1 What Are the Memory Systems of 1994?

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> Imagine that our present civilization develops more or less peacefully and that the world is still intact a thousand years from now. Imagine further that you could visit the future world and bring back with you, among other things, the answer to one crucial question about human memory. What would the question be, and why?... Our question has to do with the subdivisions of human memory. We assume, along with most other students of the subject, that memory is not a monolithic, unitary entity and that what we label memory in fact represents a number of separate but interacting systems. All these systems have a common function: They make possible the utilization of acquired and retained knowledge. It is their differences that are the subject of our crucial question: How can we characterize the various systems that comprise human memory? (Schacter & Tulving, 1982, pp. 33–34)

When we offered the foregoing reflections over a decade ago, we hoped to arouse the interest of contemporary students in an issue that we believed was scientifically important, although it had not been systematically pursued: the nature and number of memory systems. Understanding of this issue seemed to us then vital to, and perhaps a necessary condition of, progress in memory research. It is even more so today. If memory can indeed be fractionated into multiple systems and subsystems that differ fundamentally from one another, then general theoretical proposals and ideas about the nature of memory are not going to be worthwhile; they have to be qualified with respect to particular systems and subsystems. Hence the choice of our crucial question for the imaginary time traveler.

Even a decade ago, various proposals concerning multiple kinds of memory existed. Indeed, the debate concerning short-term versus long-term memory stores that flourished during the 1960s and 1970s had already passed its peak. During the past ten years, however, discussions concerning the nature and number of memory systems have become more pervasive and intense. They now occupy an unprecedented prominence in cognitive, neuropsychological, and neurobiological research. A large body of empirical observations has accumulated, numerous distinctions among memory systems have been proposed, and discussions of the conceptual and metatheoretical issues surrounding the memory-systems enterprise are gathering force.

1 MULTIPLE FORMS OF MEMORY: SOME HISTORICAL PERSPECTIVES

1.1 Early Speculations

Systematic analysis and discussion of multiple forms of memory is, for the most part, a relatively recent development in memory research. In the experimental study of human memory, for example, the issue was first brought into sharp focus by the debate over short-term versus long-term memory that prospered during the 1960s and 1970s (e.g., Atkinson & Shiffrin, 1968; Melton, 1963; Waugh & Norman, 1965). Discussions of multiple long-term memory systems only began in earnest during the mid 1970s, following the introduction of the distinction between episodic and semantic memory (Tulving, 1972). In the study of nonhuman animals, sustained interest in the issue of memory systems was sparked by several seminal publications in the mid 1970s (Gaffan, 1974; Hirsh, 1974; Nadel & O'Keefe, 1974; O'Keefe & Nadel, 1978). Nevertheless, as noted by several contributors to this volume (see especially the chapters by Eichenbaum and Nadel), there are a number of nineteenth- and twentieth-century antecedents to the distinctions among memory systems that have been put forward recently. Historical overviews can be found in Herrmann and Chaffin (1988), Polster, Nadel, and Schacter (1991), Schacter (1987a), and Schacter and Tulving (1982), and we draw on them to develop the present account.

As with many other scientific ideas, it is difficult to specify unambiguously the first articulation of the hypothesis of multiple memory systems. Certainly, distinctions among types of information retained in memory are about as old as theorizing about the nature of memory itself. For example, the basic distinction between memory and knowledge, which represents one of the diagnostic features that distinguish episodic and semantic memory systems, is traceable in some form to the Greek philosophers and is present in the analyses of numerous seventeenth- and eighteenth-century philosophers (see Herrmann & Chaffin, 1988). Similarly, philosophers of this latter period such as G. W. Leibniz and J. F. Herbart distinguished between conscious and unconscious forms of memory (see Schacter, 1987a, for discussion).

What was missing from these early discussions, however, was the idea of multiple memory systems, that is, the idea of different neurocognitive (brain/mind) structures whose physiological workings produced the introspectively apprehensible and objectively identifiable consequences of learning and memory. Early ideas were based on casual observations; they could be readily dismissed by anyone who decided to wield Ockham's razor. In contemporary discussions of memory systems, as we will discuss at greater length in section 3, the tight coupling between psychological and physiological evidence plays a crucial role; neither alone is decisive.

The fact that concern with the neural mechanisms underlying psychological manifestations of memory and knowledge was absent in the earliest thought about different forms of memory is not surprising. On the one hand, there was little understanding of the brain at the time, and thus the neural influence was necessarily absent. On the other hand, the doctrine of associationism held almost universal sway over philosophical and psychological thinking about memory, rendering any kind of physiologizing superfluous. Moreover, the associative doctrine was dominated by the idea that all expressions of memory could be attributed to the functioning of a single associative mechanism, an idea that is still around even today (for discussion, see Anderson & Bower, 1973; Schacter, 1982).

1.2 Nineteenth-Century Perspectives

In considering the historical antecedents of the hypothesis of multiple memory systems, we are interested principally in those theorists who articulated the idea that the acquisition and retrieval of different kinds of information depends on distinct mechanisms characterized by different properties and principles of operation. Our historical investigations indicate that the initial expressions of this approach are found in the writings of two early nineteenth-century French thinkers: Maine de Biran and Francois Joseph Gall.

Marie François Pierre Gonthier de Biran, known professionally as Maine de Biran, was an eminent French philosopher of the day who wrote a number of treatises in the first two decades of the nineteenth century. For our purposes, his most significant work is a monograph published originally in 1804 and entitled "The influence of habit on the faculty of thinking" (Maine de Biran, 1929).

One of his theses was that the development of habit with repetition is accompanied by increasing automaticity of execution and decreasing conscious awareness, so that habits are eventually carried out with "such promptitude and facility that we no longer perceive the voluntary action which directs them and we are absolutely unaware of the source that they have" (1929, p. 73). Though he argued at great length for the importance of habit in understanding human behavior, Maine de Biran recognized that habit is not the basis of all forms of learning and memory. He went on to postulate the existence of three separate kinds of memory that depend on different mechanisms and can be characterized by different properties: mechanical, sensitive, and representative memory. Mechanical memory, he said, is involved in the acquisition of motor and verbal habits and operates largely at a nonconscious level; sensitive memory (sometimes referred to as sensory memory) is involved in acquiring feelings, affects, and fleeting images, and it too frequently operates nonconsciously; representative memory is involved in conscious recollection of ideas and events.

Maine de Biran was quite specific in distinguishing among these three forms of memory: "If signs ['sign' is his term for a motor-response code] are absolutely empty of ideas or separated from every representative effect, from whatever cause this isolation may arise, recall is only a simple repetition of movements. I shall call this faculty for it mechanical memory. When the ... recall of the sign is accompanied or immediately followed by the clear appearance of a well circumscribed idea, I shall attribute it to representative memory. If the sign expresses an affective modification, a feeling or even a fantastic image whatsoever, a vague, uncertain concept, which cannot be brought back to sense impressions ..., the recall of the sign ... will belong to sensitive memory" (1929, p. 156).

Maine de Biran argued that mechanical and representative memory serve "two essential but very distinct functions," explicitly noting that "one of these functions can be exercised without the other" (1929, pp. 209, 210). He also argued that sensitive memory differs sharply from representative memory, contending that "the language of sensations and generally of feeling cannot be representative" (1929, p. 164). Although he treated sensitive memory as a third, distinct form of memory, he also acknowledged that "the gradation which separates mechanical memory from sensitive memory is, in certain cases, rather difficult to grasp" (1929, p. 163). Both mechanical and sensitive memory operate without representation and largely unconsciously. And sensitive memory, like mechanical memory, gives rise to habitual forms of behavior; Maine de Biran contended that sensitive memory is the source of "the most deep-seated, obstinate habits, those the causes of which it would be most important to know in order to avert and moderate their terrible influence" (1929, p. 165). The main difference between the two is that mechanical memory is involved primarily in motor learning, whereas sensitive memory operates in the affective domain: "We attribute to sensory memory every term which, deprived of any representative capacity whatsoever, nevertheless excites some more or less obscure or confused feelings" (1929, p. 168). Maine de Biran, then, distinguished among his three forms of memory with respect to the processes and functions that they perform on the one hand and the type of information that they handle on the other. In many ways his ideas have a surprisingly modern ring to them. The second early forerunner of the perspective of multiple memory systems, Franz Joseph Gall, focused exclusively on differences in the type of information handled by different forms of memory. Gall is well known today largely because of his association with phrenology, but recent authors have attempted to disentangle his useful contributions to neuropsychological thinking from the less useful phrenological component of his work (Fodor, 1983; Young, 1990). Gall's arguments for multiple forms of memory emerged as a natural consequence of his argument for what Fodor (1983) has called "vertical" mental faculties: content- or domain-specific modules that operate on particular kinds of information. These vertical faculties can be contrasted with what Fodor has labeled "horizontal" faculties, which cut across content domains, such as unitary faculties of memory, judgment, perception, and so forth. Gall contended that apparently monolithic (horizontal) faculties should be further subdivided into multiple, content specific (vertical) ones: "Perception and memory are only attributes common to the fundamental faculties, but not [among] the fundamental faculties themselves" (1835,

p. 251). Gall divided his faculties according to particular content domains (e.g., music, mathematics) and assumed that each specialized faculty has its own memory. To support this argument, Gall drew heavily on observations of within- and between-individual differences in memory for particular kinds of information. Noting that some individuals have excellent memory for places but not music whereas others exhibit the opposite pattern, Gall contended such differences could not exist if memory constituted a unitary faculty. He expressed the general point clearly: "If perception and memory were fundamental forces, there would be no reason why they should be manifested so very differently, according as they are exercised on different objects. There would be no reason why the same, and, in fact, every individual, should not learn geometry, music, mechanics and arithmetic, with equal facility since their memory would be equally faithful for all these things" (1835, pp. 251–252).

As far as we can ascertain, the ideas put forward by Maine de Biran and Gall failed to generate widespread interest in the multiple forms of memory hypothesis. To be sure, the general proposal that motor memory or habit should be distinguished from recollection of personal experiences can be detected in the later writings of several nineteenth-century authors. They included William Carpenter, who wrote one of the earliest treatises on physiological psychology (1874, pp. 524–525); Ewald Hering, who argued in a well-known 1870 lecture for the existence of an "organic memory" involved in heredity, development, and habit (for discussion of other proponents of this idea, see Schacter, 1982); and William James, who treated memory and habit in separate chapters of his 1890 classic, *Principles of psychology* (see Eichenbaum, this volume). The most extended discussion of the notion that recollection and habit should be viewed as fundamentally different kinds of memory did not appear until the early twentieth-century, when the French philosopher Henri Bergson devoted most of his celebrated monograph *Matter and memory* (1911) to the elaboration of a single idea: "The past survives under two distinct forms: first, in motor mechanisms; secondly, in independent recollections" (p. 87). Maine de Biran and his ideas are nowhere mentioned in Bergson's work, although Ellenberger (1970) has suggested that he influenced Bergson's thinking.

Gall's ideas were elaborated by fellow phrenologists, such as Spurzheim (1834), who also relied on observations of within-individual variations in memory abilities to make the case that each mental faculty has a separate memory: "A person may, therefore, possess an excellent memory of one kind, be very deficient in another, and be without a third entirely" (p. 84). A number of later writers too endorsed this general logic and reiterated the same conclusions (see Bascomb, 1901; Luys, 1887). As was the case with Maine de Biran, Gall's arguments for multiple forms of memory were largely ignored by later students, perhaps because the kind of evidence that he cited to support it could be more parsimoniously interpreted as a consequence of an individual's differing levels of prior knowledge about different subjects. Ladd, for instance, noted that "the diverse forms of memory are chiefly to be ascribed to diverse tastes and habits, and the interest and attention which accompany them" (1909, p. 138; see also, Fodor, 1983, for a similar argument). Although they appear to be the earliest proponents of a nonunitary view of memory, Maine de Biran and Gall were not the only nineteenth-century thinkers to advance the idea forcefully. Around the middle of the century the hypothesis surfaced again, this time supported by a new and powerful kind of empirical evidence: specific impairments of particular types of memory in brain-damaged patients. The first brain scientist to advance a nonunitary memory hypothesis on the basis of neuropsychological evidence was the French physician Paul Broca. His seminal observations on selective loss of expressive linguistic abilities in an otherwise intact patient, referred to as Tan, are usually discussed in the context of research on aphasia and language processing. However, as Rosenfield (1988) has argued, Broca in fact conceptualized Tan's inability to generate language output in terms of damage to a particular kind of memory: "Is it not, after all, a kind of memory, and those who have lost it have lost, not the memory for words, but the memory of the procedures required for articulating words" (Broca, 1861, cited in Rosenfield, 1988, p. 18). Broca elaborated on this idea in relation to language development: "This gradual perfecting of articulated language in children is due to the development of a particular kind of memory which is not a memory for words, but a memory for the movements necessary for articulating words. And this special memory is in no way related to other memories nor to intelligence" (cited in Rosenfield, 1988, p. 20).

A decade after the publication of Broca's pathbreaking paper, the German neurologist Carl Wernicke published his observations of an aphasic condition in which patients had no difficulty producing linguistic output but had severe comprehension problems. As Rosenfield has noted, Wernicke interpreted these symptoms in terms of damage to a special memory center for auditory word representations, a center that was distinct from the memory center damaged in Broca's case. This view was accepted and developed at length by the German physician Ludwig Lichtheim, who contended that "we may call 'centre of auditory images' and 'centre of motor images,' respectively, the parts of the brain where these memories are fixed" (1885, p. 435; see also Rosenfield, 1988, p. 22). Lichtheim applied his view of multiple memory centers to neurological deficits of reading and writing as well. The French psychologist Theodule Ribot too drew on these kinds of observations to argue for the hypothesis of multiple memories in his well known book *Diseases of memory* (1882). Ribot contended that "if, in the normal condition of the organism, the different forms of memory are relatively independent, it is natural that, if in a morbid state one disappears, the others should remain intact" (1882, p. 142). He went on to suggest that verbal memory, visual memory, and auditory memory are all separate from and independent of each other.

In summary, by the close of the nineteenth century, various hypotheses concerning multiple forms of memory had been advanced and discussed. As Polster, Nadel, and Schacter (1991) point out, however, interest in the issue disappeared rather quickly. With the exception of Bergson's (1911) book, it is difficult to find any relevant discussions of multiple forms of memory during the first half of the twentieth century.

1.3 The Modern Era

In the two decades following World War II, a variety of ideas and hypotheses concerning multiple forms of memory began to appear in the literatures on animal and human learning and memory. The earliest and best known of these hypotheses was advanced by Tolman (1948). He attempted to resolve his ongoing debate with Hull (1933) concerning place learning versus response learning by arguing that, as stated in the title of his 1948 paper, "There is more than one kind of learning." Tolman contended that place and response learning depend on different mechanisms, so there is no need to choose one or the other as the sole or exclusive basis of learned performance. As Nadel (1992, this volume) has pointed out, however, Tolman's arguments failed to ignite widespread interest in the issue of multiple forms of learning, perhaps because of a later, influential paper by Restle (1957) that argued forcefully that place and response learning do not differ fundamentally.

The issue was brought into much sharper focus during the 1970s. The decisive impetus for these developments was provided by the discovery of the important role played in memory by brain regions in the medial temporal lobes, including the hippocampus. A key component of this new realization was Scoville and Milner's (1957) description of a young man, known by the initials H.M., who had undergone a complete bilateral resection of the medial temporal lobes for relief of intractable epilepsy. H.M. exhibited a severe and pervasive impairment of his ability to remember recent experiences and acquire new information, even though his overall level of intelligence remained above average and other perceptual and cognitive functions were unaffected. The selective nature of H.M.'s impairment suggested a special role for the medial temporal region in memory. In the search for an appropriate animal model of the kind of brain damage and cognitive impairment that H.M. exhibited, a number of authors advanced the idea that the hippocampus participates in a kind of memory that can be distinguished empirically, functionally, and neuroanatomically from other kinds of memory (e.g., Gaffan, 1974; Hirsh, 1974; Nadel & O'Keefe, 1974; O'Keefe & Nadel, 1978; Olton, Becker, & Handelmann, 1979; Weiskrantz, 1978). The general conclusion that emerged from these early studies was that rats with hippocampal damage exhibit normal learning on certain kinds of memory tasks despite severely impaired performance on other tasks. Particularly influential were the distinctions between taxon versus locale memory (O'Keefe & Nadel, 1978) and working versus reference memory (Olton et al., 1979), which set the stage for the development in the 1980s of related distinctions based on data from studies of nonhuman animals (see Eichenbaum, Fagan, & Cohen, 1986; Mishkin & Petri, 1984; Packard, Hirsh, & White, 1989; Rudy & Sutherland, 1989; Zola-

Morgan & Squire, 1984). The development of these distinctions over the subsequent years and their current status are discussed in the chapters by Eichenbaum, Lynch and Granger, Nadel, Rudy and Sutherland, and Squire.

In the literature on human memory too, a number of distinctions among forms of memory appeared during the postwar years. As noted earlier, the distinction between short-term and long-term memory was diligently pursued during the 1960s and 1970s. Various kinds of experimental and neuropsychological evidence suggested that retention across delays of seconds and minutes is based on a fundamentally different mechanism than is retention across delays of hours, days, and weeks; the most detailed expression of this idea can be found in the well-known model of Atkinson and Shiffrin (1968). Although serious objections to this "modal model" of short-term versus long-term memory were made (see Craik & Lockhart, 1972; Crowder, 1982), the conceptual core of the idea appeared again in a new and more powerful form with the advent of the working-memory model advanced by Baddeley (e.g., Baddeley & Hitch, 1974; see also Baddeley, 1992a, 1992b, this volume).

It is perhaps less well appreciated that a number of distinctions among forms of long-term memory were proposed at around the same time as the distinction short-term versus long-term memory. For example, Reiff and Scheerer (1959) discussed at great length a distinction between remembrances (recollections of contextually specific, personally experienced events) and memoria (general knowledge, skills, and habits), a distinction that had been foreshadowed a decade earlier by Schactel's (1947) distinction between autobiographical memory and practical memory and by Ryle's (1949) philosophical distinction between knowing how and knowing that. The neurologist Nielsen (1958) used observations of dissociations among forms of memory in brain-damaged patients as a basis for offering a conceptually similar distinction between temporal memory and categorical memory. A decade later, Bruner distinguished between "memory with record" (recollection of the "facts we acquire and events we experience in daily life") and "memory without record" ("some process that changes the nature of an organism, changes his skills, or changes the rules by which he operates, but are virtually inaccessible in memory as specific encounters") (1969, p. 254).

None of these distinctions among forms of human long-term memory exerted a major or even detectable effect on the course of research and theorizing. The establishment of the hypothesis of multiple memory systems as a major research focus occurred only by the confluence of three initially unrelated developments from the late 1960s to the early 1980s. First, neuropsychological research during the 1960s and 1970s revealed, quite surprisingly, that severely amnesic patients retain some learning and memory abilities. Studies by Milner and Corkin and colleagues (e.g., Milner, Corkin, & Teuber, 1968) demonstrated normal or near-normal motor-skill learning in the amnesic patient H.M., which allowed them to infer that motor learning depends on a system different from other forms of memory. Experiments by Warrington and Weiskrantz (1968, 1974) showed that amnesics relatively retained their ability to perform on fragment-cued tests of previously encountered verbal and pictorial material, despite their greatly impoverished ability to recognize these materials as previously encountered. The deeper significance of these studies for the ensuing debate on memory systems was not immediately obvious; it became clear only gradually in the course of subsequent research (for the unfolding story of this clarification, see Cohen & Squire, 1980; Graf, Mandler, & Haden, 1982; Graf, Squire, & Mandler, 1984; Jacoby & Dallas, 1981; Mandler, 1980; Polster, Nadel, & Schacter, 1991; Rozin, 1976; Schacter, 1987a; Squire, 1987; Tulving, Schacter, & Stark, 1982; Warrington, 1979; Warrington & Weiskrantz, 1982). But Warrington and Weiskrantz's (1968, 1970, 1974) findings pointed to the possibility that different kinds of memory are differentially susceptible to lesions of the hippocampus and related structures that are typically damaged in amnesic patients.

A second relevant development was the reemergence of the distinction between remembrances and memoria, under the names of episodic and semantic memory, as "two parallel and partially overlapping information processing systems" (Tulving, 1972, p. 401). Although the 1972 paper focused on the heuristic value of the distinction and had little hard evidence to point to in support of the idea, it served to stimulate discussion and debate concerning the usefulness of postulating separate episodic and semantic systems (see Anderson & Ross, 1980; Herrmann & Harwood, 1980; Kinsbourne & Wood, 1975; Schacter & Tulving, 1982; for a review, see Tulving, 1983).

The third development was, to a large extent, a direct consequence of the previous two: studies of normal subjects that revealed striking dissociations between what we would now refer to as explicit and implicit memory tests (Graf & Schacter, 1985; Schacter, 1987a). On explicit memory tests, such as free recall, cued recall, and recognition, subjects engage in conscious or intentional recollection of previously studied information. By contrast, on implicit memory tests, such as identification of briefly flashed words or completion of incomplete word stems and fragments, no reference is made to a prior study episode; subjects simply perform the task as best they can. Memory is inferred from changes in task performance, typically referred to as priming effects, that are attributable to previously studied information. Several studies published during the early 1980s, all of them motivated to some extent by previous observations of amnesic patients and a concern with the distinction between episodic and semantic memory, revealed that priming effects on implicit memory tests could be dissociated experimentally from performance on standard tests of recall and recognition (Graf, Mandler, & Haden, 1982; Jacoby & Dallas, 1981; Graf & Mandler, 1984; Tulving, Schacter, & Stark, 1982). These results, along with a large amount of subsequent work, provided strong support for the idea that brain lesions in amnesic patients and experimental task manipulations in normal healthy subjects divide systems subserving different memory functions along natural fault lines. The next decade witnessed an explosion of research on priming in both normal subjects and amnesic patients (for reviews, see Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993; Schacter, 1987a; Schacter, Chiu, & Ochsner, 1993; Shimamura, 1986). The question of whether dissociations between priming and explicit memory require that we postulate multiple memory systems or whether they are more parsimoniously viewed in terms of different processes operating within a unitary system has occupied center stage in the development of this research (for discussion, see Hayman & Tulving, 1989; Roediger, 1990; Schacter, 1992b; Witherspoon & Moscovitch, 1989).

The initial development of ideas about memory systems in the human and animal literatures proceeded on largely independent tracks. As research and theorizing progressed, however, the question naturally arose as to the possibility of interrelating, and perhaps even integrating, the fruits of the experimental and theoretical efforts in these two domains (e.g., Cohen & Eichenbaum, 1993; Olton, 1989; Mishkin, Malamut, & Bachevalier, 1984; Schacter, 1985; Squire, 1992b). One of our goals in inviting contributions from researchers who study humans, monkeys, and rats was to assess the extent to which further cross-fertilization between the human and animal domains is feasible, a point to which we will return later in the chapter.

2 CONCEPTUAL AND LOGICAL ISSUES: WHAT ARE SYSTEMS?

In the preceding sections, we have written rather casually about such notions as "multiple forms of memory" and "different memory systems" and have contrasted them with the "unitary memory" view. But what exactly do these terms mean? And how can we distinguish between the unitary-memory and multiple-memory-systems views, or among different kinds of multiple-systems views? What kinds of evidence are relevant to making such distinctions? These are rather thorny issues that lurk just beneath the surface of most discussions of memory systems. They merit commentary and discussion, even if, as it will turn out, they do not have simple answers.

2.1 Memory: Forms, Processes, Tasks, and Expression

Because of uncertainties in the existing literature, it is helpful to begin with a brief discussion of what memory systems are not. Memory systems are not forms of memory or memory processes or memory tasks or expressions of memory. All these terms, of course, are related to the concept of a memory system, but to minimize terminological and conceptual disorder, they need to be distinguished carefully from it. Two sets of concepts have been frequently confused in the past: forms or kinds of memory (or learning, or learning and memory) and memory systems. These concepts are not equivalent. The latter concept includes the former, but the former does not necessarily include the latter. The criteria for naming a new form of memory are not stringent (see Shettleworth, 1993). Thus, one can think of verbal memory, recognition memory, and olfactory memory as different kinds of memory. Distinctions of this sort can help to describe and organize empirical facts. But these kinds of purely descriptive forms of memory do not constitute memory systems. The criteria for systems are more stringent, as we will discuss shortly.

The notion of a memory process too must be distinguished from that of a memory system. A memory process refers to a specific operation carried out in the service of memory performance. Processes such as encoding, rehearsal, activation, retrieval, and the like are constituents of memory systems but are not identical with them (see, for example, Johnson & Chalfonte, this volume). Indeed, there are good reasons to believe that particular memory processes may participate in the operations of more than one memory system, as in the "weak" version of memory systems discussed by Sherry and Schacter (1987, p. 440).

It is also helpful to consider the logical status of the construct of memory task in relation to that of memory system. It is not uncommon for memory tasks to be described in terms that imply an isomorphism between them and the system they are purported to tap, for example, free recall is often referred to as an episodic memory task, pursuit rotor learning as a procedural memory task, and so forth. Although these kinds of expressions frequently constitute relatively harmless terminological conveniences that simply allow researchers to talk about their work, they can be deceptively problematic. First, they tacitly encourage the idea that performance on a particular task relies exclusively on the output of a single system. This assumption may occasionally be justified, but in many cases it is highly likely that more than one system contributes to performance on a particular task (see Eichenbaum, 1992, this volume; Jacoby, 1991; Schacter, this volume; Tulving, 1983). Tasks can be viewed as probes that tap some systems more than others, but they should not be unthinkingly equated with the operation of a single system. A second, related point is that inferences about systems should be based on converging evidence from a variety of tasks that rely on the output of a hypothesized system and should not depend solely on results from a single task (Roediger, 1990; Schacter, 1992b; Tulving, 1983; see also the discussion below). Thus the relation between tasks and systems is many-to-many: a variety of different tasks can tap, to varying degrees, the functioning of different underlying systems and subsystems.

Finally, a frequently made confusion concerns the concepts of explicit and implicit memory (Graf & Schacter, 1985; Schacter, 1987a). References to the explicit memory system and the implicit memory system are not uncommon in the literature. Explicit and implicit memory are not systems. These terms were put forward to describe and characterize expressions of memory: "explicit" refers to intentional or conscious recollection of past episodes, whereas "implicit" refers to unintentional, nonconscious use of previously acquired information. Schacter noted specifically that the implicit/explicit distinction "does not refer to, or imply the existence of, different underlying memory systems" (1987a, p. 501). Thus, according to this formulation, implicit and explicit memory, though psychologically and behaviorally distinguishable forms of memory, could either depend on the same underlying memory system or different underlying systems; the question is open and subject to experimental investigation. (For further discussion, see Schacter, 1990, 1992a, this volume.)

2.2 Defining Memory Systems

One of the earliest references to memory systems as a concept whose domain was eventually to exceed that of a form or kind of learning or memory appeared in the 1972 paper by Tulving. The very first appearance of the term "memory systems" in the title of a paper, as far as we know, was in a 1979 article by Warrington in which she discussed neuropsychological evidence supporting a distinction between short-term and long-term memory systems and between two kinds of long-term memory systems: event memory and semantic memory. By 1982 the quest for understanding memory systems was advanced enough that we felt it appropriate to speculate that the then recently discovered new form of learning now called perceptual priming is based not on episodic or semantic memory but rather on "some other, as yet little understood, memory system" (Tulving, Schacter, & Stark, 1982, p. 341). The concept of a system was only vaguely specified during these early years of the development of the systems approach. It was only when the critics of this approach began asking the question, What does a memory system mean, anyhow? that attempts were made to confront the issue explicitly.

Like any other complex concept, that of memory system can be defined broadly, narrowly, or in between. One broad definition is that it is "a set of correlated processes" (Tulving, 1985, p. 386). The advantage of this and other similar broad definitions lies in their general acceptability and the fact they allow us to ask further, more specific questions. The disadvantage is that they do not direct, guide, or constrain research, or specific questions that researchers may pose, in any way.

A narrower early formulation (Tulving, 1984) proposed that different memory systems are distinguished in terms of

- different behavioral and cognitive functions and the kinds of information and knowledge they process,
- operations according to different laws and principles,
- different neural substrates (neural structures and neural mechanisms),
- differences in the timing of their appearance in phylogenetic and ontogenetic development, and
- differences in the format of represented information (the extent to which the aftereffects of information acquisition represent the past or merely modify future behavior or experience).

Thus a memory system is defined in terms of its brain mechanisms, the kind of information it processes, and the principles of its operation (see also the section entitled "The concept of system" in Tulving, 1985, p. 386).

Sherry and Schacter (1987) approached the concept of memory systems from an evolutionary perspective, proposing that different systems evolve as special adaptations of information storage and retrieval for specific and functionally incompatible purposes. They defined a memory system as "an interaction among acquisition, retention, and retrieval mechanisms that is characterized by certain rules of operation" (p. 440) and suggested that the term multiple memory systems "refers to the idea that two or more systems are characterized by fundamentally different rules of operation" (p. 440). They also included the specification of brain structures as a necessary component of the definition of a system, although, as in Tulving's (1984) case, this is more of a prescriptive than a descriptive declaration. Sherry and Schacter (1987), unlike Tulving (1984), did not include the criterion that different systems must process different kinds of information, a point to which we will return shortly.

More recently, Nadel (1992, this volume) has focused on similar issues in the section of his contributions to this project entitled "What is a system"? He specifies two criteria for distinguishing among systems: computational differences in different neural architectures (approximately corresponding to Sherry and Schacter's "functional incompatibility") and length of time that information is stored in them. Johnson and Chalfonte (this volume) too have compared and contrasted a number of different criteria by which memory systems and subsystems have been distinguished from one another by various investigators.

The early attempts to clarify the concept of a memory system were meant primarily to launch a debate on the complex issues involved. Now that the debate has begun, we will update and elaborate on the ideas that remain valid. Yet because the concept of a memory system is still in its formative stage and will undoubtedly undergo alterations and modifications as research proceeds, our purpose at this time remains largely unchanged: to stimulate relevant discussion. We present our views of the concept of a memory system, we specify criteria by which candidate systems can be adjudged and evaluated for admission into the domain of hypothetical systems, and we propose an organizational table of memory systems as they appear to us now. Reference to the memory systems of 1994 is meant to underscore our expectation that all these ideas will change in the future. How rapidly they will change and in what ways will necessarily depend on the efforts of scientists who decide to join the enterprise.

2.3 Three Criteria of a Learning and Memory System

We specify three broad criteria that we deem useful for identifying different memory systems. These can be used to make decisions about what is and what is not a memory system and about how different systems are related to one another. We expect that whenever reference is made to a putative memory system, these three criteria should be satisfied.

Our current list of the criteria includes class-inclusion operations, properties and relations, and convergent dissociations. These criteria, like everything else in our proposal, are up for grabs, and we expect others to come up with additional criteria or with ideas for improving the suggested ones.

Class-inclusion operations An intact memory system enables one to perform a very large number of tasks of a particular class or category, regardless of the specific informational contents of the tasks. Thus a short-term ("working") memory system allows the individual to hold any sample of certain kinds of information (e.g., verbal or verbalizable information) in a buffer storage and to perform a variety of cognitive operations on the information (Baddeley, 1992a, this volume). As long as the system is intact, it operates class-inclusively, in the sense that it can process any particular input or information of the specified kind. Another system, episodic memory, enables people to remember past happenings from their own lives even after long retention intervals, a category of tasks beyond the reach of working memory. Episodic memory can be described as the conscious recollection of personally experienced episodes.

If an environmental condition affects the brain in such a fashion that a whole class of memory functions is selectively altered (e.g., eliminated), the alterations can be thought of as a consequence of changes in the operations of a particular system. The brain regions and mechanisms thus involved are crucial neural components of the system. We take the normal waking adult brain as the reference and define changed brain states with respect to it. Brain-state changes may be brought about through a variety of means, including development (in infancy, childhood, and old age), sleep and sleep deprivation, effective hypnosis, emotional trauma, clinically significant depression, ingestion of a drug, other kinds of pharmacological interventions (such as general anaesthesia), disease, injury, and surgically produced lesions. By a "whole class of memory functions" we mean both particular, objectively identifiable memory processes (such as encoding, recoding, rehearsal, consolidation, storage, and retrieval) and particular kinds of processed information (such as perceptual stimuli, referential symbols, and execution of motor acts).

It is important to emphasize that the stipulation of a category, or whole class, of operations must be accompanied by an insistence on selectivity; that is, while specifiable memory functions subserved by a given system are affected by particular changes in the brain state, nonmemory functions, and memory functions subserved by other memory systems, must not be similarly affected. If all cognitive functions are impaired as a result of brain injury or disease, then any whole class of memory operations also is, which thus satisfies the criterion of class inclusiveness. But the lack of selective specificity invalidates the inference that a memory system has thus been identified, because factors operating outside of the memory system in question may be responsible for the observed effects. We recognize, of course, that many contemporary theorists have intentionally blurred the distinction between processing and memory (e.g., Craik, 1983; Kolers & Roediger, 1984; McClelland & Rumelhart, 1986), and that clean distinctions between memory and nonmemory functions are not always easy or even desirable to draw (for discussion, see Nadel, 1992, this volume; Schacter, 1987b). However, it is well known that memory impairments can exist without global deterioration of cognitive processing—the amnesic syndrome is a clear example—and so we wish to maintain an important role for selectivity when assessing class inclusion in memory systems.

These conditions leave considerable latitude in determining the identity of individual systems and leave open to a large degree the question of how class-inclusive some selective effects must be before we are justified in proposing a candidate system. Nevertheless, they encourage theorists to consider what we think are critical properties of systems, and to this extent they should help to accelerate progress in thinking about systems.

Properties and relations A memory system must be described in terms of a property list, that is, an enumeration of its features and aspects by which its identity can be determined and its relation to other systems can be specified. For example, the reader may recall that Maine de Biran specified his proposed forms of memory in terms of descriptions of their various properties. Early examples of property lists from the contemporary era can be found in a number of publications, including O'Keefe and Nadel's (1978) description of the properties of taxon and locale systems, Tulving's enumeration of the properties of procedural memory (1983, pp. 8–9) and listing of the "diagnostic features" of episodic and semantic memory (1983, p. 35), and Tulving and Schacter's listing of properties of the perceptual representation system (PRS) (1990, p. 305). Most of the contributors to the present volume too describe and elaborate property lists of hypothesized memory systems.

The properties of any system include rules of operation, kind of information, and neural substrates. In addition, because memory systems presumably evolved as specializations, and hence serve biologically useful functions, the property list of any system should include one or more statements about what the system is for (see, for example, Tulving, 1983, pp. 52–53, for a preliminary attempt). As noted earlier, Sherry and Schacter argued on evolutionary grounds that multiple memory systems evolved because they serve different and functionally incompatible purposes. They write "Evolutionary change and the various adaptations that result could occur within a unitary memory system. The reason, we will argue, that the evolutionary outcome has been multiple memory systems rather than a single system capable of serving many functions is that the memory system that effectively solves some environmental problems may be unworkable as the solution to others. The kind of memory used by birds, for example, to learn the songs that they sing, or humans to learn certain skills, may be incompatible with an effective solution to other memory problems." (1987, p. 443)

Sherry and Schacter went on to suggest that when proposing a new memory system, it is important to consider whether the system performs functions that are incompatible with those performed by other systems. They acknowledged that it is not a straightforward task to determine whether functional incompatibility exists, yet emphasized the importance of including functional considerations in discussions of multiple memory systems. We agree with this emphasis on functional considerations and view it as a natural component of our more general concern with properties and relations of memory systems.

At the present time, because of the relative immaturity of the classification enterprise, most of the items will be included in such property lists on the basis of intuition and informed speculation rather than on the basis of objective rules, and hence the lists may well be rather ill defined and even intolerably vague. This is where we expect time to come to our aid. The clarity of the lists will be enhanced and the rules of the admission of particular properties into lists will be sharpened as research on memory systems proceeds. Also at the present time, the rules of operation of different systems are typically specified solely in psychological terms. One of the future research objectives in classifying learning and memory will be the inclusion of physiological, chemical, and physical mechanisms in the description of the operations of different memory systems. Similar considerations apply to the description of the information that different systems process: even at the level of a highly abstract analysis, indicated by the extreme inclusiveness of such terms as "information" and "processing," our currently available vocabulary is rather primitive and in obvious need of refinement and elaboration.

Our second criterion, then, holds that to suggest a candidate for a new memory system, a person must be able to do two things, among others: list a number of properties of the candidate system, and specify something about the relations among it and already existing (invented or accepted) systems in terms of these properties. Like all other entities in the known universe, the postulated system will share some properties in common with previously proposed entities in its reference class (i.e., other systems) and will differ with respect to others.

Convergent dissociations Dissociations between task performances that different systems differentially contribute to constitute a necessary condition for the postulating independent systems. Such postulation is clearly not warranted in the absence of such relevant evidence, that is, where there is no empirical basis for thinking that something is fundamentally different about how memory works in two different situations.

A single kind of a dissociation between the performance of two memory tasks is not sufficient for postulating different memory systems. If it were, those critics of multiple-systems views who have expressed alarm at the prospects of mindless proliferation of systems as more and more (and more and more specific) dissociations are observed (e.g., Roediger, Rajaram, &

Srinivas, 1990) would have a valid argument on their side. But no system has ever been proposed on such flimsy grounds, so the critics' concern is ill founded. Memory systems are postulated on the basis of *converging* dissociations: dissociations of different kinds, observed with different tasks, in different populations, and using different techniques (Schacter, 1992b; Tulving, 1983).

Relevant dissociations can be observed in many forms: functional dissociations on tasks alleged to tap different systems, neuropsychological dissociations that involve contrasts between spared and impaired performance in relevant patient populations, or stochastic independence between tasks that are sensitive to the operation of different systems. Ideally, one would like to see dissociations in which multiple tasks that tap the same system are contrasted with multiple tasks that tap different systems (e.g., Roediger, Rajaram, & Srinivas, 1990). We emphasize convergent dissociations as a way of highlighting the point that the case for a particular system is strengthened in proportion to the amount of independent evidence from separate sources that can be marshalled for it, i.e., evidence from multiple tasks, experimental manipulations, patient populations, and so forth.

To the extent that analogies can help to clarify new ideas, it may be worthwhile to mention that we think of memory systems as comparable to such systems as the economic system of a modern state. One can also think of the frequently invoked notion of subsystems of memory as analogous to such systems as the transportation system or communication system. Memory processes can be seen as analogous to components of the larger systems and subsystems, i.e., (constructing) highways in the transportation system or (installing new) telephone cables in the communication system. In other words, in our view, memory systems are large, elaborate, and complex. They have fuzzy boundaries, have overlapping constituent processes, and interact with one another in intricate ways (see Johnson & Chalfonte, this volume). For example, as the transportation system can be used in the service of the communication system and parts of the communication system can be used to transport goods from one location to another, so too, for example, the semantic memory system may provide information about past events, and the episodic system can provide knowledge about the world, although these are not the functions for which they are specialized (see, e.g., Rajaram, 1992; Tulving, 1987).

2.4 Memory Systems versus Subsystems or Forms of Memory

With the three general criteria for memory systems in mind, it is useful to consider next issues pertaining to the notion of a memory subsystem and the related issue of forms or kinds of memory, which we discussed earlier.

The terms "memory system" and "memory subsystem" are sometimes used interchangeably. For example, Johnson and Chalfonte (this volume) use the term "subsystem" very much in the general spirit of our use of the term "system." Other investigators have used "subsystem" within the context of a hierarchical arrangement to indicate a subordinate relation of a subsystem to a system, as in Schacter's (1992a, 1992b, this volume) discussion of the perceptual-representation system and its various subsystems.

Although the question of exactly what is a system and what is a subsystem is still quite fluid and although we do not wish to rigidly insist on any particular usage now, we do think that it is useful at this early stage of analysis to suggest a distinction between a system and a subsystem. Specifically, whereas systems are characterized by different rules of operation, as embodied in property lists and relations, subsystems, we suggest, are distinguished primarily by different kinds of information (subsystems share the principal rules of operations of their superordinate system, but they differ from one another with respect to the kinds of information each one processes) and different brain loci (although subsystems are all instantiated in the neural circuitry that defines their superordinate system, they can occupy distinct loci within the broader network). This general approach is consistent with ideas suggested previously by Sherry and Schacter (1987), who contended that the existence of domain-specific modules or subsystems that handle different kinds of information and have distinct neural bases but operate according to similar rules does not necessitate postulating multiple memory systems. Our view allows us to conceptualize the overall organization of memory in the form of a hierarchy, with systems and subsystems specifiable at different levels. Whereas postulating of full-blown systems requires satisfaction of all three of our major criteria, postulating of subsystems requires satisfaction of the first (class inclusion operations) and third (converging dissociations) but not the second (property lists and relations, with the corresponding emphasis on different rules of operation).

In addition to allowing a principled distinction between systems and subsystems, our criteria also provide a basis for distinguishing between a memory system or subsystem, on the one hand, and a form or kind of memory on the other. As noted earlier, numerous forms of memory have been discussed, and it is easy to confuse the relatively neutral description of a form of memory with a theoretical statement about the existence of an underlying memory system. Consider again the distinction between explicit and implicit memory. As noted earlier, the terms "explicit" and "implicit" memory are descriptive concepts that are concerned with different ways in which memory can be expressed, but it is not uncommon in the literature to see references to the "explicit memory system" and the "implicit memory system." In light of our three criteria, however, it is relatively easy to see that explicit and implicit memory should not be granted the status of memory systems. While one can find evidence of converging dissociations for separating explicit and implicit memory, the explicit/implicit distinction fails the criteria of class inclusion and properties/relations: explicit and implicit memory do not refer to a "whole class of memory functions" that can be characterized by extensive property lists but rather refer to two different ways in which memories can be expressed.

Thus, in light of our criteria, explicit and implicit memory are more properly viewed as forms of memory than memory systems.

Similar considerations apply to the idea that just about any kind of neuropsychological dissociation can be taken as evidence for a new memory system. Roediger (in press), for example, found patients with extremely specific deficits in accessing particular kinds of knowledge (e.g., impaired knowledge of red fruits) and wondered whether such dissociations imply the existence of a "red fruit" memory system. However, these kinds of observations do not meet any of our three criteria and hence are easily excluded as providing evidence for new memory systems. Similarly, Roediger (in press) noted that women typically deliver their second child faster than their first, and he suggested that this reproductive priming might provide evidence for yet another distinct memory system. However, application of our three criteria makes it difficult to sustain this argument: the criterion of class inclusion is not satisfied, there is no sensible list of properties and relations, and the suggestion is not based on converging dissociations. While both of the examples offered by Roediger can be reasonably viewed as evidence for distinct forms of memory, our criteria exclude them as candidates for memory systems.

3 CLASSIFICATION OF MEMORY SYSTEMS

We now provide a brief overview of how the various contributors to this volume have approached the problem of classifying memory systems, and then summarize some of our own views in light of the three criteria of the previous section.

3.1 Studies of Animal Learning and Memory

An international symposium was convened in 1984 in Umea, Sweden, to examine the nature of the gulf between animal learning and human memory and to discuss possible ways of bridging it (Nilsson and Archer, 1985). The attendants, productive practitioners in the fields of animal learning and human memory, agreed that a rift existed and that overcoming it might be beneficial to all concerned. This project, which was an attempt to systematize memory systems, also included representatives of the two research domains of neuropsychological or neuroscientific studies of animal learning and cognitive/neuropsychological investigations of human memory. What the ambassadors of these two domains have in common is the conviction, or at least a desire to believe, that memory is not a unitary entity and that classification of learning and memory constitutes a worthwhile scientific problem.

Ideally, one would like to take advantage of this kind of a consensus among the representatives of two otherwise noninteracting disciplines. And, indeed, there is basic agreement among students of human and animal memory on the existence and importance of multiple memory systems. Nevertheless, the chapters in this volume indicate that we still have some way to go before we will possess a classification system that will embrace both animal learning and human memory (for attempts to bridge the gap, see Cohen & Eichenbaum, 1993, and the chapters by Eichenbaum, by Johnson & Chalfonte, and by Squire, this volume). Thus at this time we are obliged to consider classification schemes separately for animal and human research, although it will become apparent that some points of contact between the two literatures are beginning to appear.

Among those who work with animals, a good deal of agreement prevails on at least the broad lines of classification of memory. The predominant multiple-systems orientation is a dichotomy, with the hippocampus and related brain regions providing the line of demarcation. As in Gaffan, 1974, Hirsh, 1974, and Nadel and O'Keefe, 1974, the core idea is that some forms of learning are critically dependent on the hippocampus and related structures, while others are not. This dependence segregates all of memory into two categories, or systems: hippocampus-dependent versus hippocampus-independent (we use the term "hippocampus" here as a shorthand for "hippocampus and related structures" including the entorhinal and perirhinal cortex, fornix, and diencephalic structures such as the thalamic nuclei and mammillary bodies). The systems-oriented theoretical debate in animal learning revolves around how to characterize these two systems, that is, how the hippocampal and nonhippocampal systems express themselves at the level of observable behavior.

Nadel's chapter elaborates the core idea that he and O'Keefe put forward two decades ago: the hippocampus constitutes the basis of a locale system whose primary function is to encode and store spatial information about the environment in a maplike form. By contrast, taxon systems do not depend on the hippocampus and are involved in various kinds of nonspatial learning. Nadel enumerates in some detail the properties and relations of the two types of systems and considers at length the question of whether the hippocampally based system is specifically and exclusively involved in the representation of spatial information.

This latter issue, whether the hippocampally based memory system is defined by its specifically spatial properties, provides a key point of contention for the other dichotomies based on animal research. Eichenbaum argues that the hippocampal-dependent form of memory is a declarative system, defined by relational representations that allow flexible responding in novel situations and permit the organism to compare and contrast different kinds of information. By contrast, the hippocampal-independent form of memory is subserved by various procedural memory systems concerned with rather rigid and inflexible individual representations and responses. In Eichenbaum's view, spatial information constitutes just one type of relational information handled by the declarative system. Shapiro and Olton agree with Eichenbaum that the key characteristic of the hippocampal-dependent system is the formation of relational representations. They further specify a computational mechanism of pattern separation that subserves the generation of relational representations, and they emphasize the importance of this mechanism for a key function of the hippocampal system: reducing susceptibility to associative interference. Shapiro and Olton do not elaborate on the nature of nonhippocampal forms of memory or memory systems, although they indicate clearly that they assume that the latter do exist.

Squire argues for a view, most closely related to that of Eichenbaum, in which a hippocampal-dependent declarative memory system is contrasted with a hippocampal-independent nondeclarative form of memory. Nondeclarative memory, according to Squire, consists of numerous specialized subsystems that support such phenomena as conditioning and skill learning. The critical role of the hippocampal-dependent system is to bind together different kinds of information, and spatial information constitutes one subset of bound representations.

Rudy and Sutherland offer a related dichotomy in which the critical distinction is between a hippocampal-dependent system that computes configural associations and a hippocampal-independent system that computes elemental associations. Elemental associations consist of simple pairwise links between two stimuli (e.g., *a* and *b*), whereas configural associations involve the construction of a higher order, joint representation (e.g., *ab*) that in turn can be linked with other stimuli. The hippocampal-dependent system is a closed memory system effectively shielded from competing irrelevant associations, whereas the hippocampal-independent system is an open system highly susceptible to interference from competing associations.

The strengths and weakness of the foregoing ideas are discussed and compared at length in the chapters by Nadel, Eichenbaum, Shapiro and Olton, Squire, and Rudy and Sutherland; we will not repeat their arguments here. In light of our earlier discussion, however, it is worth noting that the declarative/procedural, declarative/nondeclarative, and locale/taxon distinctions are all in a certain sense asymmetrical. In each dichotomy, the first term refers to a specific memory system with reasonably well characterized functional and neural properties that meet our criteria for a system. The second term, however, is used in a more descriptive sense to a refer to a class or collection of memory functions that share certain features in common but also differ from one another in various ways. This use is most explicit in Squire's invocation of the term "nondeclarative" to refer a variety of disparate memory functions that are tied together by their hypothesized independence from the hippocampal-dependent system, but it is also apparent in the writings of Eichenbaum and Nadel.

We think that it is important to be alert to asymmetries of this kind, because they can complicate the job of classifying memory systems. Thus, although there is a sense in which the distinctions offered by Eichenbaum, Nadel, and Squire are dichotomies, there is another sense in which they are not: the contrast is between a declarative or locale system on the one hand and a number of other systems and/or subsystems on the other. The ambiguity arises because one term of each distinction refers to a specific system, and the other is a descriptive label. The ambiguity could be avoided by offering distinctions that are symmetrical with respect to the level of the terms contrasted: systems should be contrasted with systems, and descriptive concepts contrasted with descriptive concepts. Lynch and Granger offer a rather different approach from that of others concerned with animal learning. They argue that different types of memory—recognition, recency, memory of recent actions, connecting events across space and time—operate in a manner analogous to an assembly line, in which each component can be thought of as a system that makes a unique informational contribution to the gradually evolving memory. The assembly line operates in a serial manner, with the product of higher-level systems including the previously assembled products of lower-level systems. According to Lynch and Granger, the lower-level systems can operate independently of the higher-level systems, but not vice versa.

In summary, the main point of agreement among the students of animal learning and memory represented in this volume is that a memory system that depends on the hippocampal system differs fundamentally from a system that can function independently of the hippocampus. Disagreements exist on the nature of the hippocampal system and on the question of whether the nonhippocampal system can be divided into multiple systems, forms, or subsystems.

3.2 Studies of Human Memory

As we noted in the historical review, the systematic classification of human memory also began with various dichotomies, such as primary or short-term memory versus secondary or long-term memory (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965), and episodic versus semantic memory (Tulving, 1972). In recent years there has been a consistent trend toward organizing various dichotomous classifications into more comprehensive and elaborate classificatory schemes.

Baddeley's chapter on working memory provides an illustration of this trend within the domain of temporary, short-term memory. Baddeley subdivides working memory into three components: the central executive (a limited-capacity workspace that allows one to perform mental computations on a small number of items of information) and two slave memory systems (a phonological loop that allows temporary storage of several items of speech-based information and a visuospatial sketchpad that can hold small amounts of visual and/or spatial information). The fractionation of working memory into multiple components was initially motivated by attempts to account for various kinds of data that were inconsistent with a unitary short-term store of the kind postulated by the modal model (Atkinson & Shiffrin, 1968). As indicated by the material reviewed in Baddeley's chapter, the model that divides working memory into multiple components has proven quite useful in accounting for a variety of experimental results and in generating novel areas of research. Although aspects of the model have evolved and changed over time, the basic architecture has remained intact.

The trend toward fractionation is also evident in the chapters concerned with distinctions among forms of long-term memory. Much of the recent research and discussion concerning multiple memory systems in humans has been motivated by, and pursued within the context of, dissociations between explicit and implicit memory. Squire considers a number of such dissociations in amnesic patients from the standpoint of the declarative/nondeclarative distinction, and he attempts to account for them with the same set of ideas that he applies to the animal literature. Squire argues that preservation of priming, skill learning, and biasing of judgments in amnesic patients are all mediated by nondeclarative forms of memory that can operate independently of the hippocampal-dependent declarative system. Squire also fractionates the general category of nondeclarative memory, arguing that such phenomena as perceptual priming and skill learning depend on distinct and dissociable subsystems. Although Squire uses the declarative/nondeclarative distinction synonymously with the explicit/implicit distinction, it is worth remembering that the term "declarative memory" refers to a specific memory system whereas "explicit memory" is a descriptive label that is mute concerning the memory system or systems that support it. "Nondeclarative memory" is a descriptive term that is in most respects synonymous with "implicit memory." We prefer to use the explicit/implicit contrast for descriptive purposes because the distinction is consistently neutral regarding the nature and number of underlying memory systems, whereas the declarative/nondeclarative distinction mixes levels of description. We refer to the memory systems themselves with terms other than "explicit memory" and "implicit memory" to emphasize the difference between the underlying systems and the kinds of psychological experience that they support.

Schacter's chapter focuses on a system that, he argues, plays a crucial role in supporting priming effects on tests of so-called data-driven implicit memory: the perceptual-representation system (PRS). Based on evidence from cognitive-neuropsychological observations of patients with deficits of word and object processing, Schacter fractionates the PRS into three distinct subsystems: visual word form, auditory word form, and structural description. Each of the subsystems shares critical properties that characterize the superordinate PRS: they operate at a presemantic level, are preserved in amnesic patients, and appear to be cortically based. However, each subsystem handles a different kind of perceptual information and probably has a different cortical locus. The PRS is distinguished from episodic memory (which supports conscious recollection on explicit memory tests) and semantic memory (which supports the acquisition of general knowledge and conceptual priming effects). Schacter also notes recent evidence suggesting that some implicit memory effects may depend on an interaction, at the time of encoding, between PRS and episodic or semantic systems. These observations highlight again the need to separate descriptive concepts (i.e., implicit and explicit memory) from the underlying memory systems themselves.

Moscovitch offers an account of priming that is similar to that of Schacter, inasmuch as he emphasizes the contribution of perceptual modules quite similar to the various PRS subsystems. Moscovitch's approach to episodic memory involves a distinction between two components. He conceives of the hippocampus as a modular system whose domain is consciously apprehended information that supports associative episodic memory, that is, episodic retrieval in which a cue directly evokes or reinstates a previously associated item or context. By contrast, parts of prefrontal cortex, Moscovitch argues, constitute a central system involved in strategic search through episodic memory. Moscovitch also notes, however, that the role of the frontal search system may be quite general, in the sense that it can be involved with different systems of strategic retrieval on both explicit and implicit tests, and may interact with various memory systems.

Johnson and Chalfonte attempt to account for some of the same phenomena that Moscovitch addresses, within a different yet related framework. They distinguish among four major memory systems—two perceptual systems (P-1, P-2) and two reflective systems (R-1, R-2)—and specify the nature of and relations between particular component processes that constitute each of the systems. P-1 is primarily concerned with the representation of relatively low-level perceptual information, whereas P-2 is concerned with objects and their spatial relations. These systems correspond roughly to the PRS discussed by Schacter and the perceptual modules considered by Moscovitch. R-1 is involved in reactivation of previously conscious information, and R-2 is involved in more strategic forms of search and reflection. The distinction between R-1 and R-2 corresponds roughly to the distinction drawn by Moscovitch between a hippocampally based associative-memory module and a more strategic frontal component. Johnson and Chalfonte discuss at length the role that R-1 reactivation processes play in binding together the various features of complex memories. Metcalfe, Mencl, and Cottrell offer a computational analysis of the relations between explicit and implicit memory, focusing on differences between the priming of performance on word-fragment completion and explicit cued recall. They observe that formal models in which elements of an episode are bound together exhibit properties associated with explicit retrieval, whereas models that do not use binding exhibit properties associated with implicit memory (priming). These differences suggest possibly important differences between the kinds of representations used by the system that supports explicit memory (bound or associated assemblies of multiple features or attributes) and the system that supports perceptual priming (individual features or attributes). Differences along these lines are in fact discussed in the chapters by Johnson and Chalfonte, Moscovitch, Schacter, and Squire, which suggests a possibly important point of convergence among multiple-system theorists.

3.3 Five Major Systems of Human Memory

On the basis of the results of the contributors to this volume, the research and theorizing of other investigators (e.g., Warrington, 1979; Weiskrantz, 1987), and our three criteria for postulating memory systems, we present in table 1 a classification of the major systems of human memory as they appear to us in 1994. The five major systems in the table are procedural memory, perceptual-representation memory, semantic memory, working memory, and episodic memory. We have also included, where appropriate, suggested subsystems or subtypes of a particular system. The contributors to this volume discuss at length the evidence for and the nature of these systems, and we will not duplicate their efforts here. A few words of clarification and elaboration are, however, in order.

The first major system is procedural memory. It is a vast category, as yet largely unexplored and unknown. It probably comprises several further major divisions and a large number of rather specific subsystems, only some of which have so far been tentatively identified (e.g., Squire, 1992a, this volume). Procedural memory can be thought of as a "performance-line" system (Hirsh, 1974). It is involved in learning various kinds of behavioral and cognitive skills and algorithms, its productions have no truth values, it does not store representations of external states of the world, it operates at an automatic rather than consciously controlled level, its output is noncognitive, and it can operate independently of the hippocampal structures (Hirsh, 1974; Squire, 1987). Procedural memory is characterized by gradual, incremental learning and appears to be especially well-suited for picking up and dealing with invariances in the environment over time (Sherry & Schacter, 1987). The

Table 1 Major systems of human learning and memory

System	Other terms	Subsystems	Retrieval
Procedural	Nondeclarative	Motor skills Cognitive skills Simple conditioning Simple associative learning	Implicit
Perceptual representation (PRS)	Nondeclarative	Visual word form Auditory word form Structural description	Implicit
Semantic	Generic Factual Knowledge	Spatial Relational	Implicit
Primary	Working	Visual Auditory	Explicit
Episodic	Personal Autobiographical Event memory		Explicit

existence of procedural memory as a category separate from cognitive memory systems is supported by converging dissociations from amnesic patients (e.g., Charness, Milberg, & Alexander, 1988; Cohen & Squire, 1980; Knowlton, Ramus, & Squire, 1992; Moscovitch, 1982), demented patients (e.g., Butters, Heindel, & Salmon, 1990), drug-induced amnesia (Nissen, Knopman, & Schacter, 1987), and normal subjects (e.g., Schwartz & Hashtroudi, 1991). Evidence from studies of patients with Huntington's disease suggests that at least one form of procedural memory, motor-skill learning, depends on the integrity of the basal ganglia (Butters, Heindel, & Salmon, 1990), a conclusion that is supported by research with animals that implicates a corticostriatal circuit in habit learning (Mishkin, Malamut, & Bachevalier, 1984; Packard, Hirsh, & White, 1989).

Because of our present lack of information about the vast terra incognita that we call procedural memory, its most adequate description at the present time probably is by exclusion: procedural memory refers to a system, or systems, concerned with learning and memory functions other than those supported by the other four major systems. Squire's (1992a, this volume) designating procedural memory as "nondeclarative" reflects the same orientation.

One major division within the procedural system likely to appear soon may be drawn along the lines of the distinction between behavior and cognition. Thus, we can distinguish between learning behavioral skills and procedures and learning cognitive skills and procedures. The neural computations that correspond to behavioral-skill learning (e.g., Butters, et al., 1990) necessarily depend on, and are expressed through, the activation of the premotor and motor cortices of the brain, whereas for cognitive procedural learning (e.g., Cohen & Squire, 1980) such activation is optional rather than obligatory.

The four other major systems are concerned with cognition. That is, the final productions of all these systems can be, and frequently are, contemplated by the individual introspectively, in conscious awareness. Any conversion of such a product of memory into overt behavior, even symbolic behavior such as speech or writing, represents an optional postretrieval phenomenon, characterized by considerable flexibility regarding the behavioral expression. Such flexibility is absent in procedural forms of memory. One of the cognitive-memory systems, working memory, differs from others in that it is concerned with temporary holding and processing of information. The other three systems are long-term systems. Working memory is described in Baddeley's chapter (this volume). It consists of three subsystems: a central executive and two slave subsystems: a visuospatial sketchpad and the phonological loop. Working memory represents a more elaborated and sophisticated version of what used to be called short-term memory, or primary memory. It enables one to retain various kinds of information over short periods of time, is critically involved in carrying out numerous kinds of cognitive tasks, and has complex relations with long-term memory systems. As Baddeley notes, the best characterized component of working memory is the auditory or phonological loop system: converging dissociations support its existence and a good deal is known about the kind of information that it handles. There is less evidence for the separate existence of the visual subsystem, and still less for the central executive; correspondingly, little is known about the kinds of information that these subsystems handle, although this situation is beginning to change (see Baddeley, this volume, 1992a, 1992b).

The other three cognitive-memory systems all can hold stored information over longer periods of time in the presence of other interpolated cognitive processes. The PRS and its subsystems are discussed at length elsewhere in this volume by Schacter, and also by Moscovitch and Squire. The system plays an important role in identifying of words and objects, it operates at a presemantic level, and it is typically involved in nonconscious or implicit expressions of memory, such as priming. The argument that the PRS is a distinct system comes from two independent and converging lines of research: memory experiments indicating that perceptual priming can be dissociated from explicit memory in normal subjects, amnesic patients, elderly adults, and drug-induced amnesias (Roediger, 1990; Tulving & Schacter, 1990) and neuropsychological research on patients with lexical- and object-processing deficits that indicates relative preservation of access to perceptual/structural knowledge under conditions in which access to semantic knowledge is severely impaired (Schacter, 1990). The subsystems suggested in table 1 include the visual-word-form, auditory-word-form, and structural-description subsystems discussed in Schacter's chapter, along with a face-identification subsystem, whose properties and involvement in various priming effects has been discussed by Ellis, Young, and Flude (1990).

The remaining two systems listed in table 1 are semantic memory and episodic memory. Semantic memory makes possible the acquisition and retention of factual information about the world in the broadest sense. The knowledge and beliefs about the world that people gain, possess, and use—whether general or specific, concrete or abstract—is critically dependent upon semantic systems. The episodic memory system enables individuals to remember happenings they have witnessed in their own personal past, that is, to consciously recollect experienced events as embedded in a matrix of other happenings in subjective time. Episodic memory is assumed to be the most recently evolved system that has grown out of semantic memory through working memory. It shares many properties and capabilities with the semantic system, but as with working memory, it transcends semantic memory in its ability to record, and subsequently to enable conscious recollection of, personal experiences and their temporal relations to one another. Episodic recollections consist of multifeature representations in which numerous different kinds of information—spatial, temporal, contextual, and so forth—are bound together with the individual's awareness of personal experiences in subjective time. (For more details, see Tulving, 1987, 1991, 1993).

The neuroanatomical location of the semantic and episodic memory systems is uncertain at the present time. But it is possible to conjecture that semantic memory depends on the medial-temporal-lobe regions and that episodic memory depends on as yet unspecified prefrontal-cortical areas. Because episodic memory depends on semantic memory in some of its operations, although not vice versa, it follows that successful functioning of episodic memory also depends on the integrity of the medial-temporal lobes (Tulving, in press).

Evidence for the separation of the semantic and episodic systems is provided by converging dissociations from several sources. Especially relevant are observations that brain-damaged patients as well as older people can acquire factual knowledge indistinguishably from healthy or younger control subjects, while their recollection of the source of such knowledge may be greatly impaired. In extreme cases, patients can acquire new semantic information while totally lacking an ability to recollect any personal experiences from their past (e.g., Hayman, Macdonald, & Tulving, 1993; Tulving, Hayman, & Macdonald, 1991).

We should note that some students of memory systems, including such contributors to this volume as Johnson and Chalfonte and Squire, doubt the need to distinguish between episodic and semantic memory systems. Johnson and Chalfonte, for example, include both episodic and semantic systems in their R-1/R-2 system, and Squire subsumes them under a single declarative system. Such an approach has the advantage of parsimony, and it is consistent with the observation that episodic and semantic memory often seem to be similarly impaired, as in many cases of amnesia. Nonetheless, we think that the reasons for making some form of an episodic/semantic distinction are more compelling than the reasons against making the distinction, and so we incorporate it into our scheme.

4 COMPARATIVE SYSTEMATIZING OF SYSTEMS: ANIMAL AND HUMAN MEMORY REVISITED

Given the hippocampally oriented dichotomies of animal learning and the somewhat more complex scheme of human memory systems, what are the prospects of mapping one onto the other? We noted earlier that fully unifying the two domains awaits future developments, but some kind of mapping is undoubtedly possible. All one needs to do is to identify a single common dimension that applies to both schemes and then align the two schemes along that dimension. Thus, for example, one could propose that the rather primitive procedural memory system corresponds to the primitive system that subserves, say, elemental associations in Rudy and Sutherland's scheme, whereas the more advanced cognitive human memory systems correspond to the more advanced system that makes possible the acquisition of relational and configural associations. The same general rule could be applied to the hippocampal criterion: align hippocampal and nonhippocampal systems in humans with those in other animals.

This latter approach has been argued most forcefully by Squire and his colleagues. Human and animal amnesia are viewed as impairments of declarative memory with (relative) preservation of nondeclarative memory. Declarative memory, in turn, is defined in terms of its vulnerability to hippocampal damage: declarative memory does, whereas nondeclarative memory does not, depend on the hippocampus. In Squire's organizational scheme, therefore, amnesia is defined with respect to hippocampal damage, and animal memory systems are readily mapped onto the human systems along the dimension of declarative versus nondeclarative. Eichenbaum has taken a similar approach and has attempted to develop experimental paradigms for the study of animal memory that allow relatively direct comparison to human memory.

Such mapping of animal memory onto human memory is a necessary prerequisite for the development of animal models of memory. To the extent that the validity of a mapping can be verified, it can be a viable enterprise. But if much of it depends on assumptions, then one needs to be cautious. Different species have evolved to solve problems of survival that are unique to them. There are good reasons to believe that each species evolved learning and memory systems are correspondingly different from those of other species. Thus the differences in the brains of different species render general comparisons, or even comparability, of behavioral and cognitive functions questionable (e.g., Preuss & Goldman-Rakic, 1991a, 1991b). Even within the boundaries of the order of primates, the homologous correspondence of brain regions concerned with higher mental processes has not yet been established and is based largely on assumptions. Learning and memory systems of animals have many features in common with those of humans. It is equally clear that human memory differs in many ways from that of animals. These simple facts suggest to us that animal brain/behavior relations cannot readily be used for the purpose of modeling aspects of human memory that are uniquely human. In any case, we urge caution in cross-species generalization: animal models constructed on invalid assumptions are more likely to confuse than to help.

In addition to the possible noncorrespondence of functional brain regions in humans and other primates, additional problems remain, including the mediating role of language in humans and the absence of such a role in nonverbal animals, and differences in the kinds of tasks and instructions that are given to humans and animals. These problems have been noted in the chapters by Eichenbaum and by Rudy and Sutherland, who nevertheless do highlight several promising points of convergence. We believe that their enthusiasm is justified, but we also wish to point out that there are several important divisions in human learning and memory that are difficult to make in animal learning: the distinction between recognition and recall, the division between behavior and cognition, and the division between explicit and implicit memory, to list a few. Only one of the five human systems in table 1, procedural memory, can be thought of as a behavioral or action system, and relatively little research has been done on it. And no one has yet succeeded in experimentally separating explicit and implicit retrieval in animals, or in conducting a priming experiment on nonhuman animals. Although gains have been made toward unifying aspects of animal and human memory (e.g., Squire & Zola-Morgan, 1991), the obstacles to a complete mapping of the two types of memory should not be underestimated. Thus we prefer to deal with the mapping problem by postponing attempts at a solution. We feel that for the time being, at least, we are probably better off developing separate classifications of memory systems for different species. Although there is nothing wrong with gleaning inspiration for one's own thoughts by listening to those working on other species, we should probably not try too hard to pursue what may be, by nature's standards, a largely procrustean enterprise.

5 SUMMARY

Our overview of the memory systems of 1994 is meant to serve three main functions: to present a summary of past achievements, to point out deficiencies and shortcomings in our current understanding of organization of memory, and to inspire others to correct our errors and to improve the account.

We have presented a sketch of the current status of research on memory systems. Although antecedent ideas already appeared early in the nineteenth century, and although the dominant attitude of unitary memory was questioned from time to time, the multiple-memory orientation has become dominant only in the course of the last twenty years or so. Multiple-memory views were engendered by several joint developments, including (a) the discovery that amnesia was a highly selective disorder of memory and that the hippocampal structures play a crucial role in the acquisition of certain kinds of information, (b) the findings of dissociations between tasks representing short-term versus long-term memory, episodic versus semantic memory, and declarative versus procedural memory, and (c) the realization that the operations of many forms of memory, including cognitive memory, are sometimes expressed implicitly rather than explicitly.

We distinguished the concept of a memory system on the one hand from some related notions on the other, notions such as a kind or form of memory, memory process, memory task, and memory expression, as explicit versus implicit. We suggested that particular memory systems be specified in terms of the nature of their rules of operation, the type of information or contents, and the neural pathways and mechanisms subserving them. For a construct to qualify as a memory system, it has to meet at least three criteria: broad, category-based operations within a specifiable domain, a list of its properties that differentiate a given system from other systems, and relevant evidence in the form of converging task-comparison dissociations. Subsystems share with their supersystems the rules and principles of operations but may process different kinds of information and have a different brain localization.

We concluded that at present there is relatively little overlap between memory systems in humans and those in other animals. Systematic classification of nonhuman memory is firmly anchored in the hippocampal structures, yielding a variety of closely related dichotomies consisting of hippocampal versus nonhippocampal systems. Human memory, on the other hand, can be classified into five major categories, plus a number of subcategories. The major human memory systems include procedural memory, the perceptual representation system (PRS), semantic memory, working (short-term) memory, and episodic memory.

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REFERENCES

Anderson, J. R., & Bower, G. H. (1973). *Human associative memory.* Washington, DC: Winston and Sons.

Anderson, J. R., & Ross, B. H. (1980). Evidence against a semantic-episodic distinction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 6,* 441–466.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (pp. 89–195). New York: Academic Press.

Baddeley, A. D. (1992a). Is working memory working? *Quarterly Journal of Experimental Psychology, 44A,* 1–31.

Baddeley, A. D. (1992b). Working memory. *Science, 255,* 556–559.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

Bascomb, J. (1901). *The science of mind.* New York: G. P. Putnam.

Bergson, H. (1911). *Matter and memory* (N. M. Paul, W. S. Palmer, Trans.). London: Swan Sonnenschein & Co.

Broca, P. (1861). Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphémie. *Bulletin de la Société d'anthropologie, 6,* 330–357.

Bruner, J. S. (1969). Modalities of memory. In G. A. Talland & N. C. Waugh (Eds.), *The pathology of memory.* New York: Academic Press.

Butters, N., Heindel, W. C., & Salmon, D. P. (1990). Dissociation of implicit memory in dementia: Neurological implications. *Bulletin of the Psychonomic Society, 28.*

Carpenter, W. B. (1874). *Principles of mental physiology.* London: John Churchill.

Charness, N., Milberg, W., & Alexander, M. (1988). Teaching an amnesic a complex cognitive skill. *Brain and Cognition, 8,* 253–272.

Cohen, N. J., & Eichenbaum, H. (1993). *Memory, amnesia, and the hippocampus.* Cambridge: MIT Press.

Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern analyzing skill in amnesics: Dissociation of knowing how and knowing that. *Science, 210,* 207–210.

Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transactions of the Royal Society of London, 302,* 341–359.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.

Crowder, R. G. (1982). The demise of short-term memory. *Acta Psychologia, 50,* 291–323.

Eichenbaum, H. (1992). The hippocampal system and declarative memory in animals. *Journal of Cognitive Neuroscience, 4,* 217–231.

Eichenbaum, H., Fagan, A., & Cohen, N. J. (1986). Normal olfactory discrimination learning set and facilitation of reversal learning after combined and separate lesions of the fornix and amygdala in rats: Implications for preserved learning in amnesia. *Journal of Neuroscience, 6,* 1876–1884.

Ellenberger, H. F. (1970). *The discovery of the unconscious.* New York: Basic Books.

Ellis, A. W., Young, A. W., & Flude, B. M. (1990). Repetition priming and face processing: Priming occurs within the system that responds to the identity of a face. *Quarterly Journal of Experimental Psychology, 42A,* 495–512.

Fodor, J. A. (1983). *The modularity of mind.* Cambridge: MIT Press.

Gaffan, D. (1974). Recognition impaired and association intact in the memory of monkeys after transsection of the fornix. *Journal of Comparative and Physiological Psychology, 86,* 1100–1109.

Gall, F. J. (1835). *The influence of the brain on the form of the head* (W. Lewis, Trans.). Boston: Marsh, Capen & Lyon.

Graf, P., & Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. *Journal of Verbal Learning and Verbal Behavior, 23,* 553–568.

Graf, P., Mandler, G., & Haden, P. (1982). Simulating amnesic symptoms in normal subjects. *Science, 218,* 1243–1244.

Graf, P., & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal subjects and amnesic patients. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 501–518.

Graf, P., Squire, L. R., & Mandler, G. (1984). The information that amnesic patients do not forget. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 164–178.

Hayman, C. A. G., Macdonald, C. A., & Tulving, E. (1993). The role of repetition and associative interference in new semantic learning in amnesia. *Journal of Cognitive Neuroscience, 5,* 379–389.

Hayman, C. A. G., & Tulving, E. (1989). Is priming in fragment completion based on "traceless" memory system? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 941–956.

Herrmann, D. J., & Chaffin, R. (1988). *Memory in historical perspective: The literature before Ebbinghaus.* New York: Springer-Verlag.

Herrmann, D. J., & Harwood, J. R. (1980). More evidence for the existence of separate semantic and episodic stores in long-term memory. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 467–478.

Hirsh, R. (1974). The hippocampus and contextual retrieval of information from memory: A theory. *Behavioral Psychology, 12,* 421–444.

Hull, C. L. (1933). *Hypnosis and suggestibility.* New York: Appleton-Century.

Humphreys, M. S., Bain, J. D., & Pike, R. (1989). Different ways to cue a coherent memory system: A theory for episodic, semantic, and procedural tasks. *Psychological Review, 96,* 208–233.

Jacoby, L. L. (1984). Incidental versus intentional retrieval: Remembering and awareness as separate issues. In L. R. Squire & N. Butters (Eds.), *Neuropsychology of memory* (pp. 145–156). New York: Guilford Press.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30,* 513–541.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340.

James, W. (1890). *The principles of psychology.* New York: Henry Holt.

Kinsbourne, M., & Wood, F. (1975). Short-term memory processes and the amnesic syndrome. In D. Deutsch & J. A. Deutsch (Eds.), *Short-term memory.* New York: Academic Press.

Knowlton, B. J., Ramus, S. J., & Squire, L. R. (1992). Intact artificial grammar learning in amnesia: Dissociation of classification learning and explicit memory for specific instances. *Psychological Science, 3,* 172–179.

Kolers, P. A., & Roediger, H. L. (1984). Prodecures of mind. *Journal of Verbal Learning and Verbal Behavior, 23,* 425–449.

Ladd, G. T. (1909). *Outlines of descriptive psychology.* New York: Charles Scribner's.

Luys, J. B. (1887). *The brain and its function.* New York: D. Appleton.

McClelland, J. L., & Rumelhart, D. E. (1986). *Parallel distributed processing.* Cambridge: MIT Press.

Maine de Biran (1929). *The influence of habit on the faculty of thinking.* Baltimore: Williams & Wilkins. First published in 1804.

Mandler, G. (1980). Recognition: The judgment of previous occurrence. *Psychological Review, 87,* 252–271.

Masson, M. E. J., & MacLeod, C. M. (1992). Re-enacting the route to interpretation: Context dependency in encoding and retrieval. *Journal of Experimental Psychology: General, 121.*

Melton, A. W. (1963). Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behavior, 2,* 1–21.

Milner, B., Corkin, S., & Teuber, H. L. (1968). Further analysis of the hippocampal amnesic syndrome: Fourteen year follow-up study of H.M. *Neuropsychologia, 6,* 215–234.

Mishkin, M., Malamut, B., & Bachevalier, J. (1984). Memories and habits: Two neural systems. In G. Lynch, J. L. McGaugh, & N. M. Weinberger (Eds.), *The neurobiology of learning and memory.* New York: Guilford Press.

Mishkin, M., & Petri, H. L. (1984). Memories and habits: Some implications for the analysis of learning and retention. In L. Squire & N. Butters (Eds.), *Neuropsychology of memory* New York: Guilford Press.

Moscovitch, M. (1982). Multiple dissociations of function in amnesia. In L. S. Cermak (Eds.), *Human memory and amnesia* (pp. 337–370). Hillsdale, NJ: Erlbaum.

Nadel, L. (1992). Multiple memory systems: What and why. *Journal of Cognitive Neuroscience, 4,* 179–188.

Nadel, L., & O'Keefe, J. (1974). The hippocampus in pieces and patches: An essay on modes of explanation in physiological psychology. In R. Bellairs & E. G. Gray (Eds.), *Essays on the nervous system: A festschrift for Prof. J. Z. Young.* Oxford: Clarendon Press.

Nielsen, J. M. (1958). *Memory and amnesia.* Los Angeles: San Lucas Press.

Nilsson, L.-G., & Archer, T. (Eds.), (1985). *Perspectives in learning and memory.* Hillsdale, NJ: Erlbaum.

Nissen, M. J., Knopman, D. S., & Schacter, D. L. (1987). Neurochemical dissociation of memory systems. *Neurology, 37,* 789–794.

O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map.* Oxford: Clarendon Press.

Olton, D. S. (1989). Inferring psychological dissociation from experiment dissociations: The temporal context of episodic memory. In H. L. Roediger & F. I. M. Craik (Eds.), *Varities of memory and consciousness: Essays in honour of Endel Tulving.* Hillsdale, NJ: Erlbaum.

Olton, D. S., Becker, J. T., & Handelmann, G. E. (1979). Hippocampus, space, and memory. *Behaviorial and Brain Sciences, 2,* 313–365.

Packard, M. G., Hirsh, R., & White, N. M. (1989). Differential effects of fornix and caudate nucleus lesions on two radial maze tasks: Evidence for multiple memory systems. *Journal of Neuroscience, 9,* 1465–1472.

Polster, M. R., Nadel, L., & Schacter, D. L. (1991). Cognitive neuroscience analysis of memory: A historical perspective. *Journal of Cognitive Neurosciencd, 3,* 95–116.

Preuss, T. M., & Goldman-Rakic, P. S. (1991a). Ipsilateral cortical connections of granular frontal cortex in the strepsirhine primate Galago, with comparative comments on anthropoid primates. *Journal of Comparative Neurology, 310,* 507–549.

Preuss, T. M., & Goldman-Rakic, P. S. (1991b). Myelo- and cytoarchitecture of the granular frontal cortex and surrounding regions in the strepsirhine primate Galago and the anthropoid primates Macaca. *Journal of Comparative Neurology, 310,* 429–474.

Rajaram, S. (1992). Remembering and Knowing: Two means of access to the personal past. *Memory and Cognition, 21,* 89–102.

Rajaram, S., & Roediger, H. L. (1993). Direct comparison of four implicit memory tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 765–776.

Reiff, R., & Scheerer, M. (1959). *Memory and hypnotic age regression: Developmental aspects of cognitive function explored through hypnosis.* New York: International Universities Press.

Restle, F. (1957). Discrimination of cues in mazes: A resolution of the 'place-vs-response' question. *Psychological Review, 74,* 151–182.

Ribot, T. (1882). *Diseases of memory.* New York: Appleton-Century-Crofts. First published in 1881.

Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Review of Psychology, 36,* 475–543.

Roediger, H. L. (1990). Implicit memory: Retention without remembering. *American Psychologist, 45,* 1043–1056.

Roediger, H. L. (in press). Learning and memory: Progress and challenge. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance* (Vol. 14). Cambridge: MIT Press.

Roediger, H. L., & McDermott, K. B. (1993). Implicit memory in normal human subjects. In H. Spinnler & F. Boller (Eds.), *Handbook of neuropsychology.* Amsterdam: Elsevier.

Roediger, H. L., Rajaram, S., & Srinivas, K. (1990). Specifying criteria for postulating memory systems. In A. Diamond (Ed.), *The development and neural bases of higher cognitive functions.* New York: New York Academy of Sciences.

Roediger, H. L., Weldon, M. S., & Challis, B. H. (1989). Explaining dissociations between implicit and explicit measures of retention: A processing account. In H. L. I. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honor of Endel Tulving* (pp. 3–41). Hillsdale, NJ: Erlbaum.

Rosenfield, I. (1988). *Invention of memory*. New York: Basic Books.

Rozin, P. (1976). The psychobiological approach to human memory. In M. R. Rosenzweig & E. L. Bennet (Eds.), *Neural mechanisms of learning and memory*. Cambridge: MIT Press.

Rudy, J. W., & Sutherland, R. J. (1989). The hippocampus is necessary for rats to learn and remember configural discriminations. *Behaviorial Brain Research, 34*, 97–109.

Ryle, G. (1949). *The concept of mind*. London: Hutchinson.

Schactel, E. G. (1947). On memory and childhood amnesia. *Psychiatry, 10*, 1–26.

Schacter, D. L. (1982). *Stranger behind the engram: Theories of memory and the psychology of science*. Hillsdale, NJ: Erlbaum Associates.

Schacter, D. L. (1985). Priming of old and new knowledge in amnesic patients and normal subjects. In D. S. Olfon, E. Gamzu, & S. Corkin (Eds.) *Memory dysfunctions: An integration of animal and human research from preclinical and clinical perspectives* (pp. 44–53), New York: New York Academy of Sciences.

Schacter, D. L. (1987a). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 501–518.

Schacter, D. L. (1987b). Memory, amnesia, and frontal lobe dysfunction. *Psychobiology, 15*, 21–36.

Schacter, D. L. (1990). Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. In A. Diamond (Ed.) *The development and neural bases of higher cognitive functions* (pp. 543–571). New York: New York Academy of Sciences.

Schacter, D. L. (1992a). Priming and multiple memory systems: Perceptual mechanisms of implicit memory. *Journal of Cognitive Neuroscience, 4*, 244–256.

Schacter, D. L. (1992b). Understanding implicit memory: A cognitive neuroscience approach. *American Psychologist, 47*, 559–569.

Schacter, D. L., Chiu, C. Y. P., & Ochsner, K. N. (1993). Implicit memory: A selective review. *Annual Review of Neuroscience, 16*, 159–182.

Schacter, D. L., & Tulving, E. (1982). Memory, amnesia, and the episodic/sementic distinction. In R. L. Isaacson & N. L. Spear (Eds.), *The expression of knowledge* (pp. 33–61). New York: Plenum Press.

Schwartz, B. L., & Hashtroudi, S. (1991). Priming is independent of skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 1177–1187.

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry, 20*, 11–21.

Sherry, D. F., & Schacter, D. L. (1987). The evolution of multiple memory systems. *Psychological Review, 94*, 439–454.

Shettleworth, S. J. (1993). Varieties of learning and memory in animals. *Journal of Experimental Psychology: Animal Behavior Processes, 19*, 5–14.

Shimamura, A. P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Experimental Psychology, 38A*, 619–644.

Spurzheim, J. G. (1834). *Phrenology: The doctrine of mental phenomena*: Boston: Marsh, Capen and Lyon.

Squire, L. R. (1987). *Memory and brain*. New York: Oxford University Press.

Squire, L. R. (1992a). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of Cognitive Neuroscience, 99*, 195–231.

Squire, L. R. (1992b). Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. *Psychological Review, 99*, 195–231.

Squire, L. R., & Butters, N. (Ed.). (1984). *Neuropsychology of memory*. New York: Guilford Press.

Squire, L. R., Ojemann, J. G., Miezin, F. M., Petersen, S. E., Videen, T. O., & Raichle, M. E. (1992). Activation of the hippocampus in normal humans: A functional anatomical study of memory. *Proceedings of the National Academy of Sciences, 89*, 1837–1841.

Squire, L. R., & Zola-Morgan, M. (1991). The medial temporal lobe memory system. *Science, 253*, 1380–1386.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*, 189–208.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory*. New York: Academic Press.

Tulving, E. (1983). *Elements of episodic memory*. Oxford: Clarendon Press.

Tulving, E. (1984). Multiple learning and memory systems. In K. m. J. Lagerspetz & P. Niemi (Eds.), *Psychology in the 1990's* (pp. 163–184). Holland: Elsevier.

Tulving, E. (1985). How many memory systems are there? *American Psychologist, 40*, 385–398.

Tulving, E. (1987). Introduction: Multiple memory systems and consciousness. *Human Neurobiology, 6*, 67–80.

Tulving, E. (1991). Concepts of human memory. In L. R. Squire, N. M. Weinberger, G. Lynch, & J. L. McGaugh (Eds.), *Organization and Locus of Change*. New York: Oxford University Press.

Tulving, E. (1993). What is episodic memory? *Current Perspectives in Psychological Science, 2*, 67–70.

Tulving, E. (in press). Organization of memory: Quo vadis? In M. S. Gazzaniga (Ed.), *The cognitive neurosciences*. Cambridge: MIT Press.

Tulving, E., Hayman, C. A. G., & MacDonald, C. (1991). Long-lasting perceptual priming and semantic learning in amnesia: A case experiment. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 595–617.

Tulving, E., & Schacter, D. L. (1990). Priming and human memory systems. *Science, 247*, 301–306.

Tulving, E., Schacter, D. L., & Stark, H. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 336–342.

Warrington, E. K. (1979). Neuropsychological evidence for multiple memory systems. In *Brain and mind: Ciba Foundation Symposium* (pp. 153–166). Amsterdam: Excerpta Medica.

Warrington, E. K. (1982). Neuropsychological studies of object recognition. *Philosophical Transactions of the Royal Society of London, 289* (Series B), 15–33.

Warrington, E. K., & Weiskrantz, L. (1968). New method of testing long-term retention with special reference to amnesic patients. *Nature, 217*, 972–974.

Warrington, E. K., & Weiskrantz, L. (1970). Amnesic syndrome: Consolidation or retrieval? *Nature* (London), *217*, 628–630.

Warrington, E. K., & Weiskrantz, L. (1974). The effect of prior learning on subsequent retention in amnesic patients. *Neuropsychologia, 12*, 419–428.

Warrington, E. K., & Weiskrantz, L. (1982). Amnesia: A disconnection syndrome? *Neuropsychologia, 20*, 223–248.

Waugh, N., & Norman, D. (1965). Primary memory. *Psychological Review, 72*, 89–104.

Weiskrantz, L. (1978). Some aspects of visual capacity in monkeys and man following striate cortex lesions. *Archives Italiennes de biologie, 116*, 318–323.

Weiskrantz, L. (1987). Neuroanatomy of memory and amnesia: A case for multiple memory systems. *Human Neurobiology, 6*, 93–105.

Witherspoon, D., & Moscovitch, M. (1989). Stochastic independence between two implicit memory tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 22–30.

Young, A. W., & De Haan, E. H. F. (1992). Face recognition and awareness after brain injury. In A. D. Milner & M. D. Rugg (Eds.), *The Neuropsychology of Consciousness* (pp. 69–90). San Diego: Academic Press.

Young, R. M. (1990). *Mind, Brain, and Adaptation in the Nineteenth Century*. New York: Oxford University Press.

Zola-Morgan, S., & Squire, L. (1984). Preserved learning in monkeys with medial temporal lesions: Sparing of cognitive skills. *Journal of Neuroscience, 4*, 1072–1085.

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