A Companion to Cognitive Science

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Memory

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Memory is a single word that refers to a complex and fascinating set of abilities which people and other animals possess that enables them to learn from experience and retain what they learn. In memory, an experience affects the nervous system, leaves a residue or trace, and changes later behavior. Types of memory are tremendously varied; so, too, are the techniques used in cognitive science to investigate them. The aim of the present chapter is to give an overall sense of types of memory as well as of techniques used in the experimental study of memory. The process of remembering will be broken up into two main components: encoding and retrieval. We shall then discuss the factors which determine the effectiveness of each component and some of the ways in which memory both succeeds and fails.

Varieties of learning and memory

Biologists, philosophers, and psychologists have described and discussed dozens of types of memory. We consider here some of the most frequently used categories.

Procedural memory refers to the knowledge of how to do things such as walking, talking, riding a bicycle, tying shoelaces. Often the knowledge represented is difficult to verbalize, and the procedures are often acquired slowly and only after much practice. (Imagine someone trying to learn how to swim from reading about swimming, but not practicing the skill.) The types of conditioning to which most species of animals are subject — classical (or Pavlovian) conditioning and instrumental (or operant) conditioning — are other examples of procedural memory.

Procedural memory is often contrasted with declarative memory, or knowing facts about the world and about one’s past (Squire, 1987). A major distinction within declarative memory is that between episodic and semantic memory. Episodic memory refers to the remembering of episodes of our lives and is contextually bound; that is, the time and place of occurrence are inextricable parts of memory for episodes. This type of memory enables the mental time travel in which we engage when we think back to an earlier occasion; because it constitutes every individual’s personal history, it is sometimes called autobiographical memory. Semantic memory (or generic memory) refers to our general knowledge of the world (that NaCl is the symbol for salt, what the word platypus means, and so on). This knowledge is not tied to one episode, and we need not refer to the time or place in which we learned these facts to know that they are true.

This is not the only way to distinguish types of memory. Another, important difference is between short-term and long-term memory. Short-term memory (or primary memory) refers to our ability to hold in mind a relatively small amount of information that is rapidly forgotten if we stop attending to it. A good example is remembering a
telephone number for a brief period after looking it up. This ability is also referred to as working memory, because it permits us to perform the mental work of manipulating symbols and thinking. Long-term memory (or secondary memory) is a rather imprecise term that is used to refer to retention of various kinds over long time periods; depending on content, long may mean anywhere from 30 seconds to many years (hence the fuzzy nature of the term).

We will leave aside many other distinctions that psychologists have made and confine our remarks to what most people have in mind when they refer to remembering or memory, which is long-term episodic memory. How do we remember what we read in the paper, where we parked our car this morning, the earliest event from our childhood, and the myriad other events of our lives? We often need to recall events from the past as accurately as possible, and this process can be effortful. The process of recognition (when we are asked to judge whether something has been presented to us previously) appears easier than recall. We have often had the experience of being able to recognize some event when we failed to recall it. Below we consider (a) the study of memory, (b) some of the major factors that have been shown experimentally to affect memory, (c) two critical principles of remembering, (d) the problem of forgetting, and (e) memory illusions and false memories.

The study of memory

Philosophical speculation about how people learn and remember dates from Aristotle and Plato, whose prescient comments on the topic are still worth reading, and continues to the present day. Empirical research on memory is much more recent, usually dated from the great experiments of Hermann Ebbinghaus (1850–1909), published in book form in 1885. Ebbinghaus made up lists of nonsense syllables composed of two consonants and a vowel, such as TEIF, and placed them in long lists which he painstakingly memorized and on which he later tested himself. Despite the fact that he was the only subject in all his experiments, he succeeded in obtaining very regular results by testing himself many times in each experimental condition. All of his findings have stood the test of time. His work was quite important, not only for the original findings about memory, but also because he showed that the higher mental processes could be subjected to careful experimental study, at a time when other psychologists were arguing that experimental methods could be applied only to the study of sensory processes.

Ebbinghaus advocated careful laboratory research as a sure path to knowledge, and the laboratory research tradition begun by Ebbinghaus still exists, albeit in radically different form. The development of alternative approaches has enriched today’s cognitive science, however. Some researchers advocate more naturalistic methods (the everyday memory tradition). Others seek the biological underpinnings of memory in studies of animals or in the tradition of cognitive neuroscience (measuring neural activity through modern neuroimaging techniques while people are engaged in memory tasks, or studying the deficits and pathologies of memory in brain-damaged patients). Yet another approach takes inspiration from artificial intelligence and asks how much human memory resembles computer memories. Some researchers seek to simulate and to understand memory processes by creating neural network models. Each of these approaches makes a contribution, but we will focus on the perspective on learning and memory that began with Ebbinghaus and continues in today’s experimental
psychology, employing behavioral methodologies as the primary tool of study. We will introduce findings from other traditions when they are appropriate.

The learning/memory process can be divided into three hypothetical stages: encoding (original acquisition of information), storage (retaining information over time), and retrieval (gaining access to information when it is desired) (Melton, 1963). Any time someone accurately remembers an event, all three stages are successfully completed. If someone forgets or misremembers an event, we can ask at what stage or stages the process went awry. However, answering this question is not as straightforward as it seems, because the three stages are interlocked, and psychology experiments cannot give clean answers to the question of what stage in the process suffered a breakdown.

A standard psychology experiment on learning and memory has two stages. In a first stage people are exposed to information to be learned, be it sets of words, numbers, pictures, sentences, a story or prose passage, or a videotape of a complex event. In the second stage, a test is given some time later in which people may be asked to recall or to recognize the material. The first stage of memory experiments corresponds to the encoding of material, but of course there is no way to tell if material was actually encoded unless it is tested. The second stage corresponds to the retrieval stage, but of course it does not measure retrieval per se – information can only be retrieved if it was encoded and stored.

Since the work of Tulving and Pearlstone (1966), psychologists have distinguished between *availability* and *accessibility* of information in memory, where availability refers to the information about events that a person has encoded and stored and accessibility refers to the information that can be retrieved on any particular test occasion. The holy grail for psychologists interested in memory would be a test or procedure that accurately measured the contents of a person’s knowledge – what the person had encoded and stored. At one time it was argued that procedures for measuring recognition represented this perfect indicator of knowledge, but this hope was ill-founded, and recognition procedures are subject to the same vagaries as are recall procedures. Every test of memory is an imperfect indicator of knowledge, whether in the classroom, in standardized tests, or in the psychology laboratory. We can never measure what information is encoded and stored; we can only measure what information is accessible or retrievable under a particular set of test conditions.

Despite these problems, the division of the learning/memory process into three stages can still be useful. We can still sometimes ascribe forgetting to failures (say) of retrieval. Imagine people studying a list of 100 words on which *umbrella* is the fifty-first word. If people were tested by being asked to recall in any order on a blank sheet of paper (a procedure called *free recall*), the probability of recalling *umbrella* would be vanishingly small. Was the word not encoded? not retained? or just not retrieved? There is no way to know from this one condition. However, if the people were then given retrieval cues to prompt memories for the words and the cue *parasol* elicited recollection of *umbrella*, then clearly the word had been encoded and stored, and the failure on the free recall test was one of retrieval. (It would be necessary to safeguard against the possibility that people are merely guessing the words from the cues, but in practice insuring this is relatively easy.)

Most experiments on memory can be classified as encoding experiments or retrieval experiments. *Encoding experiments* involve manipulation of some factor during the encoding stage (e.g., the type of material, the way the material is processed), with other
Factors (e.g., the type of test that is used to assess knowledge) held constant. *Retrieval experiments* hold constant the encoding factors but manipulate the retrieval factors, such as the type of test given or the particular instructions given before the test. One particularly useful research strategy in investigating memory combines these two types of experiments and has been called the *encoding/retrieval paradigm* (Tulving, 1983). In this type of analysis, of which we will provide examples below, one manipulates both encoding and retrieval conditions within the same experiment. For example, two different strategies for studying material might represent the encoding manipulation, and two different forms of test might be used to assess knowledge. The encoding/retrieval paradigm is efficient, because it permits several questions to be asked at once. For example, will the outcome of the encoding manipulation generalize across more than one kind of test? Similarly, will different types of test show different patterns of knowledge acquired and stored during the earlier phases of the experiment?

Besides specific encoding and retrieval factors, memory is affected by many other conditions. The outcome of any experiment is, in a sense, affected by the factors that were *not* manipulated but which the experimenter chose to hold constant. Jenkins (1979) developed a tetrahedral model of memory experiments, shown here in figure 17.1, to illustrate the fact that remembering is always contextually conditioned. The four general factors emphasized are orienting tasks (or factors that are used to orient the learner to the situation), materials (the stuff that the learner will be exposed to and how this will occur), the type of subjects or participants in the research (e.g., adults, children, brain-damaged patients), and the retrieval tasks (or the type of test used to assess knowledge). These four factors can interact in complex ways, but Jenkins's main point was that any experiment on memory involves making choices and holding some factors constant while varying others. A question that always needs to be considered is how the results of an investigation might change if other variables were manipulated. Would the findings generalize across these other factors? It is useful to keep the analysis represented in figure 17.1 in mind while reading (below) about factors that have been shown to critically affect remembering.

In the sections below we organize some of the main factors that have been shown to affect remembering by reference to two critical principles: effectiveness of encoding and the effectiveness of retrieval cues. These factors are studied through encoding and
retrieval experiments, respectively. We will see that these two principles are not independent of one another and will illustrate their interaction with experiments employing the encoding/retrieval paradigm.

Effectiveness of encoding

One critical aspect of the learning and memory process is the original acquisition or learning of information. Many experiments have documented the importance of a general principle: namely, that the more effectively information is encoded, the better later recall is. Of course, such a statement runs the risk of being tautologous, unless we can specify a way (independently of level of recall or recognition) of defining effectiveness of encoding. Frequently, that is impossible to do. However, we will persevere despite that difficulty and show how this general principle can at least order many findings from the experimental study of remembering. In general, all the research in this section conforms to an encoding paradigm, as discussed above: experiments are conducted in which a variable is manipulated during the study phase of an experiment, and the interest is in seeing how it affects performance on a later test.

Meaning

All else being equal, more meaningful information is better remembered than less meaningful information. For example, coherent passages are remembered better than chaotic ones (created, for example, by keeping the words from the coherent passage the same but rearranging them). Similarly, new information about bridge, chess, or baseball will be better remembered by experts in those domains than by novices. The new information can be better assimilated (encoded) in terms of the expert’s knowledge base.

Even very simple materials — such as words studied in a long list — can reveal this effect. Craik and Tulving (1975) reported an experiment showing a levels-of-processing effect in remembering. Before describing the experiment itself, we identify their guiding assumptions. The basic idea that Craik and Tulving were exploring is that the cognitive system processes information to different levels, or depths, and that the depth of processing determines later retention. For example, in reading the German word Gedächtnis, a reader of English (with a knowledge of the orthography of Western alphabets) could apply at least an orthographic or graphemic analysis and identify the graphemes of the word. A person with some knowledge of phonology in German could sound the word out, even if he or she did not know its meaning. Finally, a person fluent in reading German could know the meaning of the word too. (And a German–English bilingual could translate it as memory.) To comprehend the word, the reader must progress through graphemic (visual), phonemic (sound), and semantic (meaning) codes. The levels-of-processing approach predicts that remembering depends on the level to which it has been processed, with deeper (meaningful) processing leading to better retention.

Craik and Tulving (1975) manipulated experimentally the depth to which subjects, college students, had to process words on a list of 60 common words, such as bear, by requiring them to answer different questions about the words. Some questions directed attention to the word’s appearance (“Is it in upper-case letters?”); others directed
Table 17.1 Results of a Craik and Tulving (1975) levels-of-processing experiment presented as proportions of correct recognition. Subjects responded Yes or No to orienting questions requiring graphemic, phonemic, or semantic analysis.

<table>
<thead>
<tr>
<th>Response</th>
<th>Graphemic</th>
<th>Phonemic</th>
<th>Semantic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>0.42</td>
<td>0.65</td>
<td>0.90</td>
</tr>
<tr>
<td>No</td>
<td>0.37</td>
<td>0.50</td>
<td>0.65</td>
</tr>
</tbody>
</table>

analysis to the word’s sound ("Does it rhyme with chair?"); whereas others required consideration of the word’s meaning ("Is it an animal?"). For half the questions the answer was yes and for the other half it was no. Subjects saw each word for five seconds while answering the question. The questions were designed to encourage graphemic, phonemic, or semantic levels of processing.

To measure the effect of this manipulation, subjects were given a recognition test in which the 60 items studied were randomly intermixed with 120 nonstudied words; subjects were told to go through the words and pick exactly 60 that they believed were previously studied. Chance performance on the test was 0.33 (60 out of 180 could be obtained by someone who had not studied the list at all). The recognition results are shown in table 17.1, which gives the proportion of words correct in each of the six conditions (three levels of processing x two answers). Clearly, the levels-of-processing manipulation had a dramatic effect on recognition. Following a graphemic analysis, recognition was barely above chance, whereas a semantic analysis produced extremely accurate retention (especially when the answer to the question was Yes). Keep in mind that the subjects viewed the words for five seconds in all conditions and that they could answer the questions in each case in under a second. What the results show is that, with all else held constant, retention could be dramatically affected by the split-second cognitive processes engendered by the questions that were asked. How well people remember events depends partly on what the events are, but also on how they are encoded: deep (meaningful) processing of information surpasses other, phonemic or graphemic analyses in its effect on later retention. We shall see this same principle in operation in the next two sections.

Imagery and vividness

Since the time of the ancient Greeks, scholars have known that imagery can aid remembering. Instructors of rhetoric taught speakers mnemonic devices, which was critical for people who could not use written reminders. Modern experimental psychologists have confirmed the wisdom of using imagery in several types of controlled experiments. In most types of test, pictures are better retained than words; this is true even in tests that would seem to favor verbal encoding. For example, if a long series of pictures and concrete words (words that refer to concrete, hence picturable objects) are presented, and people are asked to recall them by writing either the words presented or the names of the pictured objects, pictures are better remembered than words. This occurs despite the fact that the verbal mode of response would seem to favor verbal over pictorial
encoding. In addition, concrete words (hyena, trampoline) are remembered better than words that refer to abstract concepts (freedom, beauty) when other factors such as word frequency are controlled. Both these outcomes (superior recall of pictures versus concrete words and better recall of concrete than abstract words) can be explained by Allan Paivio’s (1986) dual coding theory (see Article 12, IMAGERY AND SPATIAL REPRESENTATION). The basic idea is that people can represent information in both verbal and imaginal form, and that if information is represented in both verbal and imaginal codes, its retention will be better than if only one code is used. Therefore, when people study pictures in preparation for a verbal recall test, they code them both imaginably and verbally, whereas they encode concrete words in a verbal code (although some imagery may be evoked by the vivid words). Because pictures are strongly encoded in both modes, they are better recalled than are concrete words. However, concrete words do weakly activate a nonverbal code relative to abstract words, so they are better recalled than are abstract words. Other experiments show that if people are given verbal material and instructed to form images representing the material, they retain more than control subjects who are not so instructed. The role of imagery in memory is unquestioned. Many mnemonic devices, such as those discussed below, use imagery to promote retention.

Distinctiveness

Another factor strongly affecting remembering is the distinctiveness of the event to be remembered. In general, distinctive, surprising, emotional events are well remembered. Suppose a person saw a series of 100 pictures and the fifty-first picture was of a standard desk chair. If asked to recall the names of the items later, few would remember chair having been in the series. Now imagine that the same picture of a chair was placed in the same position in a series of 99 words. Now the same object, being distinctive, would be recalled almost perfectly. The general point is that recall of any event depends not only on its nature, but on the context in which it occurs.

This same principle extends to remembering events from our lives. Most of us can recall with more accuracy what we did on some salient occasion (New Year’s Eve, our birthday) than a day occurring a week earlier or later. A special name, flashbulb memories, is employed for memories of occasions that are emotionally very powerful, such as witnessing the birth of a child or participating in some great national tragedy (an assassination). The analogy is that our memories are so clear as regards details surrounding the place of occurrence, our feelings, and even fine details of the event (or our reaction to it), that they seem to have been caught as in a photographic flash and indelibly imprinted in memory. People have great certitude about such memories, even though studies show that some of the retained information is false. There is debate about whether flashbulb memories must be explained by some special mechanism, or if they are simply strong variants of particularly distinctive events working through the same general mechanism that makes a picture well remembered when placed in the context of many words (see Conway, 1995).

The three factors listed above – endowing events with meaning, using imagery, and making events distinctive – are all examples of how factors manipulated at encoding can powerfully affect memory. However, as we shall see below, just because the manipulation occurs during encoding does not mean that retrieval processes are not
important. In most cases, the interaction between encoding and retrieval factors critically determines retention.

**Effectiveness of retrieval cues**

If you reflect on experiences you have had in trying to remember events from the distant past, the importance of retrieval conditions for remembering will become obvious. You see someone familiar but cannot remember her name; a bit later the name comes to you. Or someone asks you who starred in a particular movie and you draw a blank; when several possibilities are mentioned, you immediately know which one is correct. In another case, you return to a place where you used to live, and the sights and sounds bring back memories of events that you had not thought of for years. All of these common experiences show that having information encoded and stored in memory is no guarantee that it will be remembered; in addition to good encoding, appropriate retrieval conditions must exist for the events to be remembered.

Psychologists have studied the critical role of retrieval processes by manipulating the conditions and the types of cues provided to people during retrieval. In one common technique, people are given long lists of words belonging to common categories (e.g., birds – pigeon, sparrow; furniture – dresser, hat rack, etc.) with instructions to remember the objects in the category. Afterwards, some people are given a free recall test in which they receive a blank sheet of paper with instructions to recall as many words as possible from the list. In one experiment people remembered 19 of 48 studied words under these conditions (Tulving and Pearlstone, 1966). What happened to the missing 29 words? Were they not well encoded and stored? Another group of people received a cued recall test with the category names given as retrieval cues. In this condition, subjects recalled about 36 words, or almost twice as many as in free recall. This shows that the failure to recall words under free recall conditions was due not solely to problems in encoding or storage, but also to retrieval factors. When supplied with strong retrieval cues, people can remember events that seemed forgotten under other conditions.

Many studies, using many different types of materials, have revealed the same general point: It is impossible to make absolute statements about how much or what kind of information has been encoded and stored in memory. We might like to know what information is available (or stored) in memory, but all we can ever know is what information is accessible (retrievable) under a particular set of test conditions. Change the retrieval conditions (or the nature of the test), and a different estimate of accessible information will be produced.

What determines the effectiveness of retrieval cues? The general rule that is supported by considerable research is the **encoding specificity principle**, which states that retrieval cues are effective to the extent that they match the way the original events were encoded (Tulving, 1983). In the experiment just described, the category names served as effective cues because they helped to re-create the encoding of the presented words, at least relative to free recall conditions. Similarly, the context in which events occurred can serve as an effective cue, which is why returning to a place from which one has long been absent can bring back memories of old experiences. The encoding specificity principle indicates that it is a mistake to consider either encoding factors or
retrieval factors in isolation when discussing memory. Rather, the interaction between encoding and retrieval is critical.

Interaction of encoding and retrieval

Remembering is best conceived as the successful interaction of encoding and retrieval. Consider, for example, the effects of distinctiveness on recall discussed in the section above. If a person sees a picture in a list of 99 words, it will be well recalled, but the same picture would be poorly recalled after being embedded in a list of 99 other pictures. Although the manipulation of distinctiveness occurs during the encoding stage of the memory experiment, the reason for its effectiveness probably depends critically on retrieval. The retrieval cue “picture in the list” identifies only one item in the list, helping to remind the person as to that one distinctive item, but the same cue is essentially useless when a huge number of pictures has been studied. The same argument can be made with the other encoding factors described in the earlier section; understanding how each affects retention would necessitate consideration of retrieval factors too.

As another illustration of the interaction between encoding and retrieval factors, consider the effects of drugs on memory. Most drugs that depress activity in the central nervous system harm memory. Drinking alcohol or inhaling marijuana, for example, create poor recall of events that occur while the person is under the influence of the drug. The traditional explanation has been that these drugs harm the brain’s ability to encode and store events, so retention is poor. Although this explanation in terms of encoding factors is probably partly correct, it is not the whole story, because retrieval factors (in interaction with encoding) come into play in an interesting way. This is observed in the phenomenon of state-dependent retrieval: how well an event is remembered depends on the person’s pharmacological state both during encoding and during retrieval. Matching states during both phases aids retention relative to mismatching states.

In the most common type of experiments on state-dependent retrieval, four groups of people are tested in various conditions, as in an experiment by Eich, Weingartner, Stillman, and Gillin (1975). Two groups studied words in a categorized list like the one described above under conditions when they were sober at study, whereas two other groups were given a drug prior to study. A day after studying the material, the people returned and were then tested either sober or intoxicated, with all four possible combinations of conditions between study and test being used (sober at study, sober at test, etc.). People were given a free recall test followed by a cued recall test. The conditions and results from the Eich et al. experiment are shown in table 17.2: because these researchers used categorized word lists, the retrieval cues were category names. First examine the free recall results. The first two rows show the standard effects of marijuana on memory: People who were intoxicated during encoding remembered less of the information when tested sober than did people who were sober on both occasions. The results in the third row show that intoxication during only the retrieval phase also hurts recall, although not as badly. The interesting case is the last row: People who were intoxicated during study actually recalled the information better if they were intoxicated again during the test! The advantage of the drug–drug condition (10.5 words recalled) relative to the drug–sober condition (6.7 words recalled) defines the phenomenon of state-dependent retrieval: Matching the pharmacological state during
Table 17.2 Results of the Eich et al. (1975) experiment on state-dependent retrieval. Subjects were given a drug (marijuana) or were sober at the time of learning and testing of materials under free recall and cued recall conditions.

<table>
<thead>
<tr>
<th>Study</th>
<th>Test</th>
<th>Free recall</th>
<th>Cued recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>sober</td>
<td>sober</td>
<td>11.5</td>
<td>24.0</td>
</tr>
<tr>
<td>drug</td>
<td>sober</td>
<td>6.7</td>
<td>22.6</td>
</tr>
<tr>
<td>sober</td>
<td>drug</td>
<td>9.9</td>
<td>23.7</td>
</tr>
<tr>
<td>drug</td>
<td>drug</td>
<td>10.5</td>
<td>22.3</td>
</tr>
</tbody>
</table>

study and test improves recall. (The same point can be made between the sober–sober condition and the sober–drug condition, but that outcome is not as surprising.) Of course, the findings in table 17.2, which have been replicated many times, do not argue that depressive drugs aid memory. The sober–sober condition always produces the best retention.

Another interesting point to emerge from table 17.2 is that the phenomenon of state-dependent retrieval occurs only under free recall conditions. With the powerful category name retrieval cues, recall improved in every condition relative to free recall, and the state-dependent retrieval effect vanished. The general pharmacological state of the person seems to serve as a weak retrieval cue. Under conditions of free recall, where there are no specific overt cues that come into play, state cues have an effect.

These same general principles also seem true of mood and memory research. People who learn information while depressed, for example, remember it better when they are depressed rather than happy (and conversely). Again this outcome occurs in free recall but not cued recall.

The phenomena just discussed show the powerful interaction of encoding and retrieval conditions: Proper understanding of all memory phenomena depends on considering encoding factors, retrieval factors, and their interaction. This is true even of mnemonic devices, discussed next.

**Mnemonics**

Mnemonic devices are memory-improvement techniques, which have been of great interest to scholars throughout recorded history. The most common techniques have been repeatedly discovered and employed. All mnemonic techniques employ the general principles described above: They supply strategies for both effective encoding and effective retrieval, as we illustrate here through two examples.

The simplest mnemonic is the link method. If you have several items you wish to remember (say, in a grocery list), each item is converted into an image, and then the images are linked one to another (milk splashing on bananas, bananas placed on a loaf of bread, etc.). To recall the items, the rememberer must retrieve the first item, which enables retrieval of the second through the interactive image, and so on. This chain of images aids recall of the series, but of course the chain is only as strong as its weakest
link. Forget one of the items, and it may be hard to break back into the chain. But the link method tries to provide both effective encoding (through images) and good retrieval cues (by linking the images). Still, the next method is more effective.

The method of loci is the oldest mnemonic, described clearly by the ancient Greeks and not really changed since then. A person establishes a path of landmarks which he or she knows well, such as a path leading from the front yard of one’s house through each room in the house. The number of salient places or locations (loci in Latin) can be as many as desired. These places serve as markers for encoding and (later) as retrieval cues. The set of items one needs to remember are then imaged and mentally placed at each location throughout the house and yard. For example, milk on the front sidewalk, bananas on the front porch, bread inside the front door, etc. When a person needs to retrieve the information, he or she mentally walks through the permanently memorized locations, which serve as retrieval cues, and looks up the item stored there. The use of interactive imagery again provides a good encoding strategy, and the locations serve as the effective retrieval cues.

There are many other mnemonic devices, but all are based on similar principles to those described above: They encourage effective encoding strategies and employ powerful retrieval cues that help recreate that original encoding.

Errors of memory

Our memories are remarkable for being as accurate as they are. People who are rendered amnesic as a result of brain damage must be institutionalized or receive complete care at home, because our ability to remember affects everything that we do and every aspect of our being. (Imagine not being able to remember names, faces, where you put things, who told you facts, and so on.) Yet, as good as our memories are under normal circumstances, we are acutely aware that they are not perfect. We forget where we parked our car, our friend’s telephone number, and important appointments. More surprisingly, we can systematically misremember events. That is, we do not forget that some event occurred, but we get the details, or even the gist of what happened, wrong. We consider these two issues – forgetting and false memories – in the next two sections.

Forgetting

The oldest problem in the psychology of memory is the nature of forgetting. Ebbinghaus (1885/1964) first described how information is lost over the course of time. He found a logarithmic relation, with greatest forgetting occurring soon after learning, with decreasing losses over time, shown in figure 17.2. Later research has confirmed this outcome. The key feature in standard research on forgetting is that different groups of people learn the same material and then are tested (using some standard test) at various times since original learning, and the forgetting curve is plotted from the various groups’ performance. So, forgetting here means loss of information over time. However, as we have already discussed, forgetting in this sense does not necessarily imply that the forgotten information has vanished from the brain; testing at any interval with more powerful retrieval cues would show recovery of the forgotten information. Nonetheless, it remains useful to speak of forgetting as loss of information over time when tested in a particular constant way.
The nature of the forgetting function is relatively clear, but the explanations for forgetting are more unsettled. The earliest idea was simply that memories decay over time. Just as muscles atrophy without use and become weaker, memory traces were thought to have a certain strength that decayed over time if they were not used. However, this notion has been discredited as a general explanation of forgetting (McGeoch, 1932). No mechanism is postulated; further, decay is occasioned by time, but time is not an explanatory construct. (Suppose a child asked why her bicycle rusted when left outside in the rain for a long time; telling her that time caused the rust would not do, whereas an explanation in terms of oxidation – the process operating over time – would be more accurate.) In addition, empirical evidence showed that forgetting could be greater or lesser over time depending on the intervening conditions. In particular, if the time between learning some event and being tested on it is filled with similar events, greater forgetting occurs. This fact turned psychologists away from decay as an explanation of forgetting and toward interference.

Interference is undeniably critical to forgetting, but there is still no complete explanation of interference effects. Two classes of interference exist: proactive and retroactive interference. Suppose you try to remember the exact spot where you parked your car when you arrived at work on Monday, two weeks ago. This represents a difficult task for most of us because of interference. We park our car in different locations every day. All the times you parked your car before the day in question produce proactive interference for the target memory; all the places you parked your car after the day in question exert retroactive interference. The names indicate that interference can either have effects on retention of events coming later, a proactive effect; or later events can interfere with earlier ones, a retroactive effect. These two classes of interference have

Figure 17.2 Ebbinghaus (1885/1964) examined the rate of forgetting by learning a list of nonsense syllables and measuring the savings in relearning the list after various periods of time.
been systematically examined for almost a hundred years, and both can be quite potent in causing forgetting under appropriate circumstances.

False memories

Forgetting usually refers to the omission of information: We try to remember something, and either nothing comes to mind, or what does come to mind can be rejected as the wrong information. The issue raised under the rubric of “false memories” is whether we can vividly remember an event and its surrounding details, but either the event never actually occurred, or it happened in a way very different from the way it is remembered. This issue of erroneous memories has been investigated, sporadically, since the turn of the century, and this research has occasionally played a large role in the wider world, such as in legal cases where the accuracy of eyewitnesses’ memories of crimes is at stake. Psychologists have now identified several factors that reliably lead to creation of false memories. We consider several here.

One of the most potent factors creating false memories is retroactive interference. We considered the role of interference in forgetting in the preceding section, but interference does not lead simply to omissions of memories, but also to false memories. People can become confused about the source of material and can incorporate information that they read or heard about after an event’s occurrence into their recollection of an event. E. F. Loftus (1991) has reported many experiments documenting this phenomenon. In the basic paradigm, people witness a simulated accident or crime (say, a robbery) presented on videotape or in a series of slides. At some later point, they read a passage or answer a series of questions. In an experimental condition, the passage or questions contain some erroneous information about the original scene, such as the statement that the robber had a mustache (when in fact he did not). Subjects in a control condition read the passage without the misleading information. Later, subjects in both conditions receive a recognition or recall test in which they are asked about the crime or accident. Interest centers on memory for the misleading information that was planted later. The outcome in dozens of experiments is that people will frequently remember the erroneous information as having actually happened in the original event, although the magnitude of the misinformation effect (as it is called) depends on many factors. The misleading information not only causes forgetting of what really happened, but seems to replace the correct information with erroneous information. One practical implication is that suggestive questioning of witnesses to a crime by police or lawyers can undermine the witnesses’ accurate retention of what really transpired.

A second method of creating false memories is through presentation of related information. If people read a list of related words, or hear a prose passage, they will often mistake another related word or sentence as actually having occurred when in fact it did not. In one straightforward paradigm for creating such a memory illusion, people hear lists of words that are all associatively related to a word that is not presented. For example, they hear “hill, valley, climb, summit, top, peak,...” all of which are associates of the nonpresented word mountain. Subjects frequently recall the word mountain as having occurred in the list and recognize it as often as they do words that actually were presented (Roediger and McDermott, 1995). These illusory memories may be due to failures of reality monitoring, as Johnson and Raye (1981) call them: Did I hear something? Or did I only imagine it?
As the previous question indicates, a third potent source of false memories is imagination. Just as imagery can boost retention of events that actually did occur, as described above, so can imagination create false memories. If people imagine events, they are more likely to think they really happened when they are tested later. In addition, imagining events can inflate one's estimate of the frequency that the events actually occurred.

The three factors listed here—interference, relatedness, and imagery—represent only some of the factors known to produce illusions of memory. The issue is a critical one to understanding memory and will be the focus of continued research in years to come.

Conclusion

The present essay has focused on the experimental study of memory: study which involves manipulation of the environment of the rememberer. Such study can be complemented by constructing computational and neurobiological models (see Article 41, NEUROBIOLOGICAL MODELING) of memory as well as by consideration of the role of an agent's personal context or situation in determining what and how well she remembers (see Article 39, EMBODIED, SITUATED, AND DISTRIBUTED COGNITION). One of the advantages of locating the study of memory within multidisciplinary cognitive science is that this encourages viewing a cognitive phenomenon like memory from a variety of different points of view.

References and recommended reading


