Memory research in the 1990s often focused on the question of whether memory is best characterized as a set of independent systems or as a set of interrelated processes (see, e.g., Foster & Jelicic, 1999). In this chapter we provide a functional analysis of memory mechanisms that allows the specification of general principles of memory. These principles, we argue, apply to all memory, regardless of the type of information, the type of processing, the hypothetical system supporting the memory, or the time scale. We critique both the multiple systems and the processing views, showing how each misses something fundamental about the psychology of memory. We end by briefly describing three models of memory that are based on the functional principles identified.

THE ENCODING/RETRIEVAL INTERACTION

Memory is usually conceived as having three stages: encoding, storage and retrieval. Encoding refers to the acquisition and initial processing of information; storage refers to the maintenance of the encoded information over time; and retrieval refers to the processes by which the stored information is accessed and used. Historically, the scientific study of human memory can be seen as focusing on each of these stages in turn before coming to the realization that a dynamic interaction between the encoding and retrieval phases critically determines memory performance (Neath, 2000a).

An appreciation of the importance of the encoding/retrieval interaction came about as the result of studies that examined the potency of various cues to elicit items from memory. A strong cue is a word that elicits a particular target word most of the time. For example, when most people hear the word BLOOM, the first word that pops into their head is FLOWER. A weak cue is a word that only rarely elicits a particular target. When people hear FRUIT, they respond with FLOWER only about 1% of the time. A reasonable prediction seems to be that strong cues should be better than weak cues at eliciting the correct item. However, this inference is not valid because it fails to take into account the relationship between the encoding and retrieval conditions. For example, Thomson and Tulving (1970) reported an experiment in which they manipulated what cues were present at study and test. Some target words were presented alone at study and some were presented along with a weak cue. At test, there were three cue conditions: no cue, a weak cue or a strong cue. The results, shown as the probability of recalling the correct target word, are displayed in Table 9.1. When there was no cue present at study, a strong cue at test led to better performance (0.68) than either a weak cue (0.43) or no cue (0.49). However, when there was a weak cue present at study, the weak cue at test led to better performance (0.82) than a strong cue (0.23). The important aspect of this result is that the effectiveness of even a long-standing strong cue depends crucially on the processes that occurred at study.

As Tulving (1983: 239) noted, the dynamic interaction between encoding and retrieval conditions prohibits any statements that take the following forms:

- Items (events) of class X are easier to remember than items (events) of class Y.
- Encoding operations of class X are more effective than encoding operations of class Y.
- Retrieval cues of class X are more effective than retrieval cues of class Y.
One cannot say, for example, that pictures are remembered better than words, that deep processing leads to better memory performance than shallow processing, or that highly associated cues are better than weakly associated cues. What is missing from each of these statements is a description of the learning and retrieval conditions. Variations at either of these stages, as detailed below, can reverse each of these phenomena.

### Pictures are remembered better than words

As Tulving (1983) suggested, one should not state that one kind of item is easier to remember than another. As its name suggests, the picture superiority effect refers to the finding that pictures of objects are usually remembered more accurately than names of those objects (Paivio, Rogers, & Smythe, 1968). The label is misleading, however, as this effect depends on the type of test. When a recognition test is used and the measure of memory is the number of items correctly recognized as being on the list, pictures are indeed remembered better than words. However, the picture superiority effect reverses if the test is word fragment completion and the measure is the amount of priming (Weldon & Roediger, 1988). In this kind of task, there are two phases. In phase 1, the subjects are exposed to the items, both words and pictures. Phase 2 is the actual test, and it requires two groups: an experimental group who were in phase 1 and a control group who were not in phase 1. The test consists of word fragments and the subjects are asked to complete the fragment with the first word that pops into their head. For example, if they saw the word fragment T.B.GG.N, a solution would be TOBOGGAN. The measure of memory, priming, is the difference between the mean proportion of fragments completed by the experimental group and the mean proportion completed by the control group. Weldon and Roediger found that word fragments that could be completed to form a word that had been shown in phase 1 were more likely to be completed than those fragments that could be completed to form the name of a picture that had been shown in phase 1. Using word fragment completion as the task and priming as the measure, words are remembered better than pictures. As a result, one cannot make the statement ‘pictures are remembered better than words’ or, more generally, that one type of item is easier to remember than another.

### Deep processing is better than shallow processing

Just as with items, one cannot make absolute statements about the mnemonic properties of various types of processes. The levels of processing framework (Craik & Lockhart, 1972) proposed that deeper types of processing, such as semantic or meaning-based processing, will lead to better memory performance than more shallow types of processing, such as processing items based on how they look or sound. Thus, if you rate words for pleasantness – a deep task because you need to think about what the word means and consider the word’s various connotations – you will recall more items on a free recall test than if you judged whether the words contained a particular letter (Hyde & Jenkins, 1973). However, if the test is changed, shallow processing can lead to better performance than deep processing.

For example, Morris, Bransford, and Franks (1977) presented sentences in which a word was missing. In one condition, subjects judged whether a target word made semantic sense if inserted in the blank. For example, the sentence might be 'The (blank) had a silver engine' and the target word might be TRAIN. In a different condition, subjects judged whether the target word rhymed with another. In this case, the sentence might be '(Blank) rhymes with legal’ and the target word might be EAGLE. Two different tests were used. One test was a standard recognition test, where a target word was presented and subjects were asked whether it had been seen previously. The second test was a rhyming recognition test, where subjects were asked whether a word rhymed with one of the target words. With a standard recognition test, the deeper encoding process (whether the word fit in the sentence) led to better performance than did the more shallow encoding process (whether the word rhymed). However, with the rhyme recognition test, the shallow processing led to better performance.
The best cue is the item itself

Just as with items and processes, one cannot make absolute statements about the mnemonic properties of retrieval cues. It might seem reasonable that the best memory cue for an item is the item itself, a so-called copy cue. That is, if we wanted to find out whether you remembered seeing the word CHAIR on a list, we would use a cue that included a copy of the item in which we were interested. If this were true, then the phenomenon known as ‘recognition failure of recallable words’ would not exist. In this paradigm (e.g. Watkins & Tulving, 1975), the subject studies a list of word pairs in which the first word in the pair is a weak cue of the second word; for example, GLUE might be paired with CHAIR. Then, a word that is a strong cue is given, such as TABLE, and subjects are asked to write down as many words as they can that are associated with TABLE. A recognition test is then given, in which a copy cue (the word CHAIR itself) is used and subjects often fail to recognize this item as one of the words on the original list. The final test is cued recall, where GLUE is the cue. Now, subjects are quite likely to recall the word they earlier failed to recognize. CHAIR is not always an effective cue when trying to remember CHAIR. As a result, one cannot say that copy cues are the most effective cue or, more generally, that one type of cue is better than another.

The three examples above illustrate that whether a particular item or event is remembered depends on the interaction between the particular study and test conditions. Our first functional principle of memory can now be stated:

(1) Remembering depends on the interaction between the conditions at encoding and the conditions at retrieval.

This principle, essentially Tulving’s (1983) encoding specificity principle, means that all statements about the mnemonic properties of items, processes and cues need to specify completely the encoding and retrieval conditions. The next three functional principles of memory, then, are just as Tulving (1983: 239) proposed:

(2) Items do not have intrinsic mnemonic properties.
(3) Processes do not have intrinsic mnemonic properties.
(4) Cues do not have intrinsic mnemonic properties.

Task Purity

There are numerous ways of assessing memory. Typically, some event or set of items is presented to the subject, followed by a series of questions. The encoding can be either intentional, in which the subject knows there is a memory test that will follow and intends to remember the material, or incidental, in which the subject is unaware that there will be a later memory test and does not intentionally try to remember the material. Similarly, at test, the subject can try to relate the cues back to the learning episode, a direct test of memory, or the subject may be unaware that the test is related to the encoding episode, an indirect test of memory.

In addition to these distinctions, Craik (1983) suggested that many commonly used tests can also be classified with respect to how much environmental support they provide or how much self-initiated activity they require. Two related variables at work are whether the test requires identification of a particular encoding context and whether the test includes a more specific cue or a more general cue.

A free recall test provides little environmental support and requires a lot of self-initiated activity. A list of items is presented, and the subject is asked to recall which items were on the list. Say the list included the words GREYHOUND, TABLE and BROCCOLI. The subject knows all of these words prior to the presentation of the list, and will know these words after the experiment is over. The experimenter simply says ‘recall the words that were on the list’ and it is up to the subject to identify which list and to discriminate the items that were on this particular list from those that were not. This is memory for an item in context. Typical recognition and cued-recall tests provide more specific cues, but still require the subject to discriminate which items were on the list. Did ‘GREYHOUND’ appear on the list or not? In this case, specific items are queried (recognition) or specific cues are provided (cued recall), which can reduce the need for self-initiated retrieval processes.

Immediate memory tests (e.g. digit span) seem to require contextual information, but on further review this may not be necessary. A person is given six or seven digits in random order, and is then asked to recall the digits in the same order. Because so little time has elapsed from the end of list presentation to the beginning of the retrieval attempt, the episodic context is unlikely to have changed and so the subject is likely to be still in the original encoding state. Thus, contextual reinstatement may not be necessary. If the same test is delayed, however, then the test is removed in time from the learning episode, the context will have changed, and the test will require more self-initiated activity.
Some tests, such as word fragment completion and general knowledge questions, provide far more targeted cues and, because neither of these tests requires the reinstatement of a particular context, little, if any, self-initiated activity is required. For both tests, it does not really matter to the subject whether a specific encoding context is remembered or not. For example, if you are given a word fragment and asked to complete it with the first word that pops into your head, you are free to try a variety of strategies. You might just try random words, or you might think back to the first part of the experiment you were in and see if any of those words fit the fragment. In one case, you are ignoring a particular learning episode, in the other you are not, and different results might obtain (e.g. Bowers & Schacter, 1990). Similarly, you might just know that Hannibal Hamlin was Abraham Lincoln’s first vice president, or you might actually remember sitting in a class and hearing the instructor use Hamlin as an example of an obscure person. Very different types of processing can be used by subjects even when given the same type of test or cue. People will use any and all processes to help them answer a question. This leads to the next principle:

(5) Tasks are not pure.

‘Task’ is meant quite generally, and can be any type of test or other cognitive functioning performed in the service of memory. As Jacoby (1991) noted, many researchers act as if they are making the assumption that tasks or certain tests are ‘process pure’; that is, they act as if a particular test taps a particular memory system or that a particular task requires only one type of process. As the examples above illustrate, this assumption is likely to be false: one cannot make the assumption that a particular test taps only one particular system or process.

FORGETTING

One of the most salient features of memory is that it often appears to fail. What causes these failures? Given the prohibition on statements of the form ‘Items of class X are easier to remember than items of class Y’, we must also prohibit the complementary statement about what types of items are harder to recall or, to put it another way, more likely to be forgotten. In more general terms, if items do not have intrinsic mnemonic properties, then it seems unlikely that forgetting is due to an intrinsic mnemonic property of the items. Given that remembering depends on the interaction of the encoding and retrieval conditions, forgetting must depend on this also. This conclusion accords nicely with one of the most influential analyses of forgetting, that forgetting is due to interference.

John McGeoch (1932) argued that forgetting is caused by interference rather than by the passage of time. His analogy was to how an iron bar might rust over time: it is not time per se that causes rust but rather oxidation. Similarly, although memory often gets worse over time, time does not cause forgetting; rather, interference does. Evidence consistent with this analysis includes the numerous instances where memory performance improves over time even in the absence of opportunities to rehearse or relearn the material (e.g. Bjork, 2001; Knoedler, Hellwig, & Neath, 1999; Neath & Knoedler, 1994; Wright, Santiago, Sands, Kendrick, & Cook, 1985). In particular, reminiscence (Payne, 1987) and spontaneous recovery (Wheeler, 1995) are exactly this type of memory phenomenon: better memory after more time has elapsed when there is no opportunity for further study. McGeoch’s arguments (see also Osgood, 1953) were such that it is hard to find a memory researcher who invokes decay or any other time-based forgetting process in all of memory, except for transient or short-term memories. We argue later that time-based forgetting is not inappropriate in those situations either.

There are two types of interference: proactive interference, in which previous information affects your ability to remember more recent information, and retroactive interference, in which information you have recently learned affects your ability to remember older information. The difference between them is conveniently illustrated by using paired associate terminology, which has the benefit of being extremely general. In a paired associate task, two items are associated, for example A and B. At test, A is given as the cue, and B is the correct response. You might be asked to respond with CHOCOLATE when you see the cue MAGAZINE. To measure interference, one must have an experimental condition in which interfering items are present, and a control condition in which there is no interfering material.

Table 9.2 illustrates when retroactive and proactive interference will occur. In all conditions, people learn A-B and are tested on their memory for A-B. In the Control 1 condition, the subjects are asked to learn C-D after learning A-B and before they are tested on A-B. The term C-D represents non-interfering items; there is no overlap between items A, B, C and D. The term A-D represents interfering items, because item A now acts as a cue for two different responses, B and D. The Experimental 1 group will perform more poorly than the Control 1 group due to retroactive interference. The bottom part of the table shows how proactive interference occurs. Again, C-D will not interfere with A-B, but learning A-D prior to learning A-B will cause interference. The Experimental 2 group will perform more poorly than the Control 2 group when trying to recall B due to proactive interference.
TABLE 9.2  A schematic illustration of when retroactive and proactive interference will occur

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Test</th>
<th>Interference Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control 1</td>
<td>A-B</td>
<td>C-D</td>
<td>A-B</td>
<td>Retroactive</td>
</tr>
<tr>
<td>Experimental 1</td>
<td>A-B</td>
<td>A-D</td>
<td>A-B</td>
<td>Retroactive</td>
</tr>
<tr>
<td>Control 2</td>
<td>C-D</td>
<td>A-B</td>
<td>A-B</td>
<td>Proactive</td>
</tr>
<tr>
<td>Experimental 2</td>
<td>A-D</td>
<td>A-B</td>
<td>A-B</td>
<td>Proactive</td>
</tr>
</tbody>
</table>

This schematic also illustrates why the term forget should be taken to mean only a failure to remember rather than a loss of information. Consider the Experimental 1 group. When cued with A at test, there are at least three options: the subject could recall B, the correct item; D, an interfering item; or the subject might not be able to recall anything. What can be assumed about the memory for B if the subject recalls D or recalls nothing? Nothing can be assumed: one cannot assume a loss of information from a lack of performance. It is always possible that a different cue could lead to successful remembering. For example, the cue A might be ‘Recall the items that you were just shown’ and the subject may only recall one or two items. The cue might then be modified by adding the phrase ‘some of which were names of indoor games.’ Recall is likely to be facilitated (Gardiner, Craik, & Birtwistle, 1972). A control group can always establish that the added cue is not sufficient to produce the word if it had not been experienced earlier.

Forgetting is a memory failure at a particular time using a particular set of retrieval cues and processes, where failure means no information was recalled or incorrect information was recalled. It does not imply that the information is lost or otherwise permanently unavailable. Indeed, the literature is replete with studies that demonstrate that a failure to remember in a particular task under one set of conditions can be readily alleviated under a different set of retrieval conditions (see Capaldi & Neath, 1995, for a review). To the extent that the different set of conditions reduces interference, performance will be enhanced. The sixth functional principle, then, can be stated as:

(6) Forgetting is due to extrinsic factors.

**Forgetting in sensory memory**

Decay is posited as the forgetting mechanism in only two areas of research, sensory memory and short-term/working memory. A detailed critique of these areas is beyond the scope of the current chapter; rather, the reader is referred to a recent review by Nairne (2003; see also Crowder & Surprenant, 2000; Neath & Surprenant, 2003). In short, the evidence for sensory memory is not nearly as strong or compelling as it used to appear.

Most researchers now distinguish between two different forms of persistence, stimulus persistence and information persistence (see Coltheart, 1980). A typical visible persistence task might involve a synchrony judgment: a stimulus is presented, followed by an interval of variable duration, and then followed by a signal, such as a tone. The subject is asked to adjust the signal so that its appearance coincides with the disappearance of the stimulus. If the subject adjusts the signal such that it appears 150 ms after the true offset of the stimulus, then one can infer that the original stimulus persisted for 150 ms. In contrast, a typical information persistence task would involve trying to extract some information from the original stimulus. The partial report task involves presenting a matrix of stimuli (usually letters) for a brief period (around 50 ms). After a variable delay, a signal is presented that indicates which part of the matrix should be recalled. Performance in this partial report condition is compared to performance in a whole report condition, in which all the information in the matrix is recalled. When the matrix is shown for 50 ms, the partial report advantage lasts approximately 500 ms. Recent experimental work suggests, contrary to claims of most conceptions of sensory memory, that visible persistence tasks and information persistence tasks are not measuring the same thing (Loftus & Irwin, 1998).

Most likely, stimulus persistence is not part of memory, as most people would define that term. Rather, there is an emerging consensus that it is the result of a particular continuing pattern of neural activity set up by the original stimulus. One key finding that argues against decay here is the inverse duration effect: stimulus persistence decreases with increases in stimulus duration (e.g. Bowen, Pola, & Matin, 1974). It is hard to conceive of a form of forgetting where the longer you are exposed to a stimulus, the faster the forgetting. Whereas stimulus persistence is best thought of as not memory, information persistence is now increasingly viewed as the same type of memory as short-term/working memory (Nairne, 2003; Neath & Surprenant, 2003). There is thus only one type of memory in which decay is proposed as a mechanism for forgetting, and we examine this next.
Forgetting in short-term/working memory

One reason why time-based forgetting, such as decay, is often invoked is the common belief that short-term/working memory is immune to interference, especially proactive interference (e.g., Cowan, 2001). This is simply not so. The suffix effect (Crowder, 1967; Dallett, 1965) is a retroactive interference effect. Recall of the last item in a list of auditorily presented items is impaired if the list is followed by a stimulus suffix, an irrelevant item that is the same on every trial and that does not need to be recalled or processed by the subject. The phonological similarity effect (Conrad, 1964), the finding that lists of similar-sounding items are harder to recall than lists of dissimilar-sounding items, is an example of both proactive and retroactive interference in short-term/working memory. As a third example, Tahan and his colleagues (e.g., Tehan & Humphreys, 1996, 1998; Tolan & Tehan, 1999) have developed a task in which proactive interference (PI) can be observed in short-term memory settings. Subjects are asked if an instance of a particular category was seen on the immediately preceding list of four items. They are to ignore any instances prior to the most recent list. However, if there are either semantically similar or phonologically similar items in the preceding list, PI can be observed. Thus, interference effects are readily observed in the short term.

The idea of a separate short-term memory has been challenged (e.g., Melton, 1963) almost since it was first proposed and has continued to be challenged (e.g., Crowder, 1982). Most recently, Nairne (2002a) provides a critical evaluation of the current ‘standard model’ of short-term/working memory (e.g., Baddeley, 1986; Burgess & Hitch, 1999; Cowan, 1995; Shiffrin, 1999). In this version, permanent knowledge is activated and the collective set of activated items is defined as short-term memory. The activation decays over time and can be offset by refreshing the decaying items through rehearsal. The key finding supporting this idea is that words that take less time to pronounce are recalled better than otherwise equivalent words that take more time to pronounce (Baddeley, Thomson, & Buchanan, 1975). This basic finding, however, has recently been challenged: Lovatt, Avons, and Masterson (2000) have shown that this result holds only for one particular set of words. When other sets of words are used, the time-based word length effect is not observed (see also Neath, Bireta, & Surprenant, 2003). The other finding historically used to support time-based decay comes from the Brown–Peterson paradigm. However, these findings are better conceived as supporting an interference rather than decay explanation (see Nairne, 2002a; Neath & Surprenant, 2003: 125–35).

Forgetting, then, is best accounted for not by time-based decay but rather by interference. The only two areas of memory research in which decay was seriously considered no longer offer good empirical support for the idea. An additional benefit of viewing memory as due to forgetting is that it provides a natural way of examining the importance of cues.

Cues

One thing all tests of memory have in common is that they are cue-driven; that is, all memory retrieval requires and depends on a retrieval cue. The cue can be explicit, in the case of ‘Did you see this word on the list?’ or ‘What is the capital of Assyria?’, or it can be less obvious, such as ‘Do you have turkey for Christmas?’ or ‘Complete this fragment with the first word that pops into your head’. With no cue, there can be no memory. This may be obvious for most memory research, and so we will not belabor the point here. For now we simply state this as the next principle:

(7) All memory is cue-driven.

Providing one cue rather than another can change performance on a memory test from failure to success (and from success to failure!). We have already argued (above) that cues do not have intrinsic mnemonic properties; rather, the effectiveness of a cue will depend on the interaction between the encoding and retrieval conditions. One can, however, turn this latter qualification into a general principle, based on the idea of cue overload (Watkins & Watkins, 1975; Watkins, 1979).

Cue overload refers to the idea that a cue will become less and less effective the more stimuli it subsumes. For example, the cue could be a particular list in a particular context. If the list contains one item, the cue is very effective. As list length increases, the probability of recalling any particular item decreases due to cue overload (Watkins, 2001). As another example, lists made up of the digits 1 to 9 in random order do not afford many cues for their successful recollection, particularly when multiple trials are presented one after the other. This is why digit span for English speakers is around 7 to 8 items (e.g., Schweickert & Boruff, 1986). On the other hand, if cues are created that are particularly well suited to discriminate the desired item from other items, digit span can increase to over 100 or more (Ericsson & Staszewski, 1989).

Cue overload, we suggest, is better expressed as its complement: the more specific (less overloaded) a cue, the more likely it is to elicit the appropriate memory. Two examples from the implicit memory literature illustrate such cue hyperspecificity. Given
Cues are subject to overload. A specific enough cue, memory should last a very long time and there should be little or no correlation between two hyperspecific cues even when they refer to the same nominal target (i.e., there should be stochastic independence).

Sloman, Hayman, Ohta, Law, and Tulving (1988) conducted a repetition priming experiment in which a list of words was presented. In the test phase, they used a word fragment completion task. Of importance, the fragments were created such that only one English word could be made. Subjects who had previously read the word AARDVARK were more likely to complete the fragment A_D_RK than those who did not. Of more interest for current purposes, this priming was still seen on a test conducted 16 months after the initial exposure. That is, seeing a word 16 months earlier facilitated completing the unique fragment.

Two hyperspecific cues should show stochastic independence: performance on task 1 should be uncorrelated with performance on task 2 even though both tasks have the same nominal target and are, apart from the cue, identical. Hayman and Tulving (1989) conducted a series of studies in which subjects first read a series of words during which they were instructed to think about the word’s meaning. The key tests involved word fragment completion. The first test might use A_D_RK as the word fragment for AARDVARK, whereas the second test, which followed 3 minutes later, would use a different fragment, such as _AR_VA__. Note that the fragments are complementary: blanks in the first fragment are replaced with letters in the second fragment, and letters in the first fragment are replaced with blanks in the second fragment. Performance on the second test was essentially independent of performance on the first test.

The more specific the cue, the more effective it will be in eliciting the appropriate memory. Thus, (8) Cues are subject to overload.

Overload, in this sense, is a result of the interaction between the processes performed at study and the processes performed at test.

CONSTRUCTIVE AND RECONSTRUCTIVE PROCESSES

Memory, like other cognitive processes, is inherently constructive. Information from encoding and cues from retrieval, as well as generic information, are all exploited to construct a response. Work in several areas has long established that people will use whatever information is available to them to help them reconstruct or build up a memory (e.g., Bartlett, 1932). The processes that can lead to successful and accurate remembering are the same ones that can lead to distortion (Estes, 1997). The reconstructive nature of memory is most obvious when conditions are set up so that errors can be observed. As the three examples below illustrate, providing a particular cue can change how an item or event is remembered; even if the item or event never occurred.

One classic example concerns the ability to reproduce a simple line drawing. Carmichael, Hogan, and Walter (1932) presented simple line drawings to subjects and told half of the subjects the drawing looked like one particular object and told the other half of the subjects that the drawing looked like a second, different, object. For example, one group of subjects might be told that the drawing resembled a pair of eyeglasses whereas the other group was told the drawing looked like a set of dumbbells. At a later test, the subjects were asked to draw the original figure as accurately as possible. Most subjects changed the figure so that it looked more like the verbal label. The idea is that adding a verbal label provided another cue that was available at test, but the label was only partially helpful (i.e., it said only what the object was like, not what the object was). At test, the cue misled the subjects into reconstructing a drawing that made sense given the cue, but differed from the original drawing (see also Moore, 1910).

A second example involves eyewitness memory. Loftus and Palmer (1974) asked subjects to watch a film that included a car accident. After seeing the film, the subjects were asked: “How fast were the cars going when they ——— each other?” The researchers varied the intensity of the verb that described the collision, using smashed, collided, bumped, hit and contacted. When the verb was smashed, the estimates averaged 41 mph; when the verb was contacted, the estimates averaged 32 mph. A follow-up question asked whether there was broken glass. Nearly one-third of the subjects who had the verb smashed said ‘yes’, but only one-tenth of those who had the verb contacted said there was broken glass. There was actually no broken glass. Clearly, the verb used led to the subjects’ reconstructing their memory to be consistent with the implied speed of the verb. Many other studies show similar findings. For example, subjects will say ‘yes’ more often to a question like ‘Did you see the broken headlight?’ than ‘Did you see a broken headlight?’ (Loftus & Zanni, 1975).

Another example involves recalling items that were not presented. Based on a series of studies by Deese (1959a, 1959b), Roediger and McDermott (1995) presented lists of words, such as THREAD, PIN, EYE, SEWING, SHARP, POINT, PRICKED, THIMBLE, HAYSTACK, PAIN, HURT and INJECTION. All these words are related to NEEDLE, which does not appear on the list, but which was recalled approximately 40% of the time. Following
recall, the subjects were given a recognition test and were asked to indicate on a scale of 1 to 4 whether each item was from one of the lists. A rating of 4 meant they were sure the word was on the list, a rating of 3 meant they thought the word was probably on the list, a rating of 2 meant the word was probably not on the list, and a rating of 1 meant the word was definitely not on the list. On average, the words that were on the list were given a rating of 3.6, whereas words that were neither on the list nor related to words in the list were given a rating of 1.2. The critical words, which were related but were not on the list, received a mean rating of 3.3, not significantly different from words that were actually on the list. In a subsequent experiment, the subjects were asked to make a remember–know judgment (Tulving, 1985). In this procedure, subjects are given a recognition test and are asked to indicate whether they actually remember the information (have a conscious recollection of the information’s occurrence on the study list) or just somehow know the answer (know that the item was on the list but have no conscious recollection of its actual occurrence). Surprisingly, the proportion of studied items that received a remember judgment (0.79) was almost identical to the proportion of critical lures that received a remember judgment (0.73).

These three examples illustrate the dynamic nature of memory and how people reconstruct a memory based on a combination of information available both at encoding and retrieval. The name given to a drawing can alter how it is subsequently reproduced, the words used in questions can affect what is recalled, and events can be recalled that were not present at encoding. As the Loftus and Palmer (1974) verb study shows, once a particular memory has been constructed, it can affect subsequent reconstructions: people who thought smashed implied fast also thought they saw broken glass; people who thought contacted implied slow also thought they did not see broken glass.

(9) All memories are reconstructed.

**False Memory**

Given that memory is a reconstructive process, it should not be surprising to find that there is a large literature showing that people have difficulty distinguishing between memories of events that happened and memories of events that did not happen (see, e.g., Conway, 1997). In a typical reality monitoring experiment (cf. Johnson & Raye, 1981), subjects are shown pictures of common objects. Every so often, instead of a picture, the subjects are shown the name of an object and are asked to create a mental image of the object. The test involves presenting a list of object names, and the subject is asked to judge whether they saw the item (i.e. judge the memory as ‘real’) or whether they saw the name of the object and only imagined seeing it (i.e. judge the memory as ‘imagined’). People are more likely to judge imagined events as real than real events as imagined.

People can remember entire episodes that did not happen (Ceci, 1995; Hyman & Pentland, 1996). This can be demonstrated in the laboratory by picking an episode (such as getting lost at a shopping mall) and ensuring that it did not happen to the subject. Then, a confederate, usually a relative or close friend, starts reminiscing about events that did occur. After a couple of these, the confederate reminisces about an event that did not occur. Although the subjects might not recall the event at first, they will usually begin to supply their own details very soon, and within a few days will have a memory that is rated as vivid and as accurate as a genuine memory (Loftus, 1993).

Even if most of a memory is accurate, making a mistake about one small piece of information can render it inaccurate. Baddeley (1990) relates one such case. Donald Thomson, an Australian psychologist, was picked up by police and identified by a woman as the man who had raped her. His alibi was that he had been on a television talk show at the time and that he had an assistant police commissioner as a witness. The police interrogator reportedly responded with ‘Yes, and I suppose you’ve got Jesus Christ and the Queen of England too!’ (Baddeley, 1990: 27). Later released and exonerated, Thomson found out that the television had been on when the woman was raped. Her memory was accurate enough to identify Thomson, but she made an attribution error: she attributed the face she remembered to her attacker rather than to the person on television.

Unfortunately, memories of events that did not happen have been termed false memories. There are two problems with this term. First, it suggests a dichotomy between those memories that are true and those that are false. The problem is that all memories are a combination of details recalled about the event supplemented by information unrelated to the actual event. For example, you might really remember seeing a particular movie and can recreate for yourself what it was like sitting there, who you were with, and so on. But your memory of eating popcorn while viewing the film might come from your general knowledge that you often eat popcorn while watching films. Thus, at least part of every memory is likely to be ‘false’ because at least some details are not of the original event but are drawn from generic memory or other sources. To divide memory up as either true or false masks the fact that all memories are constructed and that the construction process draws on a lot of different types of information. If one has to label memories as either true or false, then all memories must be false, in the sense that memories are rarely, if ever, veridical to the actual event.

The second problem with the term false memory is that it suggests that the memory system stored false information. This obscures the important point that
the memory system is not like a library where the books (memories) are stored on shelves and just sit there. When retrieved, the books may be a little dusty but are otherwise the same as when they were stored. In contrast, memory is dynamic and continuously changing, as the examples above demonstrate. As Wechsler (1963: 151) phrased it: ‘Memories are not like filed letters stored in cabinets or unhung paintings in the basement of a museum. Rather, they are like melodies realized by striking the keys on a piano.’ Each time the piano is played, the melody is slightly different: the pianist might occasionally strike the wrong key, might speed up or slow down, might press a key slightly harder or more softly, might misread a note, might press the foot pedal slightly earlier or later, or the piano itself might be slightly out of tune or have a slightly different timbre. Each time an event is recalled, the memory is slightly different. Because of the interaction between encoding and retrieval, and because of the variations that occur between two different retrieval attempts, the resulting memories will always differ, even if only slightly.

MEMORY: SYSTEM, PROCESS, OR FUNCTION?

There are three basic conceptions of memory. The multiple systems view emphasizes the structure of memory, fractionating it into separate but related systems. The processing view focuses on the cognitive processes that are used, both at encoding and at retrieval. The functional view stresses the role of memory, addressing the question of how memory works and what its fundamental characteristics are.

The systems view

Advocates of the systems approach (e.g. Schacter & Tulving, 1994; Schacter, Wagner & Buckner, 2000) identify five major memory systems: working memory, semantic memory, episodic memory, procedural memory, and the perceptual representation system. Working memory (Baddeley, 1994) is a system for the temporary maintenance and storage of internal information and can be thought of as the place where cognitive ‘work’ is performed. It has multiple subsystems, most notably one for the processing of verbal or speech-like stimuli (e.g. the phonological store and articulatory control process) and another for the processing of visuo-spatial information (e.g. the visuo-spatial sketchpad and the visual scribe). Semantic memory refers to memory for general knowledge and includes facts, concepts and vocabulary (Tulving, 1983). A better term is generic memory (Hintzman, 1984) because ‘semantic memory’ implies storage of only semantic information, which is not the case. Rather, the distinguishing feature of this system is the lack of conscious awareness of the learning episode. In contrast, episodic memory is the system that does provide this awareness of the learning episode and enables the individual to mentally ‘travel back’ into his or her personal past (Tulving, 1998). All of these systems are together part of declarative memory, which is contrasted with procedural memory, the fourth proposed major memory system. Declarative memory is concerned with knowing ‘that’ rather than with knowing ‘how’. For example, if you know that two plus two equals four, the information is said to be in declarative memory. In contrast, if you know how to ride a bicycle, that information is said to be in procedural memory. Finally, the perceptual representation system is a collection of non-declarative domain-specific modules that operate on perceptual information about the form and structure of words and objects (Schacter et al., 2000).

There are many current descriptions of the systems approach; the interested reader is referred especially to the various chapters in Tulving and Craik (2000), Foster and Jelicic (1999), and Schacter and Tulving (1994). Here we focus on what we think are the major weaknesses of this approach for the psychology of memory.

One major weakness with the systems approach is the lack of consensus on what the systems are and even on what the criteria should be. One set of criteria are those of Sherry and Schacter (1987):

1. Functional dissociations: an independent variable that has one effect on a task thought to tap system A either has no effect or a different effect on a task thought to tap system B.
2. Different neural substrates: system A must depend on different brain regions than system B.
3. Stochastic independence: performance on a task that taps system A should be uncorrelated with performance on a task that taps system B.
4. Functional incompatibility: a function carried out by system A cannot be performed by system B.

Roediger, Buckner, and McDermott (1999) show how recall and recognition meet the first three of these criteria: the variable word frequency produces functional dissociations between recall and recognition (Gregg, 1976); neuropsychological dissociations between recall and recognition are observable in amnesic subjects (Hirst, Johnson, Phelps, & Volpe, 1988); and numerous studies have found essentially no correlation between performance on the two tests (Nilsson & Gardiner, 1993). A Gedanken experiment suggests that recall and recognition might also demonstrate functional incompatibility: memory for taste or odors is a function that is well supported by recognition (consider the case of Marcel Proust) but not very well supported by recall. Of course, no memory researcher proposes that recall and recognition are separate memory systems, but this is precisely the problem with the criteria. A slightly different set of criteria have
been proposed by Schacter and Tulving (1994). Essentially, they propose that memory systems should be defined in terms of their brain systems, the particular kind of information they process, and their principles of operation (but see the original for a detailed discussion). Neither set of criteria results in producing just the five systems mentioned above.

A second major problem with the multiple systems account is the reliance on dissociations. Although there exist numerous dissociations between episodic and semantic memory, for example, there also exist dissociations between two tasks thought to tap the semantic memory system (Balota & Neely, 1980) and between two tasks thought to tap the episodic memory system (Balota & Chumbley, 1984). Even some of the dissociations between episodic and semantic memory are questionable. As Parkin (1999) notes, many studies show that retrieval in episodic tasks involves right prefrontal activation whereas retrieval of semantic information involves left prefrontal activation. This neuropsychological dissociation, however, reverses when the two tasks are equated for difficulty: retrieval of semantic information produces larger amounts of right frontal activation than the episodic task. In one sense, then, semantic memory under one set of conditions has a different neural substrate than semantic memory under a second set of conditions.

Another problem related to dissociations is the inability of the systems view to predict which way a particular dissociation will turn out (Hintzman, 1984; McKoon, Ratcliff, & Dell, 1986). Thus, variables are found that have one effect on semantic memory and a different effect on episodic memory, but there is nothing in the systems view that predicts a priori which way around the dissociation should occur. Had results come out exactly the reverse of what was seen, these completely opposite findings would still have been taken as evidence for the proposed distinction.

The multiple systems view, then, lacks a principled and consistent set of criteria for delineating memory systems. Given the current state of affairs, it is not unthinkable to postulate ten or twenty or even more different memory systems (Roediger et al., 1999). Even for a particular system, there seem as many opportunities for dissociations within it as dissociations between it and other systems. It is always possible that as knowledge of underlying brain anatomy increases, researchers will specify an increasingly precise and principled set of criteria and will develop a consistent and useful taxonomy of systems. Until that time, however, many researchers have adopted a different approach, one that emphasizes processing rather than structure.

The processing view

The processing or proceduralist view (e.g., Bain, 1855; Crowder, 1993; Kolers & Roediger, 1984) emphasizes the encoding and retrieval processes rather than the encoding or location in which the memory might be stored. Rather than saying that performance on a memory test depends on the memory system that supports the information, processing theorists propose that what is important is the type of processing that the person used. The original idea was that memory is a by-product of a successive series of analyses, from the perceptual to the conceptual (Craik & Lockhart, 1972). The idea was refined to become transfer appropriate processing: a given type of processing at study will lead to better memory performance if it is appropriate for the particular test (see Morris et al., 1977; Tulving & Thomson, 1973).

The basic idea of transfer appropriate processing, as Nairne (2001, 2002b) documents, is often misrepresented as saying that memory depends on the similarity of the processes performed at study and those required at test or, to put it another way, on the match between the cue and target. There are two things wrong with this ‘transfer similar processing’ account. First, it is not transfer appropriate processing. Transfer appropriate processing requires only that the processes be appropriate, not that they be similar. It allows for the processes to be similar, but it also allows them to be dissimilar. Second, transfer similar processing is empirically wrong. There are numerous examples in the memory literature of cases where a copy cue – a cue that is identical to the target – does not elicit the target, such as in recognition failure of recallable words (Watkins & Tulving, 1975). Another example is part-set cueing (Slamecka, 1968): cueing you with part of a set of items (which presumably provides a better overall match between cue and target) can lead to worse performance than cueing you with none of the items in the set (which presumably has a worse match between cue and target).

One problem with transfer appropriate processing is in identifying the processes used. One popular approach has been to focus on two different types of processing (or, more accurately, the endpoints on a continuum): data-driven and conceptually driven processing (Jacob, 1983). Data-driven processing emphasizes more perceptual or low-level aspects of an item (e.g., whether upper or lower case, whether male or female voice, whether it rhymes with ORANGE) whereas conceptually driven processing emphasizes more semantic or high-level aspects of an item (e.g., whether it is an antonym or synonym of another item, whether it has pleasant or unpleasant associations).

A second problem with this approach has been the almost exclusive focus on data-driven versus conceptually driven processing. Dividing all possible cognitive processing into just two types is most likely oversimplified. Clearly, there are more than just two basic types of processing, and evidence supporting this comes from studies in which dissociations have been found between two conceptually
driven tasks (McDermott & Roediger, 1996). Until a more reasoned and complete account of the varieties of processing is provided, the processing view will remain vulnerable to the charge that it is vague in its predictions and certainly incomplete.

**Three functional views**

There currently is no model of memory that encompasses all of the principles we have presented above and that addresses all of the main research areas. However, there are three models, which are all clearly functional in approach, that do address much of the more heavily researched areas: short-term/working memory, episodic memory and semantic memory.

**The feature model**

Rather than invoking separate sensory and short-term or working memory systems, the feature model (Nairne, 1988, 1990; Neath & Nairne, 1995; Neath, 2000b) proposes that sensory and short-term memory phenomena can be accounted for within a single framework. Items are represented as vectors of features. Modality-dependent features represent information that is dependent upon the presentation modality (e.g. male or female voice, upper or lower case) whereas modality-independent features represent information that is the same regardless of the presentation modality (e.g. that the word was ‘dog’). There are no capacity limits and there is no decay. Rather, features from one item can retroactively interfere with features from an earlier item. At test, a cue samples all the items and the one with the best relative match is selected. The model can account for suffix effects, modality effects, word length effects, phonological similarity effects, grouping effects, and the effects of articulatory suppression and irrelevant speech. It predicts not only which items will be recalled, but also the error patterns (Neath, 2000b; Surprenant, Kelley, Farley, & Neath, in press). Perhaps its most impressive accomplishment is the prediction of complex interactions among these variables. For example, it predicts the correct pattern of results when word length, phonological similarity, presentation modality and presence or absence of articulatory suppression are factorially manipulated. Although it does not account for all short-term/working memory data, it does suggest that concepts such as separate systems and time-based forgetting may not be necessary.

**Compound cue theory**

We have argued that items do not have intrinsic mnemonic properties, but spreading activation theory, one very popular account of association priming, posits just such a property (Collins & Loftus, 1975; Anderson, 1983). Association priming is the finding that processing of a word such as NURSE is facilitated if the word DOCTOR has been seen immediately before. The basic idea is that when a concept is processed, it becomes activated and that activation spreads to all related concepts. Because the concept NURSE is partially activated, it can be processed more accurately and quickly when it is encountered. An alternative account avoids attributing specific mnemonic properties to items and instead accounts for the facilitation of primed items by invoking cueing. According to compound cue theory (Dosher & Rosedale, 1989; Ratcliff & McKoon, 1988, 1994), semantic memory functions in the same way as any other form of memory. Rather than having just one item serve as a cue, multiple items can enter into a compound cue. Thus, when NURSE is presented, but DOCTOR is shown just prior, the compound cue of DOCTOR and NURSE is what enhances processing (see Neath & Surprenant, 2003, for details).

**Simple**

SIMPLE (Brown, Neath, & Chater, 2002) stands for Scale Invariant Memory, Perception, and Learning. It proposes that items are represented internally on a log-transformed scale of the relevant physical dimension. All retrieval is cue-driven and there is no decay or time-based forgetting. Items do not have intrinsic mnemonic properties; rather, a particular item will be retrieved if it has the most local relative distinctiveness given a particular cue. This account explains many memory phenomena, but of particular note here is that the model claims scale invariance (see below). It explains data when the time scale is a few seconds, a few minutes, several hours or several weeks. Thus, it accounts for data from three separate memory systems: short-term/working memory, episodic memory and semantic memory.

**Summary of functional models**

Although all three functional models of memory above have as their focus different areas of memory research, the models are similar in that they reflect functional principles. All posit that memory is cue-driven, that there can be cue overload, and that neither items nor cues nor processes have intrinsic mnemonic properties. Forgetting is not due to time-based decay but rather is due to interference or discrimination problems. All predict that an item that might not be retrieved under one set of circumstances might be retrievable under a different set. A final similarity is that none requires that the principles it proposes change as a function of time scale, type of processing or type of structure; they propose principles that are invariant.
All ten of the principles noted in this chapter should apply widely; they should be invariant. Invariance has several components, most notably scale invariance. It is a characteristic of natural laws to apply or to hold over a wide range of temporal, spatial or physical scales (see Chater & Brown, 1999). For example, physical laws apply whether the unit of measurement is 1 milligram, 1 gram, 1 kilogram or 1 tonne. Thus, from 1 mg to 1,000,000,000 mg, the laws all hold or, to put it another way, demonstrate scale invariance.

The claim that memory principles are scale invariant is more controversial and is rarely made (although see Gallistel & Gibbon, 2000, for a notable exception). For example, it has long been common practice (e.g. Izawa, 1999) to divide memory into one system that operates from 0 to 500 ms (sensory memory), a second system that operates until approximately 20 or 30 s (short-term or working memory) and a third system that operates on all temporal durations beyond that (long-term memory). Not only does this view propose that the natural laws of memory fundamentally change over a range as small as 200 ms to 20,000 ms, but it proposes they change twice! In contrast, scale invariance means that the fundamental principles of memory apply regardless of the scale, whether remembering immediately after an event or several years after an event. Brown et al. (2002) review much of the evidence for the argument that principles of memory do not change as a function of time scale involved. Here we focus on just three examples.

In a free recall task, subjects are given a list of items and are asked to recall as many of them as they can in any order they like. With free recall, people usually recall the first few items well, which is known as the primacy effect, and the last few items well, which is known as the recency effect. The inter-item presentation interval (or IPI) is the time between items and the retention interval (or RI) is the time between the offset of the final item and the beginning of recall. The ratio rule (Glenberg, Bradley, Kraus, & Renzagila, 1983; see also Bjork & Whitten, 1974) relates the size of the recency effect to the ratio of the IPI to the RI. For example, if items are presented with a 1 s IPI and 1 s RI, the ratio is 1:1. If the items are presented with a 1 week IPI and a 1 week RI, the ratio is still 1:1. The size of the recency effect (defined as the slope of the best-fitting line over the last three points) is proportional to the log of the ratio of the inter-item presentation interval (IPI) and the retention interval (RI).

Figure 9.1 The ratio rule in free recall. The size of the recency effect (measured as the slope of the best-fitting line over the last three points) is proportional to the log of the ratio of the inter-item presentation interval (IPI) and the retention interval (RI).

The subject is asked to recall the items in order. There are a variety of ways of measuring span, one of which is the identification of the list length at which performance is 50%. Nairne and Neath (2001) conducted an experiment based on the memory span technique but delayed recall for 5 minutes. The results are shown in Figure 9.2: long-term memory span for two-syllable words is approximately...
MECHANISMS OF MEMORY

A

Item 1

Item 2

Monday

Tuesday

B

Item 3

Wednesday
the same as short-term memory span for two syllable words: about 4–5 items.

A final example of scale invariance concerns the type of errors observed when people are asked when a particular item or event occurred. When an error is made, the item is most likely to be recalled in an adjacent position. Nairne (1992) asked subjects to reconstruct the order in which they had seen a list of five items 30 seconds earlier. Huttenlocher, Hedges, and Prohaska (1992) asked subjects to recall the day on which they had participated in a telephone survey that had taken place between 1 and 5 weeks earlier. Figure 9.3 shows these data (adapted as described by Neath & Surprenant, 2003: 303) as black circles. Similar patterns are seen when subjects are tested immediately (Healy, 1974) or after 24 hours (Nairne, 1992). The white squares are a fit of a one-parameter model of memory for order, perturbation theory (Estes, 1972). Consistent with the claim of scale invariance, one would not be able to tell the duration of the retention interval just by looking at the figures; one needs additional information.

These three examples all demonstrate that certain memory phenomena are scale invariant, that the principles that govern them do not change solely as a function of the time scale. Our final principle, then, may be stated as

(10) Memory principles are invariant

By this, we mean to imply not just time-scale invariance, but that all of the previous nine principles apply to all of memory, regardless of the hypothetical underlying memory system, the time scale or the processing.

**Summary and Conclusions**

Tulving (1983: 265) proposed that the encoding specificity principle (which is represented as...
Principle 1 in our accounting) ‘holds for all phenomena of episodic memory … [and] probably also holds for semantic memory … The postulated generality implies that such interactions could be demonstrated with all kinds of rememberers, to-be-remembered events, encoding operations, and retrieval information, in appropriately controlled and sufficiently sensitive experiments.’ The encoding specificity principle has been attacked as untestable (see Tulving, 1983, for a review) and, indeed, all the principles noted above are subject to similar attacks. In response, Tulving makes the point that although a principle might be ‘untestable’ in the sense that one could never test all possible experiments, this is unrelated to whether the principle has empirical support. We have presented only a fraction of the studies that support the principles in the current chapter. However, we too want to claim that the principles identified above apply to all of memory. They are not restricted by time scale, by type of processing or by type of structure. These principles are, we claim, invariant.

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NOTES

1 For simplicity and due to space constraints, we omit consideration of factors that occur after encoding but before retrieval. Such factors can and do affect memory performance (e.g. Proctor & Fagnani, 1978).

2 McGeoch’s (1932) three-factor theory of forgetting focused on response competition, set, and altered stimulating conditions. All three can be seen as forms of interference.

3 The paired associate terminology is a useful schematic for comprehending retroactive and proactive interference, but it is oversimplified in that it assumes the cue A will be processed in exactly the same way at both study and test, which is rarely the case.

4 Note that Luce’s (1963) choice rule predicts a form of cue overload in a way that does not attribute an intrinsic mnemonic property to a cue.

5 Within the working memory framework (e.g. Baddeley, 1986), the proposed temporal divisions differ. The articulatory control process and the phonological store are no longer factors after as few as 2 to 4s. It has recently been proposed that an episodic buffer handles memories in situations that require longer storage than this, but shorter than long-term memory (Baddeley, 2000). This view still requires fundamental changes in principles over a very small time scale, but whether one or two or three changes are required depends on the particular version of the theory.

6 There is one apparent departure from the ratio rule. Cowan, Saults, and Nugent (1997) presented data that suggested that the absolute amount of time that has passed before a memory test takes place does have an effect on subsequent performance even when the temporal information is held constant (i.e. the ratios remain constant). However, Cowan, Saults, and Nugent (2001: 326) performed further analyses and concluded that ‘we have failed to find clear evidence of decay in a situation that has often been viewed as one of the simplest paradigm cases for decay, namely in two-tone comparisons.’

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