS**

We still need to ask, however, why it is that attention to meaning improves memory. What exactly do deep processing and understanding accomplish that promotes retention and subsequent recall? Many investigators believe that the answers lie in the memory connections linking one memory to the next. Their proposal is that, in understanding something—a story, perhaps, or an event—we grasp how each element of the material is linked to the others: We realize that this caused that, and that this aspect is in place despite that aspect; this element has to balance some others; and so on. In essence, then, we can think of understanding as largely a matter of seeing these connections, and the more connections seen, the deeper the understanding.

When the time comes to recall something, these connections, established during the initial learning, can serve as *retrieval paths*. If, in your understanding of an event, you saw that Jane’s smile caused Tarzan to howl, then, later, thinking of Jane’s smile will bring Tarzan’s howl into your thoughts. The connection you saw early on will lead you from one memory to the other, as if the connection were a pathway along which your thoughts could travel.

There are, to be sure, many questions we need to ask about these connections—what they involve, how they are created, and how exactly they can guide retrieval from one memory to the next. And, in fact, there is considerable disagreement about these issues. According to some researchers, the connections are simply links among ideas (or links among *elements* of ideas), in some ways similar to the associations discussed by Locke and Hume centuries ago (Christiansen, Chater, & Seidenberg, 1999; McClelland & Seidenberg, 2000; Rumelhart, 1997). According to other researchers, the connections are far more complex and, in fact, must have a structure, because otherwise they could not possibly represent our knowledge and our thoughts (Fodor, 1997; Fodor & Pylyshyn 1988; Pinker, 1999).

However the connections are conceptualized, though, psychologists agree that it is useful to think about memory in terms of interconnected ideas. Let us consider some of the evidence for this claim. (For more on memory connections—what they are and how they work—see Reisberg, 2006.)

**MNEMONICS**

Some of the evidence favoring the idea of memory connections comes from a practical endeavor—the development of techniques for improving memory. These techniques are called *mnemonics*, and, as it turns out, virtually all mnemonics build on the same base: To remember well, it pays to establish memory connections, and, if those connections are established, then remembering is almost guaranteed.

Mnemonics come in many forms. The ancient Greeks were well aware, for example, that it is easier to remember verbal material if it is organized, with each word linked to others within the material being memorized. Verse, with word sequences that maintain a fixed rhythm or rhyme, provides one way to achieve this organization, and
this is surely why many cultures record their history and their wisdom in verse. Indeed, without the use of verse, preliterate societies might never have transmitted their oral traditions intact from one generation to the next. Even in modern times, verse is still used as an effective mnemonic (“Thirty days hath September, April, June, and November”).

Other mnemonics involve the deliberate use of mental imagery. One such technique is the method of loci, which requires the learner to visualize each of the items she wants to remember in a different spatial location (locus). In recall, each location is mentally inspected and the item that was placed there in imagination is retrieved.

The effectiveness of this method is easy to demonstrate. In one study, college students had to learn lists of 40 unrelated concrete nouns. Each list was presented once for about 10 minutes, during which the students tried to visualize each of the 40 objects in a specific location on their college campus. Tested immediately, they recalled an average of 38 of the 40 items; tested one day later, they still managed to recall 34 (Bower, 1970, 1972; Higbee, 1977; Roediger, 1980; Ross & Lawrence, 1968). In other studies, participants using the method of loci were able to retain seven times more than their counterparts who learned in a rote manner.

In order for imagery to be helpful, however, the image must link the to-be-remembered materials to each other or to other things the person knows—so here, too, we see the importance of memory connections. To make this point concrete, consider a person who has to learn a list of word pairs and who chooses to use imagery as an aid. He might construct mental pictures that bring the items into some kind of relationship, linking them in some way. For example, to remember the pair *eagle-train*, he might imagine an eagle winging to its nest with a locomotive in its beak. Alternatively, he might only imagine the eagle and the locomotive side by side, not interacting. Evidence indicates that images of the first (interacting) sort produce much better recall than non-unifying images (Wollen, Weber, & Lowry, 1972). A similar effect is found...
when the test items are pictures, rather than words. Pictures with interacting parts are remembered much more effectively than are pictures with their constituents merely side by side and not interacting (Figure 7.8).

Whether based on imagery or some other system, though, there is no question that mnemonics are enormously useful in memorizing, say, a list of foreign vocabulary words or the names of American presidents. But what about memorizing more meaningful materials, such as a philosopher’s argument or a pattern of evidence favoring a particular historical claim? Here it might actually be a mistake to use mnemonics, because the mnemonics, powerful as they are, will not lead to the sort of memory most people want.

Why is this? Part of the reason mnemonics are so effective is that they lead the memorizer to focus on a narrow set of memory links—just the fact that the locomotive is in the eagle’s beak, or just the fact that September rhymes with November. This lavishing of attention on a few links virtually guarantees that the relevant memory connections will end up well established, and thus able to serve as efficient retrieval paths later on.

The problem, though, is that people often want more than a narrow set of links; instead, they want a rich network of connections, tying the to-be-learned material to a range of other beliefs and ideas. Why is this desirable? Seeking this range of connections during learning will place the material into a broader mental context, and this will promote understanding—obviously a good thing. Then, during retrieval, having a range of connections will provide the person with a variety of retrieval paths, all leading to the target material. This will allow the person to recall the material from multiple perspectives and in multiple contexts, which in turn will allow more flexible retrieval, certainly helping the person to use the material she has learned.

These gains, though, all depend on finding multiple memory connections—precisely what mnemonics do not accomplish. Thinking about the eagle with the locomotive in its beak does nothing to draw one’s attention to other potential connections—and so does nothing to promote understanding of the fragile ecosystem within which eagles live, or the locomotive’s role in moving freight. As a result, when the time comes to remember, the mnemonic will be quite helpful if one is asked, “What word went with eagle?” but may be of little value in responding to some other memory cue.

In short, mnemonics are useful for memorizing material that, by itself, has no internal organization. But if the material to be learned is meaningful or already organized, the best approach is to seek an understanding of the material when it is being learned. This will lead to the best memory as well as to flexibility in how the target information can be retrieved.

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Figure 7.8 Interactive and noninteractive depictions. Research participants shown related elements, such as a doll sitting on a chair and waving a flag (A), are more likely to associate the words doll, flag, and chair than participants who are shown the three objects next to each other but not interacting (B).
Once a stimulus is encoded—through deep processing, the use of a mnemonic, or any other means—it must be stored in long-term memory until it is later needed. The “record” in memory, storing the new information, is referred to as the memory trace or engram; surprisingly, we know relatively little about how exactly engrams are lodged in the brain. At a microscopic level, it seems certain that engrams are created through the forms of neural plasticity described in Chapter 6: Presynaptic neurons can become more effective in sending signals; postsynaptic neurons can become more sensitive to the signals they receive; and new synapses can be created. At a larger-scale level, evidence suggests that the engram for a particular past experience is not recorded in a single location within the brain. Instead, different aspects of an event are likely to be stored in distinct brain regions—one region containing the visual elements of the episode; another containing a record of our emotional reaction; a third area containing a record of our conceptual understanding of the event; and so on (e.g., Damasio & Damasio, 1994). But, within these broad outlines, we know very little about how the information content of a memory is translated into a pattern of neural connections. Thus, to put the matter bluntly, we are many decades away from the science-fiction notion of being able to inspect the wiring of someone’s brain in order to discover what he remembers, or being able to “inject” a memory into someone by a suitable rearrangement of her neurons.

One fact about memory storage, however, is well established: Engrams are not created instantly. Instead, a period of time is needed, after each new experience, for the record of that experience to become established in memory. During that time, memory consolidation is taking place; this is a process, spread over several hours, in which memories are transformed from a transient and fragile status to a more permanent and robust state (Hasselmo, 1999; McGaugh, 2000, 2003; Meeter & Murre, 2004; Wixted, 2004).

What exactly does consolidation accomplish? The answer is not clear, although the best bet is that this time period allows adjustments in neural connections, creating a pattern of communications among neurons that can represent the newly acquired memory. This process seems to require the creation of new proteins, so it is disrupted by chemical manipulations that block protein synthesis (Davis & Squire, 1984; Santini, Ge, Ren, deOrtiz, & Quirk, 2004; Schafe, Nader, Blair, & LeDoux, 2001).

Some of the clearest evidence for consolidation comes from a type of memory loss sometimes produced by head injuries. Specifically, people who have experienced blows to the head sometimes develop retrograde amnesia (retrograde means “in a backward direction”), in which they suffer a loss of memory for events prior to the brain injury. This form of amnesia can also be caused by brain tumors, diseases, or strokes (Cipolotti, 2001; Conway & Fthenaki, 1999; Kapur, 1999; Mayes, 1988; Nadel & Moscovitch, 2001).

Retrograde amnesia usually involves recent memories. In fact, the older the memory, the less likely it is to be affected by the amnesia, a pattern that is so robust that it is often referred to as Ribot’s law, in honor of the nineteenth-century scholar who first discussed it (Ribot, 1882). What produces this pattern? Older memories have presumably had enough time to consolidate, so they are less vulnerable to disruption. Newer memories are not yet consolidated, so they are more liable to disruption (Brown, 2002; Weingartner & Parker, 1984).

There is, however, a complicating factor: Retrograde amnesia sometimes disrupts a person’s memory for events that took place months or even years prior to the brain injury. In these cases, interrupted consolidation could not explain the deficit unless one assumes—as some authors do—that consolidation is an exceedingly drawn-out process,
occuring over very long periods (Hasselmo, 1999; Mcgaugh, 2000; Squire, 1987; Squire & Cohen, 1979, 1982). However, this issue remains a point of debate, making it clear that the last word has not yet been written on how consolidation proceeds.

**Retrieval**

When we learn, we transfer new information into our long-term store of knowledge, and then we consolidate this newly acquired information. But successful acquisition of a memory is not enough. We must also be able to retrieve the information when we need it, and the success of retrieval is far from guaranteed. This is obvious to anyone who has ever experienced a “block” on a familiar name. We may know the name (we have encoded and stored it) but be unable to retrieve it when trying to introduce an old friend to a new one—an experience that can be quite embarrassing!

Failures to remember something can happen for many reasons, including (as we have already discussed) inadequate encoding. We know that retrieval is the problem, though, in cases in which you initially fail to remember something, but then later on, do remember the desired information, once an adequate retrieval cue is provided. A clear illustration of this pattern often arises when someone returns to his hometown after a long absence. This return can unleash a flood of recollection, as the sights and sounds of the place trigger the relevant memories. A word, a smell, a visit from a school friend not seen for years—any of these may summon memories the person thought were utterly lost.

**The Relation between Original Encoding and Retrieval**

What makes a retrieval cue effective? Why do some reminders succeed, while others have no effect? One important factor is whether the cue re-creates the context in which the original learning occurred. For example, if an individual focused on the sounds of words while learning them, then she will be well served by reminders that focus on sound (“Was there a word on the list that rhymes with log?”); if she focused on meaning while learning, then the best reminder would be one that again draws her attention toward meaning (“Was one of the words a type of fruit?”; Fisher & Craik, 1977).

Why should this be? Our earlier discussion of memory connections provides the answer. Learning, we suggested, is essentially a process of creating (or strengthening) memory connections that link the to-be-remembered material to other things you already know. When the time comes for retrieval, these same connections serve as retrieval paths, leading you back to the desired information. If, therefore, an individual focused on the sounds of words during learning, this established a corresponding set of memory connections—a connection, for example, between dog and log. That connection will be useful later if the person is asked the question about rhymes: If she thinks about log, the connection will guide her thoughts to the target word, dog. But the same connection will play little role in other contexts. If she is asked, “Did any of the words on the list name animals with sharp teeth?” the path from log to dog is irrelevant; what she needs with this cue is a retrieval path leading from sharp teeth to the target.

In this example, the retrieval cue helps someone remember because the cue re-creates a mental context in which the person was thinking about words’ sounds, not their meaning. But other forms of context reinstatement (a re-creation of the state of mind someone was in during learning) can also help someone to remember. In all cases, though, the logic is the same: If the cues and mental context in place during retrieval match those in place during the initial encoding, then this will help the person to use the connections established earlier.
We have already seen a different example of context reinstatement—the case in which someone returns to his hometown, so that he is re-exposed to the sights and sounds that were present during the to-be-remembered events. As a different example, participants in one study were asked to read an article similar to the ones they routinely read in their college classes; half read the article in a quiet setting, and half read it in a noisy environment. When tested later on, those who read the article in quiet did best if they were tested in quiet; those who read it in a noisy environment did best if tested in a noisy setting (Grant et al., 1998). In both cases, participants showed the benefits of context reinstatement—and, with that, the benefit of being able to use, at time of retrieval, the specific connections established during learning (for another example, see Figure 7.9).

These results make it sound like the physical setting is crucial for memory, but, in truth, the physical setting matters only indirectly: A return to the physical circumstances of learning does help, but only because this return helps re-create the mental context of learning—and it is the mental context that matters. This was evident, for example, in a study in which participants were presented with a long list of words. One day later, the experimenter brought the participants back for an unexpected recall test that took place in either the same room or a different one (one that differed in size, furnishings, and so on, from the context of learning). Not surprisingly, recall was better for those who were tested in the same physical environment, but, crucially, the investigator found a straightforward way of overcoming this context effect. A different group of participants was brought to the new room, but just prior to the test they were asked to think about the room in which they had learned the lists—what it looked like, how it made them feel. By doing so, they mentally re-created the old environment for themselves; on the subsequent recall test, these participants performed just as well as those for whom there was no change of rooms (Smith, 1979; Smith & Vela, 2001). In essence, then, what matters for retrieval is your mental perspective, not what room you are sitting in. If you change the physical context without changing your mental perspective, the physical relocation has no effect.

**Encoding Specificity**

The effectiveness of context reinstatement is important for several reasons, including the fact that it tells us something crucial about how materials are encoded in the first place: When people encounter some stimulus or event, they think about this experience in one way or another, and, as we have discussed, this intellectual engagement serves to connect the new experience to other thoughts and other knowledge. We have talked about the fact that these connections can serve as retrieval paths, helping people to recall the target information, but let us note that this is possible only because those connections are themselves part of the memory record. Thus, continuing an earlier example, if people see the word *dog* and think about what it rhymes with, what is stored in memory is not just the word. What is stored is the word plus some record of the connections made to rhyming words, and that is why these connections are available for use during retrieval. Likewise, if people see a picture and think about what it means, what is stored in memory is not just the picture, but a memory of the picture with some record of the connections to other, related ideas.

In short, what is placed in memory is not some neutral transcription of an event. Instead, what is placed in memory is a record of the event as understood from a particular perspective or perceived within a particular context. Psychologists refer to this broad pattern as **encoding specificity**, and this specificity has powerful effects on how—or whether—the past is remembered (Tulving & Osler, 1968; Tulving & Thompson, 1973; also Hintzman, 1990). For example, participants in one study read target words (e.g., *piano*) in either of two contexts: “The man lifted the piano” or “The man tuned the
piano.” These sentences led the participants to think about the target word in a specific way, and it was this thought that was encoded into memory. Thus, what was recorded in memory was the idea of “piano as something heavy” or “piano as a musical instrument.” This difference in memory content became clear when participants were later asked to recall the target words. If they had earlier seen the “lifted” sentence, then they were quite likely to recall the target word if given the hint “something heavy.” The hint “something with a nice sound” was much less effective. But if participants had seen the “tuned” sentence, the result reversed: Now the “nice sound” hint was effective, but the “heavy” hint was not (Barclay, Bransford, Franks, McCarrell, & Nitsch, 1974). In both cases, the memory hint was effective only if it was congruent with what was stored in memory—as just as the encoding specificity proposal predicts.

**When Memory Fails**

All three of the processes we have been discussing—acquisition, storage, and retrieval—usually function extremely well, so that each of us can learn an enormous quantity of information, store that information for long periods of time, and then retrieve the information, when we need it, with relative ease. But of course there are also circumstances in which remembering is less successful. Sometimes we try to remember an episode, but simply draw a blank. Sometimes we recall something, but with no conviction that we are correct: “I think it happened on Tuesday, but I’m not sure.” And sometimes our memories fail us in another way: We recall a past episode, but it turns out that our memory is mistaken. Perhaps details of the event were different from the way we recall them; perhaps our memory is altogether wrong, misrepresenting large elements of the original episode. Why, and how often, do these memory failures occur?

**Inadequate Encoding**

It seems self-evident that we cannot remember something if we never learned it in the first place: If a friend never told you what her middle name is, then obviously you will not be able to recall the name when asked. But, obvious or not, we need to bear in mind that at least some cases of failure to remember are best understood as the result of inadequate learning.

This point can be documented in many ways, including a study we mentioned earlier in the chapter (pp. 239–240). The investigators used fMRI recording to keep track of the moment-by-moment brain activity in participants who were studying a list of words (Wagner et al., 1998; also Brewer et al., 1998). Later, participants were able to remember some of the words they had learned, but not others, allowing the investigators to compare brain activity during encoding for words-later-remembered with the activity during encoding for words-later-forgotten. Figure 7.6 shows the results, with a clear difference, during the initial encoding, between words that were remembered later on and words that were forgotten. The strong implication of this result is that the subsequent “forgetting” was caused by differences that took place during encoding—differences that caused the later-forgotten words to be less well learned in the first place.

**Forgetting**

In other cases, though, materials are learned, so that they can (at least for a while) be remembered. Later on, though, those same materials cannot be recalled. What produces this pattern? One clue comes from the fact that it is almost always easier to recall recent
events (yesterday’s lecture, for example, or this morning’s breakfast) than it is to recall more distant events (a lecture or a breakfast 6 months ago). In technical terms, recall decreases, and forgetting increases, as the **retention interval** (the time that elapses between learning and retrieval) grows longer and longer.

This simple fact has been documented in many studies; indeed, the passage of time erodes memory for things as diverse as past hospital stays, our eating or smoking habits in past years, car accidents we experienced, our consumer purchases, and so on (Jobe, Tourangeau, & Smith, 1993). The classic demonstration of this pattern, though, was offered more than a century ago by Hermann Ebbinghaus (1850–1909). Ebbinghaus systematically studied his own memory in a series of careful experiments, examining his ability to retain lists of nonsense syllables, such as *zup* and *rif*. Ebbinghaus plotted a *forgetting curve* by testing himself at various intervals after learning (using different lists for each interval). As expected, he found that memory did decline with the passage of time. However, the decline was uneven, being sharpest soon after the learning and then becoming more gradual (Ebbinghaus, 1885; Figure 7.10).

**DECAY**

What accounts for the pattern observed by Ebbinghaus? One theory holds that memory traces **decay** as time passes, like mountains that are eroded by wind and water. The erosion of memories is presumably caused by normal metabolic processes that wear down memory traces until they fade and finally disintegrate.

One line of support for this theory exploits the fact that, like most chemical reactions, many metabolic processes increase their rates with increasing temperature. If these metabolic reactions are responsible for memorial decay, then forgetting should increase if body temperature is elevated during the retention interval. This prediction is difficult to test with humans (or any other mammal), because internal mechanisms keep the temperature of our bodies relatively constant (see Chapter 2). However, this prediction was tested with animals such as goldfish whose bodies tend to take on the temperature of their surroundings. By and large, the results are in line with the hypothesis: the higher the temperature of the tank in which the fish were kept during the retention interval, the more forgetting took place (Gleitman & Rozin, as reported in Gleitman, 1971; for more evidence documenting decay, see Altmann & Gray, 2002; Bailey & Chen, 1989).

**INTERFERENCE**

Other findings, however, make it clear that decay cannot provide the entire explanation of forgetting. As one concern, we will later review evidence for remembering that lasts across many, many years, an observation that is puzzling if the mere passage of time somehow erodes recollection. In addition, several experiments suggest that it is **interference from new learning**, and not the passage of time, that really matters for forgetting. For example, Baddeley & Hitch (1977) asked rugby players to recall the names of the other teams they had played against over the course of a season (Figure 7.11). Not all players made it to all games, because of illness, injuries, or schedule conflicts. These differences allow us to compare players for whom “two games back” means 2 weeks ago, to players for whom “two games back” means 4 weeks ago. Thus, we can look at the effects of retention interval (2 weeks vs. 4) with the number of intervening games held constant. Likewise, we can compare players for whom the game a month ago was “three games back” to players for whom a month ago means “one game back.” Now we have the retention interval held constant, and we can look at the effects of intervening events. In

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**7.10 Forgetting curve** The figure shows retention after various intervals since learning. Retention is here measured in percent saving, that is, the percentage decrease in the number of trials required to relearn the list after an interval of no practice. If the saving is 100 percent, retention is perfect—no trials to relearn are necessary. If the saving is 0 percent, there is no retention at all, for it takes just as many trials to relearn the list as it took to learn it initially.

**7.11 Forgetting from interfering events** Members of a rugby team were asked to recall the names of teams they had played against. Their performance was influenced by the number of games that intervened between the game to be recalled and the attempt to remember. This pattern fits with an interference view of forgetting.
this setting, Baddeley and Hitch report that the mere passage of time accounts for very little; what really matters is the number of intervening events, just as we would expect if interference, and not decay, is the major contributor to forgetting. (For other—classic—data on interference this issue, see Jenkins & Dallenbach, 1924; for a more recent review, see Wixted, 2004.)

Interference can also be easily demonstrated in the laboratory. In a typical study, a control group learns the items on a list (A) and then is tested after a specified interval. The experimental group learns the same list (A), but, in addition, they must also learn the items on a second list (B) during the same retention interval. The result is a marked inferiority in the performance of the experimental group. List B seems to interfere with the recall of list A (Crowder, 1976; McGeoch & Irion, 1952).

It turns out, though, that not all new learning produces interference; in fact, interference emerges only under certain circumstances. No interference is observed, for example, between dissimilar sorts of material—learning to skate does not interfere with one's memory for irregular French verbs. In addition, interference occurs only if the things to be remembered are essentially incompatible. If the new learning is consistent with the old, no interference is observed; in fact, the subsequent learning helps memory, rather than hindering it. Thus, learning more algebra helps you to remember the algebra you mastered last year; learning more psychology helps you to remember the psychology you have already covered.

RETRIEVAL FAILURE

But why does memory interference occur at all? Why can’t newly acquired information peacefully coexist with older memories? One hypothesis is that the forgotten material is neither damaged nor erased; it is simply misplaced. By analogy, consider someone who buys a newspaper each day and then stores it with others in a large pile in the basement. Each newspaper is easy to find when it is still sitting on the breakfast table; it can still be located without difficulty when it is on top of the basement stack. After some days, though, finding the newspaper becomes difficult. It is somewhere in the pile but may not come into view without a great deal of searching. And, of course, the pile grows higher and higher every day; that is why the interference increases as the retention interval grows longer.

If this hypothesis is correct, then forgetting should be reversible. After all, the hypothesis proposes that the “lost” memories are still in storage, even if they are difficult to locate. With a suitable cue or prompt, therefore, these memories might be recovered. And, in fact, we know that this is true for some cases of forgetting, so at least some forgetting can be understood as the result of retrieval failure.

We have already seen some of the evidence for this claim. As we have noted, memories can often be triggered by returning to the context in which learning took place. Prior to that return, the target information might not be recalled—an apparent case of forgetting. But then, once the right retrieval cues are available, the memory resurfaces, making it clear that the problem was retrieval failure and not a genuine memory loss.

The idea that forgetting is sometimes produced by retrieval failure also has another implication: It implies that forgetting can be incomplete, so that we might be able to retrieve some aspects of a memory but not others. This pattern is perhaps most clearly evident in the phenomenon psychologists call the tip-of-the-tongue effect.

Try to think of the word that means a type of carving done on whalebone, often depicting whaling ships or whales. Try to think of the name of the navigational device used by sailors to determine the positions of stars. Try to think of the name of the Russian sled drawn by three horses. Chances are that, in at least one of these cases, you found yourself in a frustrated state: certain you knew the word but unable to come up with it. The word was, as people say, right on the “tip of the tongue” (TOT).