

Introduction

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MEMORY is many things, even if not everything that has been labeled memory corresponds to what cognitive neuroscientists think of as memory. Memory is a gift of nature, the ability of living organisms to retain and to utilize acquired information or knowledge. The term is closely related to *learning*, in that memory in biological systems always entails learning (the acquisition of information) and in that learning implies retention (memory) of such information.

Memory is a trick that evolution has invented to allow its creatures to compress physical time. Owners of biological memory systems are capable of behaving more appropriately at a later time because of their experiences at an earlier time, a feat not possible for organisms without memory.

Memory is a biological abstraction. There is no place in the brain that one could point at and say, Here is memory. There is no single activity, or class of activities, of the organism that could be identified with the concept that the term denotes. There is no known molecular change that corresponds to memory, no known cellular activity that represents memory, no behavioral response of a living organism that *is* memory. Yet the term *memory* encompasses all these changes and activities.

Memory is a convenient chapter heading designating certain kinds of problems that scientists study. Methods of science have been brought to bear on the problems of memory for over a hundred years, in many different organisms, and at many different levels of

analysis, extending from molecular mechanisms to phenomena of conscious awareness.

The eight chapters in the Memory section of *The Cognitive Neurosciences* provide summaries of and glimpses into contemporary memory research. The overarching concern has been the search for the identity of the neural substrates of memory and for understanding of the correlation between neural mechanisms and memory processes.

Two recent conceptual developments have played an especially significant role in shaping the temper of today's research. One represents a consequence of the analytical and empirical separation of encoding, storage, and retrieval processes in human memory. As a result, it is no longer adequate to talk about, say, variables affecting "memory performance," or conditions responsible for "memory impairment." *Performance* and *impairment* now have to be specified in terms of specific memory processes and their interaction. The other development concerns the discovery, or the emergence of the concept, of different dissociable forms of memory, or multiple memory systems. Against the backdrop of traditional thought, this is a radical idea whose eventual implications and ramifications may well exceed all current expectations.

Although one finds suggestions in the earlier literature that learning and memory may assume different forms, the prevalent even if unarticulated view used to be that the underlying mechanisms of all learning and memory are basically the same. This unitarian view, rooted in the desire to adhere to the principle of parsimony, succeeded in escaping inimical data for a long time. Yet it overlooked the fact that nature itself is seldom parsimonious, and that, as has been noted, evolution is a tinkerer, not an engineer. Facts that are difficult to fit into the unitarian framework have been appearing on the scene, under the rubric of task dissociations, with accelerated frequency.

The new concepts of memory processes and memory systems have considerably changed the way cognitive neuroscientists pursue their mission. The quest for understanding of the identity and localization of the neural substrates of what we call "memory" has metamorphosed into the search for the neural correlates of encoding, consolidation, storage, and retrieval, separately for the different, dissociable forms of memory. Thus, for instance, it is now reasonably clear that the hippocampal structures are necessary for the encoding and consolidation of some but not other kinds of input,

but that they do not play a significant role in the retrieval of any kind of stored information. All eight chapters that constitute the Memory section of *The Cognitive Neurosciences* are concerned with some aspect of this basic issue of the identity and localization of different processes of different forms of memory.

Historically, the basic questions regarding the neural substrates of memory were two. The first one was: Are memories localized in the brain? The "localizationists," who included Broca, Fritsch, Hitzig, and Ferrier, said yes; their detractors, the "integrationists," whose roster included Flourens, Franz, and Lashley, said no. As in all difficult-to-decide issues, the fortunes of the two sides have waxed and waned indecisively over time, and are likely to continue to do so in the foreseeable future. In our Memory section, Squire and Knowlton represent the localizationist camp, whereas Markowitsch holds aloft the integrationist banner. The second question was raised by those who adopted the affirmative position regarding localization: Where are memories localized? During much of the history of the science of memory, the relevant evidence on this question was derived from brain-damaged patients whose lesions could be identified. After the famous case of H. M. appeared on the scene, with well-documented bilateral surgical lesions in the medial temporal lobes, including the hippocampus, the hippocampal structures that were already known to be implicated in memory disorders were rapidly elevated to the position of prime candidate for the "seat of memory."

Today's consensus holds that the limbic system, including the hippocampal structures, plays a critical role in certain forms of memory, even if that role and the exact identities of the "certain forms" are not yet clear. In addition the consensus holds that some other brain regions are also involved in memory processes. One of the most thoroughly studied of these other regions is the frontal lobes, although their role in memory has been somewhat controversial. Shimamura's chapter provides a contemporary review of some of the issues and some of the evidence.

Lesion analysis has yielded a great deal of valuable intelligence about the brain-mind interaction. But it is not without problems, as its critics have been fond of pointing out. This is why recent technological developments that allow objective observation of the activity of living brains engaged in cognitive tasks have been eagerly welcomed by students of memory. Two chapters in the present collection cover these developments.

Rugg discusses the promise of, and problems with, the use of evoked (event-related) potentials to track the happenings at the neural level that accompany memory processes, while Roland et al. present an overview of the recent achievements of, and remaining difficulties with, the use of positron emission tomography (PET) in identifying brain regions that are involved in various operations of memory.

The other chapters bring to the reader the latest word on the "kinds" of memory that localizationists, integrationists, electrophysiological recorders, and brain imagers have to keep apart in their probes into memory. Baddeley presents an analysis of working memory, the human brain/mind's executive functions that integrate cognitive information from a variety of sources, including recent inputs, for use in meeting the needs of the present. Schacter provides an overview of some of the latest discoveries in the domain of implicit memory, which is currently one of the "hottest" areas

of memory research. Tulving presents a classificatory scheme of five major human memory systems and considers their interrelation in terms of the seriality, parallelism, and independence of the processes of information acquisition, storage, and retrieval.

The advances that have been made over the last one hundred years in the understanding of the brain/mind of memory have been steady and substantial, even if at times they have appeared to be frustratingly slow. Over the last 20 years or so, however, the pace of discovery has quickened. The painstaking early studies have now laid a solid foundation on which to build; the new techniques and methods will deepen our understanding of the workings of the brain/mind; and, perhaps most important, new insights into the basic character of memory, and the character of the scientific problem of memory, will help to guide research in even more rewarding directions.

54 Organization of Memory: Quo Vadis?

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ABSTRACT Research in cognitive psychology and neuropsychology of memory has produced a wealth of data that can be meaningfully ordered with the help of two general classes of concepts—memory processes and memory systems. This chapter proposes a simple model of organization of memory in which cognitive memory systems are related to one another in terms of the principal processes of encoding, storage, and retrieval. The central assumption of this SPI model—serial, parallel, independent—is that the relations among systems are *process specific*: Information is *encoded* into systems *serially*, and encoding in one system is contingent on the successful processing of the information in another system; information is *stored* in different systems in *parallel*; and information from each system can be *retrieved independently* of information in other systems.

Memory is one of Nature's most jealously guarded secrets. At the beginning of the second century of its scientific study, it continues to baffle, frustrate, and mystify those who would explore it. Although we have learned a great deal about memory over the years, it often seems that whenever we discover yet another previously unknown fact about memory, we have succeeded in adding more to what there is to know than to what we do know.

Past research has generated an immense wealth of data, and more is being added every day. In cognitive psychology alone we have a staggering number of findings and facts. Surprisingly perhaps, from the perspectives of some other disciplines, these findings and facts are reliable and robust. The problem of replicability of data hardly ever arises. Over a hundred years of patient and sometimes plodding study we have apparently learned a few useful tricks about how to get Nature to provide reasonably consistent answers to the questions that we are capable of putting to her in the form of experiments. However, our success has been

somewhat less remarkable in interpreting and making sense of this abundance of data (cf. Tulving, 1979). There is less agreement among practitioners as to what the findings and facts tell us about the larger picture of memory than about what the findings and facts are that require explanation and understanding. Thus it is that a major challenge facing memory researchers today lies in correcting the imbalance between what we know well and what we know less well, the imbalance between what the facts about memory are and what they mean. How are we to make sense of the data? How are we to order the facts into a more comprehensive totality? What is the story that Nature, through the bits and pieces of empirical facts she has seen fit to share with us, is trying to tell us about the organization of the complex functioning structure that we think of as memory?

This chapter explores these questions and proposes some tentative answers. After a brief historical sketch, it describes a plausible organization of different forms of human memory, or memory systems, and then suggests how the different systems are related to one another in terms of some of the major processes of memory. The major objective of the chapter is to take the first step toward integrating memory processes and memory systems.

A historical sketch

The first era of scientific memory research began with Ebbinghaus (1885) and ended around 1960. This was the long period of "verbal learning." Its emphasis was on experimental design and precise measurement of basic phenomena of learning and forgetting, in normal adults, of serial and paired-associate lists of verbal items. The concept of association, and its single property of "strength," explained most of the known facts to the satisfaction of most practitioners.

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Around 1960 the associative verbal learning framework was largely replaced by the "information processing" paradigm. A wider variety of problems, issues, approaches, methods, and theoretical interpretations were adopted. Paired-associate and serial learning procedures were largely abandoned in favor of free and cued recall, as well as recognition and various kinds of memory judgments—recency, frequency, and the like. Experimental studies of short-term memory led to theoretical distinction between primary (short-term) and secondary (long-term) memory. Units of analysis shifted from lists to single items. Experimenters and theorists began to think of single items as "to-be-remembered events." The analytical distinction between storage and retrieval was translated into experimental paradigms that allowed the separation of the two processes. Influential theoretical concepts such as levels of processing, encoding specificity, and encoding/retrieval interactions emerged during this stage, as did "context" and "context effects." Connections were established between the previously isolated disciplines of cognitive psychology and neuropsychology. The concept of association as the basic theoretical building block was replaced by the concept of multiple processes, among which encoding, storage, and retrieval played a dominant role.

The current era of research, beginning sometime around 1980, can be thought of as cognitive neuroscience of memory. It is characterized by further expansion and liberalization of methods, techniques, and choices of questions and problems. The domain of "memory" has expanded considerably, both horizontally and vertically. The dominant concepts of the era so far have been *priming* and *memory systems*. There has been a steadily growing convergence between cognitive psychology and neuropsychology; interest has deepened in the study of learning and retention in memory-impaired patients; increasingly more attention is being paid to memory across life-span development; theoretically motivated and precisely controlled psychopharmacological studies of memory have appeared on the scene; computer modeling of memory processes has become more and more sophisticated; and the neuroimaging approach to the study of memory is rapidly overcoming its initial difficulties. This is the age of multidisciplinary study of memory.

All three epochs of memory research have contributed to the data and theory. The major theoretical tools that are available today for ordering the data

have been developed in more recent times. They can be conveniently divided into two main classes of concepts—*memory processes* and *memory systems* (Tulving, 1991). Memory processes represent a bequest of the information-processing era. Their story has been told in some detail by a number of writers elsewhere (e.g., Crowder, 1976; Eysenck, 1977; Klatzky, 1980; Tulving, 1983). The concept of memory systems is a gift of the cognitive neuroscience of memory (e.g., Shallice, 1979; Warrington, 1979; Tulving, 1983, 1985a; Cohen, 1984; Mishkin, Malamut, and Bachevalier, 1984; Schacter and Moscovitch, 1984; Weinberger, McGaugh, and Lynch, 1985; Weiskrantz, 1987). The time seems ripe now for uniting the two sets of concepts—processes and systems—into a more comprehensive framework. To set the stage for such an understanding, we consider first what we know about different memory systems.

Human memory systems

Our current understanding of the organization of human memory has gradually evolved from various conceptual dichotomies: memory and habit, short-term and long-term memory, episodic and semantic memory, procedural and declarative memory, and the like (e.g., Sherry and Schacter, 1987; Schacter and Tulving, *in press*). Combining these dichotomies into a more general scheme allows us to identify at least five major categories of human memory, or memory "systems," together with a number of subcategories or subsystems. These systems and subsystems are listed in table 54.1.

The procedural systems are behavioral or cognitive *action* systems, whereas the other four forms in table 54.1 are cognitive *representation* systems. One of the major differences between the two kinds of system lies in the feasibility of characterization of the changes that result from learning or acquisition in a propositional or some other symbolic form: it is possible to do so for the four cognitive systems, but not quite possible for the procedural systems. The operations of procedural memory are expressed in the form of skilled behavioral and cognitive procedures independently of any cognition. Skillful performance of many perceptual-motor and cognitive tasks, such as balancing a stick on one's finger or reading text, are examples of tasks that depend heavily on the procedural memory systems.

The other four systems mediate changes in cognition, or thought. In the course of normal activity of an individual, the computational outputs of the cognitive

TABLE 54.1
Major categories of human learning and memory

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

memory systems typically guide overt behavior, but such conversion of cognition into behavior is not an obligatory part of memory. Rather it is an optional postretrieval process. The ultimate output of cognitive memory systems is expressed in conscious awareness, which can, but need not, be converted into overt behavior such as verbal expression. Behavioral responses that subjects make in cognitive memory tasks in the laboratory serve merely as reports of cognitive processes.

Perceptual priming—recently reviewed by Schacter, Chiu, and Ochsner (1993) and by Roediger and McDermott (1993), and covered by Schacter's chapter in this volume—is a special form of perceptual learning that is expressed in enhanced identification of objects as structured physical-perceptual entities. A perceptual encounter with an object on one occasion primes or facilitates the perception of the same or a similar object on a subsequent occasion, in the sense that the identification of the object requires less stimulus information or occurs more quickly than it does in the absence of priming. Because perceptual priming represents a rudimentary capability whose biological utility seems to be obvious, it seems reasonable to expect that it is represented across a wide spectrum of species. Nevertheless, priming has not yet been observed or measured in non-human animals or in preverbal humans.

Semantic memory makes possible the acquisition and retention of factual information in the broadest sense; the structured representation of this information,

semantic knowledge, models the world. Semantic knowledge provides the individual with the necessary material for thought, that is, for cognitive operations on the aspects of the world beyond the reach of immediate perception. The semantic memory systems are not tied either to language or to meaning. The designation *semantic memory* is merely a historical accident, and a better phrase to refer to the same concept might be "general knowledge of the world." It is a conjecture that human semantic memory has evolved from the spatial learning and knowledge of the ancestors of humans.

Primary memory, also referred to as short-term memory or working memory, registers and retains incoming information in a highly accessible form for a short period of time after the input. Primary memory, like other memory systems, is identified through dissociations of its products from those of other systems. It makes possible a lingering impression of the individual's present environment beyond the duration of the physical presence of the stimulus information emanating from the environment. This topic is covered in Baddeley's chapter in the present volume.

Episodic memory enables individuals to remember their personally experienced past, that is, to remember experienced events as embedded in a matrix of other personal happenings in subjective time. It depends on but transcends the range of the capabilities of semantic memory. The most distinctive aspect of episodic mem-

ory is the kind of conscious awareness that characterizes recollection of past happenings. This awareness is unique and unmistakably different from the kinds of awareness that accompany perceptual experiences, imagining, dreaming, solving of problems, and retrieval of semantic information. To distinguish the episodic-memory awareness from these other kinds, it has been referred to as *autonoetic consciousness* (Tulving, 1985b).

Relations among memory systems

Two entries in table 54.1, semantic and episodic memory, are sometimes categorized together as *declarative* (Squire, 1982) or *propositional* (Tulving, 1983) memory, as they share a number of features. Another frequently used distinction is that between implicit and explicit memory (Graf and Schacter, 1985; Schacter, 1987a). These are not memory systems, but forms of *expression* of memory. Implicit memory designates the expression of stored information without awareness of its acquisition coordinates in space and time, that is, expression of what the individual has learned without necessarily remembering how, when, or where the learning occurred. Explicit memory, on the other hand, refers to the expression of what the person is consciously aware of as a personal experience. Retrieval operations in the earlier systems, as shown in table 54.1, can be said to be *implicit*, whereas in the later systems they are *explicit*.

The forms of memory in table 54.1 are listed in order of their assumed emergence, from the earliest to the latest, both with respect to the phylogenetic and ontogenetic development, and with respect to the dependence relations that govern certain aspects of their operations. Thus, procedural forms of learning and memory probably evolved first and develop early in human infants, and episodic memory evolved last and develops later in human children. Learning to make appropriate responses to simple sensory stimuli (procedural memory) has obvious biological utility to organisms at all stages of evolution and development. So does the ability to identify objects in one's environment, and learning to do so quickly and effortlessly (perceptual priming). Forms of learning and memory that evolved later, such as primary or working memory and episodic memory, are not necessary for survival in a relatively simple and stable environment such as that in which the Paleolithic ancestors of humans lived, and in which human infants and amnesic patients live

today. Working memory becomes more critical when the demand arises for intra- and interindividual communication—that is, for abstract thought and language. Episodic memory becomes critical as a catalyst for the acquisition of knowledge of the world (semantic memory) through its capability of encoding and storing information about similar events at different times, and for counteracting associative interference (Tulving, 1991, 1993). The ordering of the major memory systems in table 54.1 also reflects the conjectured relations among the systems: Some of the operations of the later ones depend on, and are supported by, the operations of the earlier ones, whereas earlier systems can operate essentially independently of the later ones. We will return to this theme when we discuss the SPI model of organization of memory.

The evidence for the biological and functional separability of the categories and subcategories listed in table 54.1 is still fragmentary, largely indirect, and of variable quality and quantity. Much of the relevant information comes from the study of brain-damaged patients with *selective* memory impairments (Milner, Corkin, and Teuber, 1968; Warrington and Weiskrantz, 1968, 1974). To test the hypothesis that perceptual priming, semantic memory, and episodic memory, like other major categories of memory, represent different neurocognitive systems and subsystems requires the boot-strapping-like delineation and unraveling of the myriad relations among tasks and systems. It represents a formidable scientific challenge. A healthy beginning has been made, however, in the form of experiments conforming to the *task-comparison* methodology (Richardson-Klavehn and Bjork, 1988). Outcomes of different memory tasks that are known or assumed to be differentially weighted by contributions of different systems are systematically compared. Dissociations among these outcomes are regarded as providing support for the hypothesis of separability of systems. Outcomes of tests are said to be dissociated if they differ as a function of an independent variable, or if they differ for different groups of subjects or patients, or for different brain states. Dissociations contrast with *parallel effects*, observations that the manipulation of an independent variable or a treatment produces similar changes in the outcomes of different tasks, or different measures of memory performance.

When a number of different dissociations—yielded by different kinds of subjects, different tasks and situations, and different techniques—are seen as converging

on the same classificatory scheme, it becomes reasonable to hypothesize the existence of separate memory systems. Although dissociations of interest are usually observed first at the level of behavior, behavioral data on their own are seldom sufficiently compelling to preclude alternative interpretations of empirical facts. Classification of memory into different systems and subsystems requires a broad-based multidisciplinary approach. Functional analyses must be integrated with relevant neuroanatomical, neurochemical, and neurophysiological methods.

SPI model of organization of memory

The work in the mainstream cognitive psychology of memory during the information-processing era yielded not only a large array of interesting, unexpected, and robust empirical facts about memory. It also produced a remarkable consensus among practitioners regarding the interpretation of phenomena of memory in terms of processes such as encoding, storage, and retrieval, and the interactions among them (Crowder, 1976; Eysenck, 1977; Klatzky, 1980). More recently, systems-based views of memory have been making steady progress. Today our understanding of the relation between working memory and long-term memory (Baddeley, 1986), between episodic and semantic memory (Tulving, 1991, 1993), and between perceptual representation systems (PRS) and episodic memory (Schacter, 1990; Schacter, Chiu, and Ochsner, 1993) is considerably richer and sharper than it was only ten years ago. Given that the usefulness of conceptualizing memory in terms of memory processes and their interactions is almost universally accepted, and that the "structural" approach to memory—through postulation of multiple systems—is gaining ground, the time has now come to tackle the next problem, that of working out the relations between the two major classes of concepts of memory—processes and systems. Is there some systematic way of integrating memory processes and memory systems?

It is possible to propose a simple model, dubbed the SPI model, that may take us a step closer to this objective. SPI stands for *serial, parallel, and independent*. The model's central assumption is that the nature of relations among different cognitive systems is *process specific*: The relations among systems depend on the nature of the processes involved, as follows. (1) Information is *encoded* into systems *serially*, and encoding in one system

is contingent on the successful processing of the information in some other system, that is, the output from one system provides the input into another. (2) Information is *stored* in different systems in *parallel*. The information in each system and subsystem, even if it all originates in one and the same act of perception, or "study episode," is different from that in others, its nature being determined by the nature of the original information and the properties of the system. Thus, what appears to be a single act of encoding—a single glance at a visual display, or a single short learning trial—produces multiple mnemonic effects, in different regions of the brain, all existing (i.e., available for potential access) in parallel. Thus, with respect to storage, different systems operate in parallel. (3) Information from each system and subsystem can be *retrieved* without any necessary implications for retrieval of corresponding information in other systems. Thus, with respect to the process of retrieval, different systems are *independent*.

The SPI model holds for *cognitive* memory systems. Its possible extension to noncognitive systems requires further study. The current list of cognitive systems (table 54.1) includes PRS, semantic memory, primary or working memory, and episodic memory. According to the model, when an event such as the presentation of an unfamiliar but meaningful sentence occurs, information about different aspects of the event may be registered in all four systems, or their appropriate subsystems. Information embodying the structural features of constituent stimulus objects (words) is registered in the perceptual representation (word form) systems. In general, the PRS information tells the brain about the kinds of objects that exist in the world. (Priming does not seem to occur for objects that the brain interprets globally but that do not exist in the world (Schacter et al., 1991; Nilsson, Olofsson, and Nyberg, 1992). The products of the processing in PRS can be retrieved, as happens in priming experiments, or they can be forwarded to the semantic systems for more elaborate processing of the relations among the

TABLE 54.2
Process-specific relations among cognitive memory systems

Process	Relation
Encoding	Serial
Storage	Parallel
Retrieval	Independent

words and their meaning. The output of the semantic system tells the brain about the contingencies of the world. This output normally also reaches both the working memory and the episodic memory systems. The former allows further elaboration of the information in terms of various kinds encoding and rehearsal operations; the latter computes the temporal-spatial contextual coordinates of the incoming information in relation to already existing episodic information, or to the self. The SPI scheme provides for the distribution of the information generated by a single event through many regions of the brain, whereby different aspects of the information are coded in their own specific, possibly unique, forms in different regions. We do not yet know whether the information within a given system is tightly localized or more widely distributed.

In summary, the SPI model suggests one possible way of answering some of the questions that can be posed about the relations between and among cognitive memory systems: In what sense are memory systems and subsystems independent? In what sense are they interdependent? How do they interact? Do they operate in series? Does information enter into, or is it retrieved from, one system through another? Do they operate in parallel? The model proposes that there is no single answer to these questions: *Relations among systems are process specific*. Different systems are dependent on one another in the operations of interpreting, encoding, and initial storing of information. Once encoding has been completed, different kinds of information about the same initial event are held in various systems in parallel, depending upon the nature of the information and the evolved properties of the systems (Tulving, 1984a). Access to different kinds of information about a given event is possible in any system independently of what happens in other systems.

By relating different systems to one another through different processes, the SPI model suggests one way of integrating—bringing into a common reference frame—the concepts of memory processes and memory systems. As an abstract model, however, it specifies neither the nature of particular processes characteristic of different systems nor any neuroanatomical or neurophysiological substrates of the systems. It is compatible with many possible more specific and more concrete cognitive, neuropsychological, and neurocognitive models. For instance, we can replace any one of the abstract systems in the model with a corresponding (known or assumed) neuroanatomical concept—such

as the hippocampal structure—without changing the basic logic. The basic assumptions of process-specific relations among systems remain the same: Encoding is serial, storage is parallel, and retrieval can be independent.

The SPI model not only helps us to order known facts, it also makes specific testable predictions. On reflection, the list of such facts and predictions turns out to be reasonably long; we consider a few examples here.

1. The model predicts that double dissociations are possible between tasks whose execution draws heavily on the resources of different systems, but only in post-acquisition situations—that is, in situations involving retrieval of previously stored information. Double dissociations may *not* be possible in comparable situations—same tasks, or using same systems—in which encoding of new information is required. Consider the double dissociation in retrieval of episodic and semantic information. Some brain-damaged patients can retrieve previously acquired semantic-memory information better than they can retrieve previously acquired episodic-memory information (e.g., Cermak and O'Connor, 1983), whereas others show the opposite pattern (e.g., DeRenzi, Liotti, and Nichelli, 1987). Such a double dissociation, however, should not be possible in situations requiring new learning. Indeed, no patients have so far been described who can remember an autobiographical encounter, say, with a celebrity, but who do not know what the celebrity is known for. According to the model such a double dissociation between semantic and episodic memory is not possible, and only single dissociations (impaired episodic memory and preserved semantic memory) can occur.

2. The model allows stochastic independence of retrieval of information representing nominally identical individual items, as revealed by contingency analyses, from PRS and semantic memory (e.g., Tulving, Hayman, and Macdonald, 1991), or PRS and episodic memory (e.g., Tulving, Schacter, and Stark, 1982), while assuming that successful encoding of information into the semantic-memory system is contingent upon successful processing of information *through* the PRS, and encoding of information into the episodic-memory system is contingent upon successful processing of information *through* the semantic system. In the absence of the model, the two sets of findings—serial encoding dependency and stochastic retrieval independence—would appear puzzling.

3. The serial encoding dependency of the SPI model allows acquisition of information by an earlier system (such as semantic) even if later systems (such as episodic) are dysfunctional, but not vice versa. Thus the model accords with experimental and clinical observations that brain-damaged patients suffering from anterograde amnesia may be capable of acquiring new semantic information even when they have no conscious recollection of any learning episodes (e.g., Schacter, Harbluk, and McLachlan, 1984; McAndrews, Glisky, and Schacter, 1987; Shimamura and Squire, 1987; Glisky and Schacter, 1988; for a review see Tulving, Hayman, and Macdonald, 1991). The learning observed in these studies was always slower than that in normal controls, but it did occur. The model's accordance with the data suggesting that semantic memory can be at least partly intact while episodic memory is severely impaired contrasts with some other models that rule out such a possibility. For instance, Squire's (1987, 1992) hippocampally oriented dichotomy between declarative and nondeclarative memory, in which declarative memory is defined in terms of the learner's ability to acquire and store information about general facts and personally experienced events, cannot be readily reconciled with the findings of differential impairment of episodic and semantic memory.

4. The SPI model accords with the many findings of asymmetries in the acquisition and retrieval of information in the brain. For example, it is well known that the limbic areas, including the hippocampal structures, play a crucial role in the acquisition of new information. The evidence comes from many observations that damage to these structures renders such acquisition difficult or impossible. (See Squire and Knowlton's chapter in the present volume.) However, after the initial acquisition, hippocampal patients or animals can frequently retrieve the learned information without difficulty (e.g., Staubli and Lynch, 1987). The famous amnesic patient H. M., whose bilateral medial temporal lobe resection rendered him essentially incapable of learning any new semantic or episodic information, has a largely unimpaired IQ, indicating unhindered access to a great deal of previously acquired information, and he can also produce reports of recollections from his youth (Milner, Corkin, and Teuber, 1968). Similar findings of asymmetry between acquisition and retrieval have been reported from experiments with amnesic drugs, such as benzodiazepines: These drugs impair new learning of semantic and episodic

information, but leave retrieval of old learning intact (Lister, 1985; Ghoneim and Mewaldt, 1990).

5. Within the general framework of the SPI model it is possible to assume that the medial temporal lobe and diencephalic structures—damage to which frequently produces global amnesia—are critical for episodic memory insofar as episodic learning depends on the intact semantic systems. It is also possible to assume that other brain regions, including certain prefrontal cortical areas, are involved in the encoding and retrieval of aspects of personal experiences, such as temporal sequencing of separate and otherwise unrelated events (Milner, Petrides, and Smith, 1985; Schacter, 1987b). At Toronto we are currently exploring the hypothesis that the frontal pole regions (Brodmann Area 10) play a special role in episodic memory and autoegetic awareness of the past, and in projection of past experiences into the future in the form of plans and intentions (Ingvar, 1985; Tulving, 1985b; Stuss and Benson, 1986). We think of area 10, in addition to other prefrontal regions, as a promising candidate region in the quest for localization of episodic memory and autoegetic awareness, because, like episodic memory, it has evolved recently, it has appropriate connections to the limbic system, including the amygdala, and its function or functions are largely unknown (Pandya, personal communication, 1993).

Quo vadis?

The current version of the SPI model represents an extension and elaboration of earlier ideas concerning the relations among memory systems, especially the conjecture that, contrary to popular views, episodic memory evolves and develops later than, and in its operations depends upon, semantic memory (Tulving, 1984b, 1985a). It has clear affinities to other theories of organization of memory. Thus, to give just a few of many possible examples, it shares with Weiskrantz (1987) the current listing of five major systems, with Squire (1987) the ideas of earlier (nonhippocampal) and later (hippocampal) systems, with Johnson (1983) the notion of multiple entries of information into different systems, and with Moscovitch (1992) the emphasis on the nature of interrelations among memory processes and components.

With respect to serial processing of information through various systems at encoding, the SPI model is closely related to Lynch and Granger's (1992) "assem-

bly line" model. In the Lynch and Granger model, too, operations occur in a serial fashion, leading, among other things, to "the expectation that late functions can be dissociably removed without affecting early functions, but that damage to early functions will also damage late functions" (1992, 1996). Lynch and Granger come to their views on the basis of work on long-term potentiation as a possible storage mechanism of olfactory memory in rats, whereas the (mono) hierarchical features of the SPI model were suggested, among other things, by observed dissociations between forms of awareness associated with retrieval of personal and impersonal information in memory pathology (Tulving, 1985b; Tulving, Hayman, and Macdonald, 1991). Such a convergence of ideas from two rather different starting points may be purely coincidental. It is also possible, however, that the convergence reflects something more than just an accident. It may even point to the future, providing a hint of an answer to the question, Organization of memory: Quo vadis?

Conclusion

The proposal for organization of memory as described is just that, a proposal. The scheme will undoubtedly turn out to be inadequate, deficient, or just plain wrong. It nevertheless provides an explicit starting point for a more systematic pursuit of what is clearly the next problem that needs to be tackled. In science, as in chess, a plan or a theory, even a poor one, is better than no plan or theory at all. The confusion that usually prevails in the absence of a theory is likely to breed only more of the same, whereas an incorrect theory can be always be corrected.

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