A Brief History of Memory Research

GORDON H. BOWER

Background: Associationism

Psychology as a discipline developed out of philosophical discussions regarding the nature of the mind and mental life. The study of memory and learning arose from philosophical questions regarding how people come to know things about their world. Learning is assuredly the primary way we acquire knowledge, and remembering is a primary means by which people support knowledge claims, as when a witness in court asserts "I remember seeing Jones with a revolver in his hand."

Philosophical speculations about learning were prominent among advocates of empiricism, which is the view that sensory experiences are the only ultimate source of knowledge and truths about the world (contra innate ideas or religious authorities). People's ideas about the world are alleged to derive from sense impressions either as simple copies or as combinations of simple ideas. Objects such as oranges, dogs, and houses are allegedly constellations of many sensory qualities (e.g., the color, shape, taste, and texture of an orange).

The empiricist program required some means for learning these constellations. Thus was introduced the fundamental theory of association by contiguity (Warren, 1921). Complex ideas are allegedly formed in the mind by connecting together in memory simple ideas based on sensations that are experienced contiguously in time and/or space. The memory that sensory quality or event A was experienced together with, or immediately preceding, sensory quality or event B is recorded in the memory bank as an association from idea a to idea b. Reviving these associative sequences from memory (when recurrence of event A makes us think of event B) is the presumed method by which people's past experiences cause their later thoughts to progress from one idea to the next. This basic notion can be elaborated to account for the way humans develop coordinated expectations about properties of objects, expectations about causal sequences of events, predictions about future events, explanations of how or why something came about, and plans of action designed to bring about particular outcomes. These are basic abilities of the mind.

Throughout the seventeenth to nineteenth centuries, empiricist philosophers such as John Locke, John Stuart Mill, and Thomas Brown speculated about various factors that might affect the degree or strength of particular associations (Warren, 1921). They recognized that associations would vary in their strength according to the vividness or distinctiveness of the original experience, its duration (study time), its frequency (repetitions),
and its interest for the observer. Revival of associations from memory was hypothesized to vary with the resemblance of the stimulating cue to the memory, the recency of the experience, the coexistence of fewer alternative associates to the cue (called "interference"), and "temporary diversities of state" (intoxication, delirium, depression). Such conjectures have generated much experimental research on learning and memory, and every learning theory deals with these factors in some way (Bower & Hilgard, 1981).

The scientific investigation of association formation began with the work of a German scientist, Hermann Ebbinghaus, whose pioneering research (with himself as sole subject) was published in his treatise On Memory in 1885. Discussion of his work will be postponed in order to examine briefly another major influence on studies of learning—namely, the doctrine of behaviorism, which became wedded for many years to the doctrine of associationism.

Behaviorism and S-R Psychology

The Behaviorist Philosophy

Behaviorism is a positivist philosophy which argues that all that observers can ever know about other persons or animals is provided by close observations of their overt actions or behaviors in specific situations (and human behavior includes speech). Behaviorism grew out of a desire for scientific objectivity in observations and for parsimony in explanations; it was especially critical of the undisciplined, introspective "mentalism" that at the turn of the century was being passed off as an explanation for behavior. On the behaviorist view, to predict someone’s behavior, all one needs is a catalog of specific facts and generalizations about his or her past responses to situations resembling the present one. These generalizations about a person’s past situation-to-action regularities are presumably carried in his or her nervous system as a set of stimulus-response (S-R) habits.

Antecedents of Behaviorism

While antecedents to behaviorism were many, an assured one was Charles Darwin’s theory of biological evolution, which suggested the continuity of all species, including Homo sapiens (Darwin, 1859). Human learning was seen as an adaptive mechanism that evolved over millions of years throughout the animal kingdom by small variations and minor accretions in the neural hardware that carries out the various learning tasks with which organisms are confronted. This “biological continuity” view justifies the many comparative studies by psychologists of behavioral adaptation and learning in lower animals. Since animals do not talk, those studies led in turn to a strong behaviorist orientation toward learning. Thus, learning came to be viewed as a change in an organism’s behavioral dispositions in particular situations (S-R habits) as a result of its experiences. It was recognized, of course, that the responses may be complex skills and the stimuli may be those stemming from a complex environment, including intricate and subtle social situations.

Behaviorist approaches to learning were greatly encouraged around the turn of the twentieth century by the pioneering studies of conditioned reflexes by the Russian physiologist Ivan Pavlov (1927) and by early studies of “trial-and-error” (instrumental) learning by Edward Thorndike (1898, 1903), an influential educational psychologist in America. This behaviorist orientation was promulgated by many influential psychologists throughout the first half of the twentieth century—from John Watson (1919, 1924), to Clark Hull (1943), to B. F. Skinner (1953, 1957). This orientation strongly affected the way in which human learning was studied and explained. That orientation began to fade with the coming of the “cognitive revolution” that began in the late 1950s and early 1960s. However, before discussing those events, we return to the earlier work of Hermann Ebbinghaus and the rote learning tradition that followed his pioneering studies. The rote learning tradition was characterized by a fusion of associationism and behaviorism.

Ebbinghaus and the Rote Learning Tradition

Ebbinghaus (1885) set out to investigate the formation of novel associations using controlled systematic experiments with careful measurements of his own learning. He introduced strict controls regarding the timing and number of study trials, recall time permitted, and retention interval (to study forgetting). He invented the notion of the nonsense syllable
(like DAX, QEH) to provide himself with learning materials of homogeneous difficulty, thus avoiding the variability of familiar words or prose. He taught himself by studying serial lists of 6 to 20 syllables, reading them aloud in sequence in pace with a metronome and then trying to recite the series from memory. The serial list was his analog of the associative chain of ideas about which philosophers had speculated.

Ebbinghaus introduced many important ideas and methods (see the Ebbinghaus symposium published in the Journal of Experimental Psychology: Learning, Memory, and Cognition). He measured the difficulty of learning a list by the number of study trials required for him to attain one errorless recitation of it. He noted how difficulty increased disproportionately with the length of the list being learned. He introduced the idea of measurable “degrees of learning” (or forgetting) by noting the savings in relearning a list he had learned earlier. The percent savings was the difference in trials for original learning (say, 9 trials) minus those needed for later relearning (say, 3) divided by the original learning trials (so, \(9 - 3)/9 = 67\%\). Using this measure, he was able to plot his famous forgetting curve relating percent savings to retention interval. This curve (figure 1.1) showed very rapid losses over the first few hours or days, with more gradual but steady decline over subsequent days, weeks, and months. Ebbinghaus also found that forgetting of a list decreased with multiple relearnings of it, that overlearning increased retention, and that widely distributed study trials (say, 1 per hour) were more effective than closely packed trials (say, 1 per minute) for long-term retention.

Ebbinghaus’s new paradigm (adults learning lists of nonsense materials) defined a task in which a multitude of variables can be defined and their influences on “relearning” behaviors observed. The phenomena that he discovered, his ideas, and his methods cast a long shadow throughout the twentieth century of research on human memory. Subsequent research has invented several other paradigms and teased out many variables that determine memory performance in these settings. The memories established can be tested by either recall, recognition, and reconstruction, or by a variety of indirect measures. The nature of the materials can be varied, as can their mode of presentation, strategies subjects use in studying them, expectations regarding the memory test, and relationships among several sets of materials being learned. As variables have been isolated and studied, a huge backlog of empirical information has accumulated about how humans learn in these situations. And many theoretical hypotheses have been proposed and tested to integrate and account for the evidence surrounding specific topics.

**Analysis of Laboratory Rote Learning Tasks**

The rote learning tradition was established around the intensive study of three different kinds of learning paradigms—serial learning, paired-associate learning, and perceptual-motor skill learning. We will briefly characterize each of these learning tasks and a few of their findings.

**Serial Learning**

The task Ebbinghaus used is called *serial learning*, an analog of learning the alphabet or learning to put letters in sequence to spell a word: the subject learns to output in a specified order a small set of temporally ordered, discrete items (letters, nonsense syllables, written or spoken words, pictured objects, sentences). Subjects are asked to remember both the items and their serial order. Retrieval may be tested by asking subjects either to reproduce (recall) all items in the order presented, or to recall what item followed a specific cued item, or to reconstruct the presented order when given the items (on flashcards) in scrambled order. In some experiments, a number of series are presented only once for recall (e.g., for measuring the immediate memory span). In other experiments, the same items may be presented many times in the same order for repeated study and test trials to examine accumulative learning.

Studies of serial learning have uncovered many facts. Increasing the study trials and time per item increases learning; increasing the time subjects are given to anticipate the next successor in the series improves their performance. While making the items very similar to one another (e.g., XON, NEH, XEH, NOH) improves their recallability, this similarity creates many confusion errors about their ordering. A robust finding is that items at the beginning and end of the list are easier to learn than items in the middle (see figure 1.2), a fact that has provoked many explanatory attempts (Johnson, 1991).
Figure 1.1 Ebbinghaus's forgetting curve. The savings percentages are plotted as a function of retention interval. After Ebbinghaus (1885).

Figure 1.2 Predicted and observed relative serial position error curves for 8-, 11-, and 14-item lists. Data from Hovland (1940). The fit to the data is provided by Johnson's theory of relative distinctiveness of different serial positions. (From figure 1 of "A distinctiveness model of serial learning" by G. J. Johnson (1991). Psychological Review, 98, pp. 204–217. Reprinted by permission.)
Conjectures regarding the effective stimulus for the next response in the series have also provoked much research. The natural hypothesis is that the series is learned by chaining together a set of pairwise associations, so that the series A-B-C-D is stored as the unordered pairs C-D, A-B, B-C. Thus, item C is both a response to its preceding cue, B, and in turn a cue for its successor, D. However, predictions from this pairwise chaining hypothesis frequently fail, suggesting that some more abstract “mental slots” for relative position (“first—A, second—B, … last—D”) may be the effective cues for the ordered associations.

**Paired-Associates Learning**

Soon after Ebbinghaus’s studies, an American investigator, Mary Calkins (1894), introduced the method of paired-associates learning. In this task, subjects study a set of pairs of discrete units (syllables, words, pictured objects) and are asked to learn to recall a specific member of a pair (the “response”) when tested by presenting the other member of the pair (the “stimulus”). The retrieval test might also request discrimination (“recognition”) of studied pairs compared to rearranged pairs. Examples of paired associates include learning French to English vocabulary with flashcards, names to faces, names of wife-husband pairs, countries with their major exports, and so on. In many respects, paired-associate learning closely mimics the S-R associationist analysis of all learning: for that reason it came to be favored for many rote learning studies.

Paired associate learning involves three distinct but overlapping phases: (1) learning the nominal response terms as integrated units (e.g., French words, nonsense syllables, etc.); (2) discriminating and reducing confusions among the stimulus terms of the many pairs being learned; and (3) associating the correct response term to its appropriate stimulus. Increasing the prior familiarity and meaningfulness of the response terms (e.g., English versus Turkish words) lowers the difficulty of the first phase. Increasing the similarity among the nominal stimuli in the list of pairs increases the difficulty of the second, discrimination phase; confusions between two similar stimuli persist until the subject selects a differentiating cue that distinguishes between them (e.g., noting that the stimuli QEH and IHQ differ in order). The difficulty of the third, associative phase is reduced by using words that are already weakly associated or ones for which subjects can easily discover meaningful relationships. This issue will be revisited later.

**Skills**

Many categories of human skills have been studied systematically since the turn of the century (for reviews, see Rosenbaum, 1991; Schmidt, 1986). They vary greatly and include (1) **perceptual motor skills** such as typing and telegraphy, athletic skills such as diving and shooting basketball, musical skills such as violin and piano playing, and laboratory tasks such as pursuit rotor tracking and reverse-mirror tracing; and (2) **cognitive skills** such as computer text editing, computer programming, chess playing, and geometry theorem proving (see Anderson, 1995). The skills differ in the degree to which they can be imparted by verbal instruction and by the learner imitating the performance of a coach or model. The development of skills in everyday life typically requires a huge amount of practice—hundreds and perhaps thousands of hours of patient, deliberate practice. Laboratory tasks are selected for study so that significant improvement can be tracked over a few minutes or hours of practice. Skills are almost always tested by subjects’ ability to perform (rather than verbally describe) the requisite activity at some level of competence.

An early hypothesis was that skills could be well represented in memory as a linear chain of associations in which proprioceptive (and external) feedback following a given response component provided the stimulus for the next response component in the chain. That hypothesis has been replaced, however, by more complex modern hypotheses involving hierarchical control of integrated motor programs (see Rosenbaum, 1991).

A major finding is that the curve plotting performance (e.g., time to do the task) against practice trials almost always approximates a power function of the form \( P = aN^b \), where \( P \) is performance, \( N \) is number of practice trials, and \( b \) (negative when \( P \) is time) determines the rate of improvement per practice trial. This function (called the “No pain, no gain” principle) says that performance speed improves rapidly at first, but then increasingly slowly as practice proceeds. But improvements can always be eked out by further practice—captured in the slogan “The difference between ordinary and extraordinary is that little bit extra.”
Second, as practice proceeds, the skill can be carried out with progressively less attention and cognitive effort (on "automatic pilot"), enabling the person to attend to other matters. This aspect of automatization is often conveyed in the slogan "When the going gets tough, the tough get going"—meaning that high-level performance can be maintained in the face of stress and distractions.

Third, the basis for most perceptual motor skills is largely nonconscious, not available to conscious introspection, beyond the skilled person’s ability to describe in useful detail how he or she does the skilled action. Highly skilled baseball hitters cannot adequately describe how they know where the pitched ball is going to be and how to adjust their swing to hit an inside versus outside pitch (the same inarticulateness characterizes golf putters or tennis pros hitting a graceful backhand). Despite this unverbalizable character of highly level skills, some of the very best, most effective instruction is conducted by athletic coaches and music instructors who provide daily demonstrations and subtle feedback to bring out the very best in their pupils. (Even tennis pros continue to have coaches.) Curiously, no such intense coaching occurs in academic subjects such as mathematics or psychology.

The Nature of S-R Theory for Rote Learning

The several tasks mentioned have been studied in many variations along with attendant theories of how humans master the tasks. For reviews, see McGeoch and Irion (1952), Hall (1971), Kaufer (1974), and later chapters in this handbook. An important development was that the investigation of human learning was expropriated in the 1930s and 1940s by strong proponents of S-R behaviorism—a marriage that was to lead to a stormy separation later during the “cognitive revolution.” To illustrate the nature of an S-R theory of human learning, its analysis of paired-associate learning in which subjects learn a collection of S-R pairs will be reviewed.

Considering each paired associate alone, the general idea is that reinforced repetitions of the pair gradually build up its associative strength (S-R habit) toward a maximum, as illustrated in figure 1.3. Associative strength of the pairing is presumed to be reflected in the probability and latency (retrieval time) for the correct response to the stimulus as well as its resistance to later forgetting. In figure 1.3, two different thresholds are postulated: the S-R strength must be above the lower, “recognition” threshold in order to support the sub-

![Graph](image)

Figure 1.3 Hypothetical curve of increase in associative strength of an S-R habit as it receives rewarded practice. A lower “recognition threshold” and higher “recall threshold” are indicated.
ject's accuracy on a pair recognition test; and the strength must be above the upper, "recall" threshold in order to support accurate response recall to the stimulus member of the pair. Strengths below these thresholds lead to errors or omissions. If the momentary strength fluctuates somewhat from trial to trial around the mean plotted in figure 1.3, then correct response proportions will gradually increase from zero to one rather than abruptly shifting from zero to one when the mean crosses the threshold.

These two thresholds reflect the general belief that recognition tests are easier than recall tests, and are more sensitive for detecting small differences among weak associations. Three implications follow: first, that any S-R pair that is recalled can also be recognized; second, that initial study trials can build up associative strength to the S-R connection in a "subthreshold" manner, even before these effects are revealed in accurate recognition or recall (this will also produce savings in relearning of "forgotten" pairs); and third, repetitions beyond the point of recall ("overlearning") continue to strengthen the habit, and this would be revealed in its retrieval speed and its resistance to later forgetting.

These remarks about single S-R connections need to be elaborated somewhat to deal with subjects' learning of a list of many pairs. First, suppose that subjects are learning a list of 12 pairs that include the pairs king–table, prince–throne, and dog–car. The associationist would first note that the stimulus words have preexisting associations from past learning, such as king having associates of queen, royalty, throne, Arthur, Henry, and so on. Thus, the new, to-be-learned association king–table must be strengthened sufficiently to overcome these preexisting ones.

Second, the theory imagines that each stimulus word will show initial generalization or confusions (based on the similarities of their appearance or meanings) to other stimuli in the list. These generalization tendencies are illustrated by dashed lines in figure 1.4. These generalization tendencies can produce errors by evoking the wrong response to a similar stimulus. However, the correct response to each stimulus will be rewarded each trial (by knowledge of results), and thus strengthened, whereas generalized responses (e.g., saying throne to king, or table to prince) will be non-reinforced (punished) and hence extinguished or inhibited. Thus, over repeated study trials, the correct association is expected to be strengthened sufficiently to win out in competition with both the preexisting and the generalized associates.

This generalization analysis explains the fact that pairs with similar stimuli and/or responses will lead to many confusion errors (e.g., saying throne to king more often than to car) and thus take longer to learn. The analysis also recognizes that preexisting associations that conflict with the correct response (such as king–throne) and that are strongly primed by other pairs in the list can create many errors of commision ("intrusions") before the correct, novel association wins out. (Obviously, if the preexisting associate were the correct one for this list, this would be a positive influence.)

Two other aspects of this analysis may be noted. First, subjects are often observed to learn such novel pairs (king–table) by finding and utilizing preexisting associations, such as king–(Arthur–roundtable)–table. These are called mediators and they chain together internal (covert) associates that successively cue one another and lead to the correct response. Note that these mediating associates are assumed to act like internal "responses" that provide stimulating aftereffects, so in some sense they preserve the stimulus-response character of the theory despite being (for the moment) unobservable. Moreover, an "editing monitor" needs to be postulated to enable the model (subject) to withhold the mediators (not to say Arthur to king) but to give overly only the correct response. It has often been noted

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**Figure 1.4** Hypothetical stimulus (left) to response (right) associations involved in learning three noun-noun pairs. The direct, correct associations (solid lines) must overcome competition from the generalized error associations (dashed lines) to produce correct recall. Adapted from Gibson (1940).

<table>
<thead>
<tr>
<th>STUDIES</th>
<th>RESPONSES</th>
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<tbody>
<tr>
<td>KING</td>
<td>TABLE</td>
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<tr>
<td>PRINCE</td>
<td>THRONE</td>
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<tr>
<td>DOG</td>
<td>CAR</td>
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that such mediators serve as only a temporary crutch during early learning; as practice proceeds and the direct king-table association is repeatedly reinforced, it is retrieved more quickly, thus short-circuiting (and beating out) the mediating associative chain that then drops away.

A second aspect of this generalization-discrimination analysis is that after learning—which, remember, occurred by inhibiting the preexisting and generalized responses—the passage of a retention interval allows the inhibition of errors to decay, thus leading to the partial recovery of errors over time. Therefore, although once inhibited, error responses such as throne-king may recover in strength over a delay interval, creating forgetting via errors of commission. While this hypothesis (due to Gibson, 1940) explains forgetting in terms of the familiar conditioning concept of spontaneous recovery, it must be admitted that it fares poorly against the evidence (see Underwood, 1961). For example, contrary to implication, once learned, high-similarity paired-associate lists are not forgotten at a higher rate than low-similarity lists.

Materials Variations

The foregoing illustrates that even in Ebbinghaus’s earliest experiments, it was clear that learning depended greatly on the nature of the materials—whether numbers, nonsense syllables, words, meaningful sentences, coherent prose, or poetry. These vary greatly in their familiarity and meaningfulness for subjects—for example, in how much prior experience subjects have had with such materials and how rich the network is of associations subjects have surrounding the units to be learned.

Researchers in the Ebbinghaus tradition soon noticed that even their favorite nonsense syllables differed greatly in how many words and other associations they evoked among learners, and that syllables evoking more associations were learned more easily. To deal with this variability, researchers tested many subjects to tabulate “association norms” or “meaningfulness norms” for collections of nonsense syllables (Glaze, 1928), other nonsense materials (consonant trigrams such as XMQ; Witmer, 1935), and words (Noble, 1952; Noble & Parker, 1969). These norms were used to compose lists of materials that were of specified associative difficulty.

Implicit in this emphasis on the association value of to-be-learned material was an important underlying idea—namely, that people learn most easily by relating the new material to things they already know. They look for the “mediators” mentioned previously. They try to transform (recode) the to-be-learned material into something familiar or close to something that is meaningful to them. Thus, the nonsense syllable MIK is recoded as “MIKE with the E missing” and QJA as “the initials of John Quincy Adams” (see Montague, 1972). Learners then remember their recoding, and convert it back into the to-be-remembered series when they are asked to recall.

This observation led different investigators in three different directions. One direction was to account for the kind of mediators subjects came up with; for example, Montague and Kies (1966) showed that learning of a paired associate was highly predictable from the ease with which adults came up with a mediator for it; and Prytulak (1971) predicted the memorability of different nonsense trigrams by how complicated were the “mental steps” subjects required to convert them into familiar words. A second and predominant direction for researchers was to abandon use of nonsense materials (as too variable) for studying elementary learning and move on to studies of learning of already meaningful materials such as words, sentences, texts, pictures of common objects, and video events; this predominant trend accounts for the fact that nonsense-syllable learning studies practically disappeared in the memory literature after the late 1960s. The third direction for researchers was to examine carefully how past learning was brought to bear upon a person’s current learning. These were called studies of “transfer” of past knowledge—a topic to be discussed briefly now.

Transfer of Knowledge

By assumption adult learners always come into a given learning situation with considerable knowledge, learning strategies, and specific associations that they use as best they can to optimize performance on the given task. These transfer effects include both general methods of attack for solving particular learning problems and more specific associations among units employed in the new task.
Nonspecific Transfer

General (nonspecific) transfer includes strategies for studying particular kinds of materials, selecting discriminating cues from the nominal stimuli, composing mediators for particular materials, optimizing use of immediate memory; and adjusting to the temporal pacing of the study and test trials in the laboratory task. An example of such general transfer effects is demonstrated in an experiment by Thune (1951). His college-student subjects learned three new unrelated lists of 10 paired adjectives on each of 5 successive days, each list practiced for 10 trials. The average correct responses over the first 5 trials on each list (in figure 1.5) reveals a swift rise in performance across the three new lists within each day (reflecting “warm up” adjustments) along with a slower improvement across days (reflecting “learning to learn” lists of this kind). Many studies of this general kind have examined the benefits of explicitly teaching subjects various mnemonic devices (Bower, 1970a), as well as useful techniques for learning educational materials (e.g., history or science textbooks), including how to analyze texts for important ideas and their relationships, memorize, organize one’s study time, and recite and review the material (see, e.g., Dansereau, 1978; Mayer, 1987; O’Neil, 1978).

Specific Transfer

The second class of transfer studies examine the influence of specific prior associations, and these are of two types. One type of study examines subjects’ preexisting associations learned over a lifetime, and investigators then notice how these operate in transfer to new learning situations—understanding, of course, that these past learnings may vary widely across subjects owing to their differing experiences. An example here is the use of familiar words rather than unfamiliar letter strings as learning materials. The perceptual system divides or segregates stimuli into discrete groups or “chunks,” and looks for a match in

![Figure 1.5 Trends in nonspecific transfer with practice. Three paired associate lists were learned for 10 trials on each of 5 days; average number of correct responses over first 5 trials on each list is plotted. Contrast the large gains within sessions with the smaller ones between sessions. (From L. E. Thune (1951), “Warm-up effect as a function of level of practice in verbal learning.” Journal of Experimental Psychology, 42, pp. 250–256. Reproduced by permission.)](image)
memory to these perceptual chunks. A chunk is defined as a familiar collection of more elementary units that have been interassociated and stored in memory repeatedly and that act as a coherent, integrated group when retrieved (Miller, 1956; Simon, 1974). The brain's mechanism for learning begins its operation (of association formation) by linking together elementary units into larger chunks. The difference can be seen in comparing, for example, letter strings such as IBF versus FIB versus FIB: the first is three chunks, the second a meaningful but unpronounceable chunk, and the third a pronounceable and meaningful word. A simple rule is that novel material will be remembered more easily if the chunks contained in it. This, of course, requires a suitably educated person who has the requisite familiarity with the verbal units.

Beyond examining these preexisting language chunks, however, investigators may aim to study the composition of transferable habits and their mode of operation by explicitly teaching subjects prior associations and then noticing how these affect later learning of related material. Different arrangements can produce either positive, negative, or zero transfer on a second learning task.

Classic cases of negative transfer arise when subjects must learn a new arbitrary response to an old stimulus. For example, having already learned who is married to whom (e.g., Bill–Sally and Dan–Ruth), subjects then learn new pairings as couples divorce and remarry, requiring new associations such as Bill–Jane and Dan–Sally. This situation produces large negative transfer relative to a control condition, because the prior specific associations compete with and interfere with the subject's quickly learning the new associations. The old associations keep coming to mind and blocking retrieval of the new associations. The effect here is similar to that in the earlier illustration of king–throne interfering with remembering king–table. The amount of negative transfer is greater the more the first-learned associations are aroused by the second stimuli. Thus, if the word-stimuli in list 2 were close in meaning to the stimuli in list 2, then the earlier associations will generalize to the second-list stimuli, creating more negative transfer the greater their similarity. In contrast, transfer is rather different when the relationship of the nominal response terms in the successive pairs is varied. When words are used as paired associates, positive transfer is observed when the successive responses to a stimulus are closely related in meaning. Having learned prince–throne, for example, subjects would be quick to learn prince–chair, presumably because the first associate is used as a mediator to aid learning of the second pair.

The topic of transfer is far richer and more complex than this brief discussion can indicate. For example, psychologists have examined the generally positive transfer that occurs when adults learn two computer programming languages or two computer text editors (see Siple & Anderson, 1989). In those situations positive transfer appears to arise owing to similar problem-solving steps that are utilized in the two domains, despite differences in details. For example, the general plan for how to “cut and paste” text must logically be nearly the same for every text editor (so that plan transfers), whereas the specific keystrokes required may differ somewhat in the two editors, causing minor negative transfer at that level.

Forgetting

The stimulus-response approach easily accommodates three basic reasons for forgetting associations after they have been learned. The first reason is simply autonomous decay in the strength of the S-R association due to physiological and metabolic processes that cause progressive erosion of the synaptic changes in the brain that had encoded the original association. The second reason for forgetting is performance loss due to a type of stimulus generalization: the training cue (or total stimulus complex) is allegedly progressively altered between training and testing owing to natural forces, so that the full stimulus complex is not reinstated at testing, resulting in progressively poorer retrieval of the original association. As a hypothetical example, suppose that the full training complex were composed of the simultaneous cues A, B, C, D, all associated with response R. If only cue A were present later (because B, C, D are altered, missing, or forgotten), then A is unlikely to retrieve the whole associative complex, so response R will not be recalled. The B, C, D cues in this example might refer to any of a diverse set of what are called “contextual stimuli”—internal postural, sensory stimuli plus emotional and associative responses of the subject, as well as environmental cues besides those experimenters explicitly recognize in their description of the stimulus situation.
A third reason in S-R theory for forgetting is that other associations learned before or after the target association in question may come over time to compete with, displace, or block out and interfere with retrieval of the target material. This happens, for example, when people have trouble remembering the name of a woman's second husband because her first husband's name is quite familiar and it keeps coming to mind and getting in the way. Another example is that people often misremember attributes of a person they met earlier by intruding those appropriate to the ethnic stereotype that they had assigned to that person.

The evidence for each of these three causes of forgetting is simply overwhelming. Throughout the history of research on forgetting, attempts have been made to eliminate theoretically one or another factor, or to explain one factor as really due to another (e.g., decay eliminated in favor of interference—see McGeoch & Atkinson, 1952; or decay eliminated in favor of progressive drift over time in the retrieval context—see Estes, 1955). Because all three factors are usually highly correlated, these attempts at colonization are typically insufficient, often requiring assumptions that are equivalent to the other factors to account for the full range of data.

The interference factor has been most often studied in the laboratory. In the paradigm most easily studied, subjects learn two or more lists of associations bearing particular relationships to one another. To illustrate with paired associates, let A-B denote a generic list of many pairs, where A and B denote the generic stimulus and response terms, respectively. In retroactive interference studies, recall of a first learned list of homogeneous A-B pairs is substantially impaired after subjects learn a second list with the same stimuli but different responses (denoted generically as A-C). The amount of retroactive interference is assessed by comparison to a control condition in which subjects learn the A-B list but then rest or engage in a distracting task for an equivalent time before receiving a recall test with their A-B list. This A-B, A-C arrangement is the same as that noted earlier that produces negative transfer in learning the second association. Indeed, across conditions, negative transfer in second-list learning correlates highly with the amount of later forgetting produced by interference. Proactive interference conditions are the converse, examining the decrement in second-list (A-C) recall caused by prior learning of a first list (A-B). The control subjects in this case learn only the A-C list.

Many facts are known about forgetting caused by such interference (see Postman, 1971). First, the stronger the training of the target response compared to the competing associates, the better it will withstand interference from other associates. Second, the stronger or more numerous the interfering associates (e.g., multiple lists such as A-C, A-D, A-E learned before or after the A-B target list), the greater the decrement in recall of the target associates. Examples of these relationships are shown in figure 1.6 (from Briggs, 1957): in this study, after 2, 5, 10, or 20 trials of second-list training, subjects were asked to give the first response that each “A” stimulus brought to mind. The panels of the figure show the data for subjects who received 2, 5, 10, or 20 trials of original learning (OL) in figure 1.6 on A-B. The more A-C trials that accumulated, the more A-C came to the fore; but the more original learning (A-B) trials, the longer A-B predominated before losing out.

Another fact about interference is that a longer interval or gap between learning of the two lists reduces the extent to which they interfere with one another. Furthermore, as the interval from the second-learned list to testing is lengthened, proactive interference increases whereas retroactive interference decreases. Such results are explicable by the ideas that all associative strengths decay, and that competing associates suppressed during learning recover somewhat as time passes and their suppression dissipates.

Interference effects are not solely a function of overt intrusion errors of the explicit competing responses. The subject may think of the competing response but recognize it as not the requested target-response, so withhold it (a process called “list discrimination”). On other occasions, interference arises as a total blocking or inability of the subject to think of any relevant response (an “omission” error). Thus, for example, if after learning two lists in an A-B, A-C relationship subjects are asked to recall both responses to the stimulus terms, they can recall both responses to some extent, but progressively more C's and fewer B's, the greater the amount of training they have just received on the second (A-C) list (Barnes & Underwood, 1959).

Although interference effects have been illustrated with paired-associate learning, the basic ideas apply to analyses of forgetting in
all learning situations such as serial learning, free recall, memorizing addition and multiplication tables, and remembering in which of multiple lists (or contexts) particular items occurred. It also applies to forgetting sentences, paragraphs, and stories when similar concepts are involved (see Anderson, 1995).

Cognitive Psychology

The Information Processing Perspective

While interest in cognitive (thought) processes had been a continuing minor sideline throughout the first half of the twentieth century, major momentum to cognitivism was imparted by developments in the 1950s and 1960s. One of the antecedents was information (communication) theory, with its concepts of encoding and decoding messages, and the concept of "limited capacity," which applied to any communication channel (for a review, see Garner, 1962). The metaphor was that the human perceptual system analyzed the stimulus array, extracted information from it in the form of neural codes (e.g., in visual or auditory modalities), and that these codes entered into mental programs designed either to store them in memory, or to reason, make decisions, and guide actions. Donald Broadbent (1958) adapted several ideas from this approach in his studies of selective attention, especially using the dichotic ("two ears") task in which adults with earphones immediately followed in mimicry ("shadowed") speech heard in one ear while trying to ignore a message piped into the other ear. Broadbent's studies led him to postulate selective sensory filters along with a
brief short-term memory that could hold unattended speech sounds for several seconds before attention could be switched over to deal with them.

Computer Models of Cognition

A second impetus to cognitive psychology was the work of Allen Newell and Herbert Simon (1961, 1972), who constructed computer programs designed to simulate details of the thought processes that people go through as they solve various kinds of problems (e.g., logic proofs, analogies, chess playing, intelligent search). Such simulation programs clearly had to have very large memories of structured knowledge about a given domain (such as rules and moves of chess), have a means for putting new information into the system (e.g., an opponent's chess moves), have a means for reasoning about the current situation by manipulating symbolic expressions in a central processor (or "short-term memory"), and have some means for reporting out the "actions" (moves) the program had decided to take. These activities are easily viewed as analogous to activities of the human mind. Simon and Newell noted that the stimulus-response analyses of problem solving were of no help whatsoever in deciding how to structure the knowledge base of the programs in order to carry out efficient retrieval, or how to reason effectively to achieve specific goals. Along with other researchers in artificial intelligence, they proceeded to create a number of computer programs that, by manipulating symbols, displayed an impressive amount of simulated "intelligent behavior" of a sort formerly carried out only by humans (see an early account by Feigenbaum & Feldman, 1963). This included not only reasoning programs but also learning programs (the EPAM program of Feigenbaum, 1959; Simon & Feigenbaum, 1964; Richmond & Simon, 1969) and many others. For reviews, see the handbooks by Barr and Feigenbaum (1981a, 1981b) and Cohen and Feigenbaum (1981).

Memory theorists were inspired by such developments to step outside the strictures of S-R theory and to begin to theorize about perceptual and attentional processes, as well as strategies and knowledge structures that were learned and used to acquire new knowledge. The "call to revolution" was urged in two important books: Plans and the Structure of Behavior by George Miller, Eugene Galanter, and Karl Pribram (1960), and Cognitive Psychology by Ulric Neisser (1967). These inspirational books provided arguments and exciting new agendas for an "information processing" view of humans. People were seen as taking information into a perceptual system, selectively attending to parts of it, encoding or transforming it for use by their cognitive abilities, storing it in memory, and later retrieving it from memory when an appropriate plan and retrieval cue were activated. The analysis of perception, attention, immediate sensory memories, short-term memory, and the structure of long-term memory became prominent topics. Since S-R theory had very little to contribute to these topics, the major developments in memory theory began breaking away from the S-R perspective.

Critiques of S-R Theory

Concurrent with these developments from communication engineering and artificial intelligence were a series of effective critiques of S-R theory as a means for dealing with complex varieties of human cognition. The critiques attacked the S-R accounts of motor skills (Lashley, 1951), thinking (Bruner, Goodnow, & Austin, 1956; Newell, Shaw, & Simon, 1958; Newell & Simon, 1961), pattern recognition (Neisser, 1967; Selfridge & Neisser, 1960), memory (Anderson & Bower, 1973; Asch, 1969; Bartlett, 1932; Bower, 1970c; Tulving & Madigan, 1970), and language (Fodor, Bever, & Garrett, 1974; Chomsky, 1959, 1972). Even in the traditional S-R domain of conditioning, new investigations of higher cognitive processes in nonhuman animals, especially higher primates and dolphins, were introducing major revisions in conceptualizations of cognitive processes (and learning) in lower organisms (e.g., Roitblat, Bever, & Terrace, 1984).

One of the most well-known critiques was that by the linguist Noam Chomsky (1959, 1972) in his review of B. F. Skinner's book Verbal Behavior (1957). In his book, Skinner, the radical arch-behaviorist, attempted an S-R account of language acquisition and use. Chomsky argued that Skinner's account (and by implication, all S-R accounts) was doomed to superficiality since it ignored the obvious cognitive processes that intervene between a situation and language utterances. He argued further that extrapolations of terms such as "stimulus," "response," "reinforcement," and "discrimination" from their animal-laboratory
setting (the “Skinner box”) to interpret language behavior were vague, metaphorical, and no better than common sense. Moreover, Chomsky argued strongly that the simple ideas of S-R associationism were inadequate in principle to account for the way children learn their language from experience. Children learn nonconscious linguistic rules that are far more abstract and complex than warranted by the language samples they hear, especially the realistic samples containing their many errors, back-ups, false starts, and ungrammatical utterances (see Chomsky, 1968, 1972). Chomsky similarly argued that S-R concepts were not rich enough to adequately explain the complexities of humans’ abilities to comprehend and generate sentences in context.

Chomsky’s critique and those of his associates established a new direction for the study of language; the new field of psycholinguistics drew its ideas and inspiration from new linguistic theories rather than S-R psychology (Fodor, Bever, & Garrett, 1974; Miller & McNeill, 1969). In turn, psycholinguistics had a very strong influence on ideas of memory researchers who recognized that some day they would have to understand in detail how and what people learn from language inputs—which, after all, is the medium through which most education proceeds.

Population of Different Memory Tasks

As noted, experiments within the S-R paradigm intensively investigated serial learning and paired-associate learning. With the advent of the cognitive approach to memory, somewhat different questions about memory were asked, leading to different memory paradigms that became popular because they provided a means for studying different kinds of memory processes. These experimental arrangements were free recall, context judgments about memorized events, and indirect memory tests, along with a renewed emphasis on short-term memory. We shall discuss these newly popular memory tasks.

Free Recall

In a free recall task, following presentation of a set of discrete experiences (words, pictures of common objects, actions), subjects are asked to recall them in any order that they choose for convenience. The set of items may be repeatedly presented, often in new scrambled orders, and repeatedly recalled. A frequent finding is that items presented at the beginning (“primacy”) and end (“recency”) of the list are typically recalled earlier and more often than items presented in the middle of the list (see figure 1.7). Longer lists and shorter study times per item cause poorer overall recall, except for the final (“recency”) items of the list. These effects are obvious in the recall curves of figure 1.7.

Free recall was difficult for S-R theories to explain, since no specific stimulus appeared to be involved and subjects were not obviously making overt responses as they were exposed to the study list. Moreover, subjects’ performance seemed to reveal a variety of “organizational processes” at work—a fact emphasized by Tulving (1968, 1962). For example, when multiple study and recall trials are given with the same list of supposedly unrelated words, subjects’ improving recall is usually accompanied by increasing stereotypy or consistency in what items they recall together as clusters (Tulving, 1962). The clusters are often idiosyncratic groups of 3 to 7 list words among which a subject finds some kind of meaningful relationship. With training, these subjective clusters grow longer (include more items) and become more stable. Recall can be substantially increased by using words in the list that have strong prior connections (e.g., instances of a taxonomic category), since subjects are likely to discover these inter-item relationships and use them for organizing their recall (see also Bower, 1970; Mandler, 1967). Such results suggest that learners are not the passive tabula rasa (blank slate) assumed in traditional associationism; rather, they are very active in using what they already know to search for meaningful relationships among the learning materials that they can utilize to ease their memorization task.

Another impressive fact about free recall is that subjects know far more of the list words than they are able to recall when given the general request to “recall the words of that list you studied.” When provided with more specific associative cues (e.g., a category name), subjects now recall many list items they formerly failed to retrieve (Tulving & Pearlstone, 1966; Tulving & Psotka, 1971). In an impressive tour de force regarding the power of retrieval cues, Mäntylä (1986) had subjects write 3 meaningful associates to each of 600 target words, with no instructions for remembering. Seven days later they received a recall test. When given none of their associates as cues,
they recalled only 6% of the target words; when given their 3 associates as cues, they recalled 65% of the 600 target words. Mäntylä and Nilsson (1988) produced even more dramatic recall (94% at 3 weeks), even without instructions for memorizing, by asking subjects to produce unique and/or distinctive associates during original exposure to the target words. The results illustrate the differing power of different retrieval cues (viz., one’s associates versus “the list studied”). It suggests that when a memory is claimed to have been forgotten, the claim should be limited to the particular kind of retrieval test that failed. If one retrieval cue fails, perhaps a more potent set of cues could be found that would revive the temporarily inaccessible memory.

Context Judgments from Memory

In this paradigm, having been presented with one or more sets of discrete items, subjects are presented with a copy of the old items (and perhaps similar new ones) and asked to retrieve and judge something about that item’s context of earlier presentation. The judgment may be whether or not the item was presented in the earlier, specified list (called a “recognition memory” test). If items were presented in several different lists, subjects may be asked to indicate in which list, if any, the test item was presented. Items may be presented several times in each of two or more distinguishable lists, and subjects later may be asked to indicate how often a test item was presented in each list. Subjects may also be asked to recall aspects of the “source”—who said the word, where or when it was presented, in what manner of voice (male or female speaker), or characteristics of its visual presentation (type font of word, size, colored vs. black-and-white slides). Some experimenters refer to all these judgments as “source memory,” whereas others distinguish “recognition memory” judgments (which could be based on an undifferentiated feeling of recent familiarity of an item) from the other explicit source judgments.

Source Memory. Source memories are laboratory analogs of people remembering where and from whom they learned certain information. The difficulty these performances raise for an S-R theory is that in no case are subjects overtly responding to these aspects of the ex-
perience as they are studying the items. Rather, it seems that the perceptual system is almost automatically recording something like sensory images that are retrieved later to support such judgments.

A basic finding of source memory is that remembering which source provided particular information grows worse the more similar are the salient properties of the several sources. For example, people are more likely to confuse in memory which of two unfamiliar speakers said a particular message if the speakers look and sound alike. Source confusions also increase the less associated are the contents of the messages with their respective sources. For example, readers are more likely to ascribe their memory of an alien abduction story to having read it in the *National Enquirer* than in the more credible *New York Times*.

A second fact is that material people imagine or produce themselves (e.g., as associates to something they saw) can be confused later in memory with something they actually saw or heard. This discrimination of "my internal vs. his external" event improves the more thinking or cognitive effort subjects engage in while generating the imagined scene originally. This is likely due to the fact that the imagined scene was stored along with a record of the cognitive operations needed to create the scene. Later retrieval of these traces helps people judge the memory as an imagined one (see Johnson & Raye, 1981; Johnson, Hashtroudi & Lindsay, 1993).

**Frequency Judgments.** Frequency judgments ask subjects how often a given word or picture was presented in a list. Hintzman (1976; Hintzman & Block, 1971) has brought those frequency-in-context judgments to bear upon a fundamental issue in memory theory—namely, how multiple repetitions of the nominally same item are treated by the memory system. The traditional theory is that different presentations of, say, the word *table* simply strengthen the one association of that memory unit to the list context, and that later judgments of its presentation frequency could be derived from the strength of this one association.

The alternative view favored by Hintzman is that each presentation of the same nominal stimulus establishes a new memory trace, each associated with its accompanying specific time, place, and mode of presentation (its "context," as he says). As evidence, Hintzman found that subjects were often able to retrieve some contextual details about each presentation of an item, almost in the manner of a videotape recording. For example, subjects might experience presentation of a long list in which 30 unrelated words are presented once mixed in among 15 presented twice and 10 presented four times, all scattered randomly throughout a 100-presentation list. Upon later testing with the test word *table*, a hypothetical subject might be able to report correctly that "the word *table* was presented twice: its first presentation was in the first quarter of the list and was spoken in a male voice; its second presentation was in the third quarter of the list and it was presented visually in red Gothic letters." While such contextual details are generally poorly recalled (as would be expected by the similarity-based interference they suffer), their moderate accuracy indicates that subjects are often successfully storing detailed records of several different experienced presentations of the same word. This in turn supports the multiple-trace over the strengthened single-trace account of how repetition works in memory. With higher frequencies (10 or more), individual memories of a given item's presentations greatly interfere with one another, and subjects appear to shift to a "frequency estimation" rather than "memory counting" strategy for making judgments of these higher frequencies.

Another interesting type of contextual judgment is the relative recency of an event. For example, the subject might be asked to estimate how many items back in a series (or how long ago) the word *table* (vs. *prince*) had been presented. In general, accuracy of judgments declines as a power function of intervening items or time elapsed; and discrimination of which of two items was more recent follows a logarithmic function—that is, discrimination varies with the ratio of their recency difference divided by the recency of the more recent one (Yntema & Trask, 1963). A multiple-trace theory also provides a better account of how repetitions of an item affects its apparent recency judgment (Flexser & Bower, 1974).

**Recognition Memory.** In recognition memory experiments, subjects judge whether or not a test item was explicitly presented on a list studied earlier. A basic fact is that access to an
item’s memory requires that subjects interpret (or “encode”) the item at test in roughly the same manner as they did when it was originally studied. This basic fact has been demonstrated for a variety of stimuli that have ambiguous (multiple) interpretations, including simple drawings (the duck–rabbit picture; the young wife–old crone picture), naturalistic sounds (trotting horses vs. tap dancers), and polysemous words (kitchen TABLE vs. math TABLE). The point is that the nominal stimulus during the test must arouse the same percept or meaningful interpretation it did during study in order for it to make contact with the memory trace of the original event. This is the sense of the “encoding specificity principle” proposed by Tulving (1983; Tulving & Thompson, 1973).

Tulving believes the principle applies far more widely than with just ambiguous words or pictures, since the context of presentation can activate somewhat different properties and associations to thousands of words or pictures that are otherwise unambiguous. For example, people think of different aspects of a piano if they speak about tuning it versus lifting it. The aspect aroused by the word during its original context of presentation can then serve later as the more potent retrieval cue for re-arousing that memory.

Indirect Memory Tests

The tasks above are called “direct” tests since subjects are asked explicitly to try to remember an earlier episode, perhaps to recall several features of the context surrounding the presented event. These tests may be contrasted with indirect tests of memory in which subjects answer general knowledge questions that presumably do not refer to recent, specific experiences (Richardson-Klavehn & Bjork, 1988; Schacter, 1987). Yet it can be shown that recent experiences affect the speed and content of what is retrieved from one’s general knowledge.

The prototypic example is repetition priming wherein a word (or picture of a common object) is accessed more readily if it is a repetition of one recently presented. Such priming (say, of robin) shows up in facilitated perceptual identification (seeing it more accurately in a degraded or quick flash), in lexical decisions (that robin is a word, but ribon is not), and in fragment completion (“Give the first word you can think of to complete r__bi___.”) The primed word is also more likely to be generated as a member of a category (list some birds) or as an associate to a related cue (“Perched in a tree is a red-breasted ___ ___ ___.”). In such indirect tests, the subject may produce the primed item with a frequency far above an unprimed baseline, and yet have no subjective awareness of remembering any specific episode from his or her past. The nature of indirect memory tests and their relation to direct tests are topics of great interest in current research (see, e.g., Bower, 1996; Tulving & Schacter, 1980), and several chapters of this handbook will touch on these issues.

Short-Term Memory Models

In the early 1960s, considerable interest arose in the study of immediate (or “short-term”) memory. While the limits of immediate memory and the “memory span” had been known since Ebbinghaus (and described by William James, 1890), the novel, startling fact observed by Lloyd and Margaret Peterson (1959) was that people very rapidly forget a few unrelated letters or words (such as T G K or glass, pen, wood) that they have just read if they are distracted and occupied with another task for just a few seconds. Figure 1.8 illustrates this rapid loss as subjects were engaged for 1 to 18 seconds in a simple subtraction task (subtracting successive 3’s from a starting number) before being asked to recall the three items they had just read. Early investigators had apparently overlooked this rapid fall-off in memory for trivially small amounts of material because they typically had used serial lists well beyond subjects’ capability for perfect immediate recall. Such results suggest a short-term memory of extreme fragility, lasting only a few seconds after the subject’s attention is drawn elsewhere. This rapid loss may be contrasted to the long-term memories for information people have stored in their knowledge base.

The next decade in memory research was filled with many studies of such short-term memories: many different paradigms were investigated, and many variables that controlled short-term retention were investigated. As evidence accumulated, several formal theories were proposed to explain the interaction between short-term and long-term memory. These built on the earlier proposals of Broadbent (1958), Bower (1964), and Waugh and Norman (1965) (reviewed in Murdock, 1974).
The most popular model of this period was that proposed by Atkinson and Shiffrin (1968, 1971) because it was the most explicit and was applied to the widest range of results.

A Popular Model of Short-Term Memory

Figure 1.9 shows the general structure of the three memory stores postulated: a sensory store that held briefly glimpsed (or heard) messages for a couple of seconds before their traces decayed. Stimulus traces in the sensory store that are attended to, identified, and recoded are thereby entered into a short-term memory (STM). The STM is of limited capacity, holding at most only a few items (e.g., 4 words or 2 paired associates). If the items are to be learned, the central-control processes initiate a plan for memorizing, such as covert rehearsal (silently going over the words). The model assumes that each rehearsal cycle also transfers into the more durable long-term memory information about the associations being studied. Information transferred to long-term memory can also be forgotten, but at a much slower rate than the information in STM. A to-be-remembered item will be eventually displaced or lost from STM since newly arriving information enters STM and bumps out the earlier items. The greater the demands or difficulty of the interpolated task, the more rehearsal suffers and so the poorer the retention of the target items.

Benefits of the Short-Term Memory Model

Several features of such models should be emphasized. First, they permit flexibility in the initial encoding of the input coding. For normal speakers, many to-be-remembered stimuli will be encoded by their names or descriptors. Thus, later confusions in recall of letter or
word strings will often be greater for items with similar pronunciations (e.g., recalling the similar letters B, T, V, C versus the dissimilar B, X, W, Q—see Conrad, 1962, 1964). Second, multiple study trials aid later recall by accumulating strength of the association recorded in LTM. Third, the model distinguishes memory structures from the momentary plans (“control structures”) that utilize these mental structures to help memorization or recall. One such memorizing plan is verbal rehearsal and Atkinson and Shiffrin developed their model’s main predictions by assuming that motivated subjects in a learning situation engage in steady verbal rehearsal when they have the opportunity. One implication of the verbal rehearsal strategy is that the number of items that can be held in the rehearsal STM increases with their covert speech rate. Thus, immediate memory span would be lower for longer words, for people who speak slowly (e.g., younger children), and for languages whose digit names take longer to pronounce (see Baddeley, 1986, 1990).

The model’s distinction between memory structures and control processes (strategies) permits an understanding of the differing results that arise if subjects use other learning strategies—such as concentrating rehearsal on some high-valued (or surprising) items at the expense of low-valued items, or searching in LTM for mediators (of the type mentioned earlier) as a way to aid association learning. This approach allows a role for motivational and individual-ability differences in partly determining memory.

The STM models were partly inspired by neurological patients (the famous H.M.) with organic amnesia caused by bilateral damage to the medial temporal lobe and hippocampus. Such patients have an intact short-term memory and long-term memory, but are greatly impaired in transferring new verbal information to long-term memory. This is exactly the pattern to be expected if the STM-LTM transfer process were impaired.

Such STM-LTM models had a ready explanation for the serial position curves seen in free recall (see the earlier figure 1.7). The better recall of the beginning words (“primacy” effect) was due to their entering an empty STM and thus receiving greater amounts of rehearsal compared to later words before being displaced; the better recall of the end-final items (“recency”) was due supposedly to subjects reading them out of STM at list’s ending.
before they return to LTM to retrieve earlier list items (see the curves in figure 1.7). Items presented for more study (2 vs. 1 sec in figure 1.7) transfer more information into LTM, thus raising recall levels of early and middle items.

Shortcomings of the
Short-Term Memory Models

Although STM models explained many facts, they suffered from several shortcomings that caused the basic ideas to be altered and elaborated. Included among these shortcomings are the following:

1. In order for a familiar word or chunk to be identified, the stimulus must first access its matching code in LTM. Thus, it seems as though the diagram in figure 1.8 should have LTM accessed by the stimulus before its code is entered into STM. Alternatively, it may be more logical to consider STM as only an activated portion of LTM (see, e.g., Anderson, 1985).

2. Several secondary tasks (e.g., repeating 4 digits) were found to have little or no effect on free recall memory for visually presented word lists. This suggested to Baddeley and Hitch (1974) that adults could place small amounts of irrelevant verbal material (the digits) into a repetitive artificatory loop whose operation did not interfere with subjects encoding and learning the visual words. The implication is that adults have multiple regions for short-term storage of stimuli received from different sensory modalities (see Baddeley, 1990).

3. Fast, repetitive, going over of verbal items results in very little memory later—that is, “mindless” rehearsal per se is not sufficient to create durable memories. Rather, some kind of meaningful associations and elaborations (some “deeper processing” to use the term of Craik & Lockhart, 1972; Craik & Tulving, 1975), connecting the new material with old chunks of knowledge already in memory, are needed to create more durable memories.

4. The model assumes that STM is the “entrance” to transferring materials into LTM; but several neurological patients were soon reported (Shallice & Warrington, 1970, 1974) who could learn visual paired associates quite normally despite having severely impaired auditory immediate memory. Such patients suggest that structures that produce durable long-term traces may be somewhat independent from those responsible for short-term maintenance of information.

In reaction to such criticisms, more recent theorists have revised and recast important aspects of the Atkinson-Shiffrin model. Baddeley (1986, 1990) has hypothesized several modality-specific short-term stores that he calls working memories—a phonological store for speech-based material, a visuo-spatial store for visual images, and an “executive controller” that holds plans that program and coordinate the activities of the separate short-term stores. Anderson (1983, 1995) has argued that rather than a separate “storage place,” short-term memory should be conceived as the temporary activation of information chunks in a single memory. According to this view, items can be in various states of momentary activation. Items that are highly activated are readily available for recall or for entering into other cognitive activities. To deal with long-term recall, Anderson supposes that different memory traces also differ in their strength or ability to be reactivated later by relevant cues. We will return later to discuss the representation of memories in the long-term store.

The Episodic/Semantic Memory Distinction

Following observations by philosophers writing about memory (e.g., Bergson, 1911; Russell, 1921), Endel Tulving (1972) introduced to psychologists the distinction between episodic memory and semantic memory. An episodic memory is about a specific event that occurred at a particular time and place, such as your memory of getting a traffic ticket or observing a car accident. In contrast, semantic memory is the “mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, and about rules, formulas, and algorithms” for manipulating them (Tulving, 1972, p. 386). In these terms, the memories typically being acquired and tested in verbal learning experiments are episodic (e.g., “I just studied the pair king–table”). Semantic memories are the abstracted words, concepts, and rules stored in our long-term memory whose context of acquisition was long ago forgotten (e.g., most people cannot say when they first learned the meaning of the word king).
Tulving noted several properties of these two classes of memories. First, episodic memories are more susceptible to forgetting. Second, retrieval of an episodic memory is usually accompanied by an explicit or implicit reference to, and image of, the time and/or place of the episode (e.g., “In the list you just learned, what was king paired with?”). Third, retrieval of any information is itself another episode that creates its own episodic memory (e.g., people can remember a test trial and how they performed). Fourth, autobiographic memories are typically dated episodic memories, although people also have many abstract generalizations about long stretches of their life that are not themselves distinct episodes (e.g., people can recall that they went to college for four years, although they may not now be recalling any specific incident).

Tulving (1983) believed the differences between episodic and semantic memories were sufficiently striking and hard-wired that he hypothesized the existence of two different memory systems—episodic and semantic. (Later he added a procedural memory system in recognition of perceptual motor skills.) These memory systems were contrasted in terms of their conditions and consequences of retrieval, nature of the stored information, vulnerability to interference, and interdependence. This hypothesis has led to much discussion in the literature (see, e.g., the discussion around the article by Tulving, 1986, in Brain and Behavioral Sciences). Critics contend that semantic knowledge consists of abstractions in LTM derived from many episodic memories (e.g., occasions when a word was used or spelled correctly for the person); they argue that although the two classes of memories clearly differ in their contents, strengths, and specific time-place contextual references, the two classes are otherwise similar in their properties. This productive discussion has continued over the years; a recent development has proposed use of brain neuroimaging data gathered during episodic versus semantic retrieval tasks in hopes of obtaining discriminating evidence for the brain-basis for the distinction (see Buckner, 1996).

*Knowledge Structures in Long-Term Memory*

**Propositions**

We noted above the development of computer models to simulate reasoning, problem solving, and learning. Approachable developments also arose in computer models for natural language understanding and learning from language input. A computer model that attempts to understand language (typed into it) obviously needs several components: a word lexicon that call up a network of interrelated concepts in long-term memory; a syntactic component that will take in a sentence, parse it, and assign a grammatical structure to its constituents (e.g., word classes, noun phrase, verb phrase, logical roles of agent, action, object), and an interpreter that splices together the grammatical structure with the indicated concepts to compose a full interpretation of the sentence in the context (see Harris, 1985; Schank & Riesbeck, 1981; Winograd, 1972, 1983). A final necessity is a sentence-creation module that is called upon to paraphrase what it has been told, draw inferences, and answer questions based on what it has been told or can retrieve from memory (see references cited).

In such systems a primary concern is in how knowledge units are to be represented in the memory of the model. Many proposals have been advanced on this topic. An early proposal is that the unit of knowledge should be elementary propositions such as subject-predicate structures (e.g., Anderson & Bower, 1973; Kintsch, 1974). Propositional structures may be either one-place predicates (“Roses are red” rendered as Red(roses)); two-place predicates (Mother-of (Mary, Jesus)); or three-place predicates (loaned (library, book, John)). The “arguments” in such propositions are concepts that exist in long-term memory; the proposition asserts (and records) a new kind of property or relation among the concepts. When someone comprehends a proposition, the theories conceive of that act as establishing in his or her memory new associations corresponding to the asserted relationships among the concepts. Thus, in comprehending “A man gave a book to a woman,” people are setting up in memory a giving predicate that interrelates instances of their preexisting concepts of man as the donor, woman as the recipient, and a new instance of a book as the object transferred. Note that in such cases the verb (give) comes with a collection of expected roles—donor, recipient, object, implicitly a time and place of the event, and a set of inferences (e.g., the woman now has the book). These roles act like empty slots to be filled by the other concepts (arguments) in the proposition. This is an elementary example of a “schema,” a notion elaborated below.
Concepts and Schemas

As noted, language understanders require a huge network of concepts and their interactions. Psychologists have speculated extensively about the nature of concepts and how they might be structured in human memory. Concepts are obviously represented in terms of their associated properties, perceptual features, intended uses or functions, and their relations to other concepts. While an early view was that concepts should be represented in memory as a set of defining features that are all necessary and jointly sufficient to recognize instances (e.g., the concept of a triangle), the more comprehensive view that has emerged proposes that naturalistic concepts are better represented in memory as probabilistic prototypes (like a summary). Different features of the prototype are more or less diagnostic, and features that are not at all diagnostic may nonetheless be so characteristic of the class that they are used for rapid identification of instances (see Smith & Medin, 1981; Rosch & Mervis, 1975). If concepts are probabilistic prototypes, different examples will vary in how closely they match the prototype, and hence vary in how “good” (or typical) an example they are of the concept. For example, a robin is a very typical bird, a stork somewhat less, and an ostrich or chicken a very poor example of a bird.

In addition to such object concepts, semantic memory includes many concepts about relations such as spatial prepositions (on, in, around, left of) and actions. Actions are typically represented as verbs in English, and have associated frames or schemas that stipulate roles for participants in the action scenario. Verbs like buy, rent, or steal denote schemas that put together concepts in a certain scenario. So, “John bought Bill’s car” means that Bill transferred ownership of a car to John, and John transferred ownership of something valuable (probably money) to Bill in exchange for his car.

Schemas (or frames) are good candidates for how long-term memory might be structured (Rumelhart & Ortony, 1977). Schemas capture clusters of organized expectations and represent abstract knowledge about some domain. Schemas can be of any “size” or “grain,” and some schemas (e.g., eyes and mouth) can be embedded within other schemas (human face). Common examples of schemas come from common objects (e.g., birds, horses, cars, faces, rooms), ethnic and personality stereo-

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to "List some parts of canaries." So, in more recent models of memory, the associations are assumed to be recorded into memory along with an attached relational label specifying its type (see, e.g., Anderson & Bower, 1973; Norman & Rumelhart, 1975).

Visual Imagery

Before the 1960s, most memory research examined verbal memory for language units, and the verbal associations to these language units were emphasized. Starting in the 1960s and thereafter, a contingent of memory researchers began investigations of visual imagery and its properties, including image associations and memories for words. This movement was led by Allan Paivio (1966, 1971) with support by Roger Shepard (1978; Shepard & Metzler, 1971). Stephen Kosslyn (1975, 1981), Lee Brooks (1968), and others (Bower, 1970a, 1970b, 1972; Finke, 1984). Paivio conceived of nonverbal imagery as a form of coding and symbolic representation of information that was alternative to the verbal coding system. He brought forth a number of compelling facts in support of his emphasis on the role of mental imagery in learning. Let us consider a few of these.

First, words differ greatly in the extent to which they evoke imagery. While this is usually correlated with whether they refer to concrete objects (apple) or abstract ideas (fidelity), many nonconcrete but image-arousing words exist (e.g., unicorn, ghost, angel). Paivio found that the imagery-arousing value of a word was the most potent determinant of its rate of learning—whether in paired associates or free recall. Second, subjects learning paired associates with high-imagery words were more likely to report spontaneous imagery mediators ("mental pictures") to learn the associations; and pairs for which imagery mediators were reported were learned more rapidly. Third, subjects instructed to use visual imagery to relate word pairs together learned far more rapidly than uninstructed subjects or other subjects instructed to use verbal repetition (Bower, 1970a, 1972). Fourth, Paivio found that pictures of common concrete objects (or presentation of the objects themselves) were even more effective items for learning than were their names.

From such facts Paivio (1971) argued that verbal and nonverbal codes provide the inputs to two separate memory stores. Imagery provides a coding system; items coded in this manner are stored in an "imagery" memory store that is more durable than the verbal memory store. Although the two coding systems are closely interconnected (so people can translate between them), memory traces established in the two systems are functionally independent. A picture of a common object is remembered better than its name because pictures typically have more distinctive codes that suffer less interference. A word that evokes a corresponding image (either spontaneous or by instruction) will be better remembered because its presentation lays down two redundant memory traces at least one of which is more likely to survive over a retention interval.

While Paivio emphasized the role of imagery in verbal learning, Kosslyn (1981), Shepard (1978) and Finke (1984) concentrated on how memory images could be manipulated in reasoning and used to extract information. The image manipulations studied included scanning across or around a two-dimensional image, enlarging or shrinking it, rotating it in either the picture plane or in depth, and so on. Measurements taken as subjects perform such tasks suggest that operations on the mental image are closely isomorphic to their corresponding perceptual operations. Moreover, evidence was obtained for modality-specific interference (Brooks, 1968; Farah, 1985; Segal & Fusella, 1970); that is, requiring people to process external sounds or spatial arrays caused selective degradation in auditory or visuo-spatial images, respectively.

While acknowledging these strong effects of imagery on memory, the critics of the imagery approach have raised questions regarding the interpreted categorical, and "proposition-like," features of many images (Anderson, 1978; Fylyshyn, 1973). Anderson has suggested that most imagery effects can be modeled with an associative network using propositions referring to points in space connected with spatial predicates, and that computational processes can be provided that will operate over these networks to simulate manipulations of images (e.g., magnifying, rotating them). Clearly, this is what is being done in the visual graphic design and graphic display programs (such as Adobe Photoshop) for modern computers.

Multiple Memory Systems

With the proliferation of theories about different kinds of memories—short-term/long-term,
visual/auditory sensory stores, precategorical/postcategorical stores, episodic/semantic, verbal/imagery, cognitive/motor—it was perhaps inevitable that attempts would be made to coordinate these different types of memories to different parts of the mammalian brain. This research has proceeded on several fronts—examining behavioral effects of specified brain lesions created in animals and of brain damage that humans accidentally suffer due to head injuries, strokes, tumors, and cerebral disorders. Additionally, the activity of the human brain may be recorded indirectly (via blood-flow patterns) using functional magnetic resonance imaging as people work on a variety of cognitive or memory tasks.

These researchers have found that parts of the medial temporal and hippocampus region seem to be needed for humans to store new episodic memories, but not for learning procedural or motor skills or for showing repetition priming (Squire, 1987). Parts of the posterior parietal cortex are strongly implicated in mental imagery and visual memory. The left temporal and right parietal cerebral cortices are especially implicated in verbal and visual memory, respectively (Kolb & Whishaw, 1991; Kosslyn, 1991). The amygdala and limbic systems of the brain seem closely related to storage of highly emotional memories. The cerebellum, motor, premotor cortex and basal ganglia are closely linked to learning and performance of motor skills. The primary sensory cortices (striate and occipital for vision, temporal for audition, somatosensory for touch) are intimately involved in the modality-specific memories displayed in repetition priming. The frontal and prefrontal cortex appear to serve working (short-term) memory, with different parts specialized for briefly maintaining either verbal, object pattern, or spatial location information. The prefrontal cortex also is strongly implicated in strategic aspects of performance and memory; it supports people’s ability to follow lengthy recall plans, keep things in order, search for obscure memories, and update working memory in rapidly changing scenarios (e.g., air traffic controllers keeping track of many airplanes entering and leaving their airspace).

One of the fascinating mysteries is to relate the person’s sense of conscious recollection to selective activation of different parts of the brain. It is clear that many indirect tests that utilize primed semantic knowledge are performed without people being aware that their facilitated performance stems from an earlier experience. On the other hand, requests to retrieve specific episodic memories typically bring forth the subject’s feeling of being in mental contact and conscious of a specific moment experienced in the past. Tulving, Kapur, Craik, Moscovitch, & Houle (1994; also Nyberg, Cabeza, & Tulving, 1996) conjectured that retrieval of these two types of memories—the conscious, explicit episodic ones versus the primed semantic ones—utilizes two different parts of the frontal cortex. This speculation has already generated considerable research that has led to advances in the understanding of the brain basis of memory. The successes of the past decade in relating cognitive and memory functions to different parts of the brain have been quite remarkable and may be expected to accelerate into the future.

The Everyday Memory Theme

The research reviewed above has all been based on laboratory work, either that of normal subjects learning tasks involving artificial materials or brain-injured patients being tested in the neurological clinic. In reaction to this dominant laboratory tradition, a group of researchers have argued that attention should be turned to the ways in which people use memory in their everyday tasks (Neisser, 1978, 1982). This movement toward “ecological validity” stemmed from concerns that the principles learned from laboratory studies of memory may not help elucidate many everyday memory phenomena and may not aid in such practical tasks as rehabilitation of stroke or Alzheimer’s patients who suffer from particular disorders.

As a consequence, a plethora of research has been published on the extent and frequencies of common types of memory errors and mental slips in everyday life, on how people commonly remember appointments, medicine-taking schedules, names, faces, dogs, cars, license plates, shopping lists, errands, parts of machinery, and so on. (An infinity of domains could be studied.) Detailed studies have also been made of memory experts, how they perform their feats, and what memory mechanisms are involved. Examples are studies of people who were trained to achieve a digit span of 80 (Ericsson, Chase & Falloon, 1980; Chase & Ericsson, 1981), novice taxi drivers learning city routes (Chase & Ericsson, 1991), musicians who memorize complex and lengthy musical scores (Ericsson, Krampe, &
Tesch-Romer, 1993; Rubin, 1995), restaurant waiters who remember large number of meal orders (Ericsson et al., 1993), and repertory actors who memorize and must rapidly retrieve lengthy roles in several plays (Noice, 1991, 1992). These studies often provide valuable insights into the means by which people use limited resources very efficiently in order to surmount limitations of memory. However, Banaji and Crowder (1989) have argued that the “everyday memory” movement has turned up very few novel phenomena or principles that had not already been known for many years based on laboratory research. (For opposing arguments, see articles in the American Psychologist, January 1991 [volume 46, issue #1], pp. 16–48.)

One especially fascinating aspect of the everyday-memory movement is its investigation of autobiographical memory (e.g., Rubin, 1986; Conway, 1992; Conway & Bekerian, 1987; Conway & Rubin, 1993). By collecting and classifying phenomenological reports, psychologists have constructed theories of how people structure in memory large segments of their life, how they salient “marking events” (e.g., graduations, marriage, birth of a child, beginning a job, moving) as signposts for ordering and reconstructing the temporal and logical sequence of events. Although people clearly have conceptual knowledge corresponding to long stretches of their past, different event memories are also multiply cross-indexed in memory according to life themes, what happened, where it happened, who was involved, and what the significance was of the event for one’s life. Some of the knowledge is in the form of personal episodic memories that are experienced in recall with imagery and often some emotion; and it has been noted that these specific memories can often be a mistaken blend of fact and fiction (Loftus & Ketcham, 1994). In addition to these episodic memories, large portions of people’s autobiography are in narrative generalizations with no more sense of “personally being there” than they have for the knowledge that they were born on a specific date.

An interesting aspect of autobiographic memory is that it is intimately tied to conceptions of self—of who and what we are. Many studies have found that memories are reconstructed to satisfy self-serving motives, and that people remember themselves in a more favorable light than is warranted (see Greenwald, 1980; Loftus & Ketcham, 1994). People also tend to distort their memory of how they used to behave (or their former opinions) to be more consistent with their opinion of today (Ross, 1989). These and other tendencies suggest that social, motivational, and personality factors play a significant role in the way memories are altered over time. More studies of this kind can be expected as the field advances and makes better contact with other branches of psychology.

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