Introduction

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Memory is the capacity of nervous systems to benefit from experience. It is a ubiquitous presence in all higher life forms. It takes many shapes, from simple to complex, from highly specific to most general, from trifling to fundamentally important. In its manifold expressions it is being observed, investigated, and measured in numerous organisms, at many different levels of analysis, from a variety of vantage points, and relying on many different approaches and techniques. It reaches its evolutionary culmination in human beings.

The study of memory has occupied the center stage of cognitive neuroscience since its inception. It continues to fascinate and frustrate large numbers of capable scientists. Novel findings are reported almost daily, yet the major insight gained from more than one hundred years of scientific study of memory may be the realization that the complexity of memory far exceeds anyone's imagination. It is clear that memory did not evolve for the convenience of the neuroscientist.

The nine chapters in the memory section of the second edition of *The Cognitive Neurosciences* provide summaries of and glimpses into some of the more active foci of contemporary cognitive neuroscience of memory. Six chapters deal solely or primarily with human memory, whereas three others focus on work done with nonhuman primates. Collectively, they illustrate the variety of methods and procedures used. These include electrical recording from single neurons in monkeys (chapters 50 and 51) and from multiple scalp sites in normal human subjects (chapter 56); the study of the effects of experimentally created lesions in monkeys (chapter 52) and the mnemonic consequences of brain damage resulting from disease or accident (chapters 53, 54, and 58); effects of psychoactive drugs (chapter 55); and functional neuroimaging of memory-related processes in healthy volunteers (chapters 57 and 58). The overarching concern in all these chapters is to gain insight into the neuronal substrates of behavioral and cognitive manifestations of learning and memory and into the nature of the relation between neural mechanisms and memory processes.

Because of the vast size and diversity of the domain, it simply is not possible to deal with memory as a whole. Nor is it possible to make any intelligent generalizations about it. Any claim about "memory" or "memory impairment" immediately requires clarification: About which kind of memory, memory task, memory process, or memory system are we talking? These terms define the major fault lines along which the whole of memory can be fractionated into more manageable components within which generalizability of factual statements and theoretical claims are more likely to be valid. The concepts represented by these terms have evolved from the observations made about memory at the level of observable behavior and reportable experience. Directly or indirectly, they provide the backdrop against which we seek to understand the relation between brain and behavior or between brain and mind.

This introduction to the section on memory describes the outlines of the conceptual framework within which much research on human memory is conducted and attempts to clarify some of the arcane terms that, although useful to insiders, frequently mystify outsiders. It touches on topics such as memory systems, memory tasks, memory processes, and conscious awareness in memory.

Memory systems

The concept of memory systems is one answer to the need to specify different "kinds" of memory. Different systems share certain basic features, such as some device or means of retaining the consequences of a current act of behavior or cognition, and they differ with respect to others, such as the functions they serve, their behavioral or cognitive manifestations, the principles of their operations, and the brain mechanisms involved in the operations.

The most fundamental division in memory deals with the distinction between behavior and thought. Many forms of learning and memory are expressed in behavior (doing something, carrying out a procedure), whereas others are expressed in thought (contemplating something, being cognizant of some mental contents). The behavioral kinds collectively are referred to as "procedural" memory; the ones expressed in thought are referred to as "cognitive" memory. Although the distinction is not a simple one, a rule of thumb that can be used for deciding how to classify any particular act of memory consists in the answer to the question–can one hold in mind the *product* of the act of memory? An affirmative answer suggests that memory is cognitive; the negative answer means that it is procedural.

The distinction between procedural and cognitive holds very broadly for learning and memory in many species. Other terms have been used to designate them. Procedural memory has been called habit memory, nondeclarative memory, and even implicit memory, although for many students of memory, implicit memory means something rather different than the broad category of learning and memory that is not cognitive. Cognitive memory has been called declarative memory, propositional memory, and also explicit memory, although, again, explicit memory does not really correspond to all forms of learning and memory that are not cognitive. The extensive, and sometimes undisciplined, use of different terms to designate the same underlying concepts is a continuing problem in the field.

Cognitive memory, which constitutes the lion's share of memory research with human subjects, can be further subdivided into four major categories, or "systems." They are (1) working memory, whose function is to hold information "on line" over short intervals of time while cognitive operations are performed on it; (2) the perceptual representation system, whose function is to mediate memory-based facilitation of perceptual identification of objects; (3) semantic memory, whose function is to mediate the acquisition and use of individuals' general knowledge of the world; and (4) episodic memory, whose function is to mediate conscious access to the personally experienced past.

The separability of the four systems from one another is widely if not universally accepted. The distinctions among them receive support from sharp dissociation between task performances that depend heavily on the different underlying systems in normal subjects and brain-damaged individuals, as well as from functional neuroimaging and psychopharmacological studies. Relevant evidence is discussed in many chapters in this section. Much of the research effort currently is directed at the refinement and elaboration of the taxonomic scheme, and at the identification and characterization of the many subdivisions of the major categories.

Tasks and processes

Cognitive memory in the laboratory is studied in segments of reality called *tasks*. A typical cognitive memory task consists of three stages: (1) presentation of some material to the subject, usually with instructions to "remember" it; (2) a retention interval during which the subject may engage in other (mental) activities; and (3) a test of the subject's knowledge of the originally presented material. The outcome of the test is expressed in terms of some measure of the subject's performance on the test. It is frequently but not necessarily a measure of how well the subject can reproduce originally presented material.

A great variety of cognitive memory tasks exists, defined in terms of a large number of possible variations in the specific features of the three stages of the task. Tasks can vary in the kinds and units of the material presented for learning and the specific parameters of the presentation, the length of the retention interval (which can range from seconds to years), the nature of the "interpolated" activities, and many other independent variables. An especially important feature of the task is the nature of the test. Tests also can vary widely with respect to the instructions that specify the subject's mission and the nature and type of cue information provided to guide and aid its execution.

Given this thumbnail sketch of the memory task, how are we to think about and describe, in general abstract terms, what happens when the subject is engaged in a cognitive memory task? For a long time in the history of learning and memory the dominant theoretical concept that provided the answer to this question was "association." During learning, associations were assumed to be formed, maintained in force, sometimes interfered with, and then expressed in behavior. The concept of association still is used in special situations, especially in studies of learning and memory with nonverbal subjects. In the mainstream cognitive psychology, however, some 30 to 40 years ago the associative paradigm was replaced by *information processing* as the general pretheoretical framework. This framework currently determines how most students of memory think and talk about the workings of memory.

The three sequential stages of the standard memory task correspond to three major memory processes of encoding, storage, and retrieval. The presentation of the to-be-remembered material is an event about which "information" is "encoded" into the memory "store." Usually, the material consists of discrete items (words, pictures, objects, faces, and simple sentences), and the presentation of each is a "miniature event" about which information is encoded into the store. During the retention interval, this information is maintained in the store as an "engram," and it may be "consolidated" or "recoded." *Consolidation* is thought of as a biologically determined autonomous process that runs its course independently of the interpolated activity, whereas *recoding* is an active psychological process that is shaped by the particulars of the interpolated activity. At the time of the test, the information "available" in the engram is "retrieved," or rendered "accessible." *Retrieval* means use of stored information, and because stored information can be used in many different ways, the term retrieval is very broad and usually needs to be specified more precisely.

The concept of information runs through this pretheoretical processing framework like a red thread. It is useful to keep in mind, therefore, that neither *information* nor *process* can be defined readily. Information simply is the intangible, ineffable, unknown "stuff" that is somehow created, transferred, transformed, preserved ("processed") in the mind/brain, which, when appropriately "converted," determines behavior and conscious thought. Both information and process are "placeholder" concepts in contemporary cognitive sciences. They will be used until a better paradigm comes along. Even though they are not readily definable, the terms make abstract thought about the workings of the brain/mind possible and the doubts about how to best study it tolerable.

Conscious awareness in memory

The products of retrieval in all cognitive memory tasks are, in the first instance, expressed as mental experiences. They can be contemplated internally, in the absence of any overt behavior, and they can be "held in mind." It would be normal to expect, therefore, that the efforts to understand cognitive memory be directed at the study of the retrieval experience. For a long time in the history of the science of memory, however, this was not done. Subjects' memory performance invariably was measured in terms of behavioral indices of various kinds. The tacit assumption, seldom explicitly formulated, was that behavioral output in the memory test faithfully reflects the mental contents of what the individual has retrieved from memory. We now know that this assumption does not always hold.

Recently, the issue of individuals' conscious experiences that accompany the act of retrieval from the memory store has been shifted into a sharp focus, in two different ways. One distinguishes between "conscious" and "nonconscious" retrieval; the other, concerned solely with conscious retrieval, distinguishes between two forms of it. The first issue is dealt with under the heading of *explicit versus implicit* memory, the second under the heading of *remembering and knowing,* or *recollection and familiarity.* We consider them in turn.

Explicit and implicit memory

The first issue of consciousness in memory has to with the rememberer's awareness, at the time of the test, of the relation between the current experience (and activity) on the one hand, and the original learning or encoding episode on the other. In ordinary everyday-type of remembering, the relation is clearly felt: when the individual recollects a previous event, such as the study of some specific material in the first stage of the experiment, he or she also is fully aware that what he or she is experiencing has its origin in the earlier episode. The technical term that is used currently to refer to this kind of awareness at retrieval is *explicit* memory.

Explicit memory contrasts with *implicit* memory: retrieval of stored information in the *absence* of the awareness that the current behavior and experience have been influenced by a particular earlier happening. It is in this sense, and this sense only, that explicit memory is said to be "conscious," whereas implicit memory is "nonconscious." Consciousness refers to the awareness of the *relation between* the present thought (and action) and a *specific* previous thought (or action).

An important point to note is that the distinction between explicit and implicit memory is that between explicit and implicit *retrieval*–that is, the distinction applies only the final stage of our typical memory task. This is because there is no difference between explicit and implicit encoding, and there is, as yet, no known way to distinguish between explicit and implicit storage. For this reason among others, explicit and implicit memories do not qualify as memory "systems."

In memory experiments, explicit retrieval is effected by the instructions given to the subject at test: "Remember what you saw, or what you did, or what happened to you at some earlier time, in some place (such as the first stage of the experiment)?" Implicit retrieval, too, is experimentally effected by the instructions given to the subjects at the time of retrieval as to what they are to do. Many different forms of implicit memory tests exist and have been used, but they all have in common the fact that the subject *need not* think back to the first stage of the task, or to any other specific episode, to perform the task at a level that has benefited from the first stage. Thus, implicit memory satisfies the definition of memory–the individual benefits from experience, but he or she is unaware that he or she has done so.

It is important to note a complication: Explicit retrieval instructions do not necessarily guarantee that the responses made by the subject are accompanied by a sense of recollection, as they ideally would. Subjects' explicit memory performance may be influenced processes that support implicit retrieval. Nor do implicit instructions guarantee that retrieval occurs in the absence of recollection of the relevant encoding experience, as it ideally should. Purification of research designs aimed at reducing or eliminating such unwanted "contamination" of the desired type of retrieval by extraneous factors is an important part of research on explicit and implicit memory. Some of these issues are discussed in chapters 55, 56, and especially 58.

Many experiments, of many different kinds, have convincingly demonstrated the reality of the distinction between explicit and implicit memory. The major theoretical import of the discovery of these two forms of retrieval lies in the sharp distinction that they draw between overt behavior and the mental experience that accompanies such behavior. The subject's ability to produce a particular over-response, whose likelihood has been enhanced by a particular earlier event, may be identical in two tests. However, the mental experiences may be altogether different.

Remembering and knowing

The second issue of consciousness emerges in situations in which the awareness of the relation between the present experience and an earlier specific event is in fact present. It has to do with two different *kinds of awareness* that may accompany explicit memory retrieval. One is referred to as *remembering* or *recollection*, the other as *knowing* or *familiarity*. In explicit tests of recognition and recall, the subject may make a correct response not because he or she actually remembers or recollects the event of the item's earlier presentation, but rather because the recognition test item "looks familiar," or because he or she "simply knows" that the word he or she has just recalled was in the presented list. Because the subject is fully aware of the previous presentation episode of the material, he or she–usually correctly–attributes the feeling of familiarity or "knowing" to the episode.

The remembering/knowing or recollection/familiarity distinctions currently are subjects of lively interest to many memory researchers. Rugg and Allan (chapter 56) discusses the electrophysiological evidence for the distinction, and Squire and Knowlton (chapter 53) deal with the issue of how remembering and knowing are related to the amnesic syndrome and whether they are both dependent on the medial temporal lobes. Schacter and Curran (chapter 58) and Curran (chapter 55) also touch on the distinction. The major theoretical point, however, is that here, finally, we have an active area of research aimed at the essence of cognition: Conscious *mental experiences* that have been changed as a result of earlier experience-induced physical changes in the brain.

Other levels and species

Concepts such as encoding and retrieval, explicit and implicit memory, or remembering and knowing make good sense at the level of behavior and cognition of the whole individual, or the whole brain. They are less readily applicable to the study of memory-related events at the level of single neurons, in analyses of the kind described by Goldman-Rakic and associates and Erickson and colleagues in chapters 50 and 51, respectively. Although encoding and retrieval ultimately are rooted in neuronal activity, a single neuron cannot encode or retrieve anything. A neuron may "fire" differentially during the interval between the presentation of the target and the signal for the saccade in the oculomotor working-memory task used by Goldman-Rakic and colleagues, thus providing for a neat neuronal mechanism for holding information "on line" in the short-term memory "store." But although it is possible to think of this "on-line holding" mechanism as comparable in principle to "holding" information in the long-term "store," the parallel probably would not work. Retrieval–use of the "stored" information–has different meanings to the organism and is based on rather different operations, in the two situations. Similarly, a neuron may respond differentially to a stimulus when presented for the first time versus the second, as shown by the studies of Erickson and colleagues (chapter 51), and it is tempting to think of the difference as in some sense paralleling novelty versus familiarity detection, or even encoding and retrieval, at the level of the whole brain, but the two levels of analyses are too far apart to allow one to feel confident about such thoughts. A challenging task for neuroscience of memory is to determine to what extent such high-level phenomena as conscious recollection of the occurrence of an event depend on the differential activity of individual units, and to what extent they represent network-level happenings, or as yet unknown mechanisms, in the brain.

Similar thoughts apply to memory in nonhuman animals. A good deal of knowledge about memory, and especially about the neural basis of memory-based behavior, has been derived from work with other animals–nonhuman primates, rodents, birds, and others, all the way to insects, worms, and sea slugs. A major advantage of this work lies in the possibility of a greater range of surgical, chemical, and other material interventions in the normal brain activity.

Because memory capabilities, functions, and processes of any two species are always not only similar in some ways but also different in others, some of the methods, findings, and theoretical ideas about human memory have no direct parallels and no direct applicability to nonhuman animals. Thus, there are as yet no known means that could be used to separate implicit from explicit retrieval, or to distinguish between what animals remember and what they know, or what they recollect and what they find merely familiar. Therefore, the important distinctions that shape thought about human memory cannot be transferred forthwith into the study of learning and memory in nonhuman animals. This simple fact also imposes certain limitations on the extent to which the findings from animal studies can be generalized to humans. When these limitations are kept in mind, however, and flat generalizations are avoided, study of memory in one species can be invaluable in providing useful information and offering inspiration to the study of memory in others. The basic structural similarity among the brains of all mammals, especially primates, cannot be gainsaid, and this structural similarity clearly implies *some* functional similarity as well. The challenging task is to identify exactly wherein the similarities lie.

Conclusion

This, then, is a brief description of the framework within which much of the neurocognitive research takes place. In one way or another, more or less directly, many empirical findings and most major theoretical ideas and debates involve memory processes, retrieval-related awareness, and memory systems. Study of amnesia and other forms of memory impairments, and theoretical disputes about it, revolve around issues of memory processes, memory awareness, and memory systems. Studies of functional neuroanatomy of memory, made possible by novel techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are focused on memory processes, their interactions with the type of remembered material, and on differences between implicit and explicit retrieval.

The outsider who is not familiar with the field should gain some idea from this section about where cognitive neuroscience of memory stands at the turn of the millennium. The insider who knows what the situation was like only 5 years ago, when the first edition of *The Cognitive Neurosciences* appeared, should find that great changes have occurred since then. New techniques, such as the use of excitotoxic lesions, described by Murray (chapter 52), have produced data that, by past standards, can be regarded as revolutionary. New phenomena, such as "false remembering" discussed and dissected by Schacter and Curran (chapter 58), were not only unknown but also even largely unimaginable 5 years ago. Moreover, most everything that functional neuroimaging techniques (PET and fMRI) have revealed about human memory, as described and analyzed by Buckner (chapter 57), has been discovered in the last 5 years. Stress-related memory impairments and the real possibility that what were thought of as "psychogenic amnesias" have as real a physiological basis as "organic amnesias," discussed by Markowitsch (chapter 54), are newcomers on the memory scene. Even approaches that have been in use for a while, such as psychopharmacology (chapter 55), event-related potentials (chapter 56), single-unit recording (chapter 51), and the study of amnesic patients (chapter 53) have yielded new discoveries and fresh insights of a kind that attest genuine progress in the field.

These are exciting times in neurocognitive memory research. Happenings at the horizon point to the next 5 years being even more so.

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