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12

Processing Subsystems of Memory

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Most students of cognition assume that human memory is not an undifferentiated system; at issue is how to conceptualize the parts of this system. We suggest that one fundamental division is between memories for the consequences of perceptual processing, such as seeing and hearing, and memories for the consequences of reflective processing, such as planning, comparing, and imagining. Cognition typically mixes both perceptual and reflective processing with such artful coordination that both phenomenal experience and memories for experiences possess an integrated, holistic quality. Consequently, the line between perceptual processing and reflective processing is often difficult to draw. Nevertheless, to understand the blend one must understand the ingredients—the separate perceptual and reflective mechanisms contributing to mental experience.

It should be emphasized at the outset that the perceptual processes we refer to include what are commonly called *top-down* as well as *bottom-up* processes (e.g., Palmer, 1975). People may make unconscious inferences in order to perceive depth, or their perception of a single word may be affected by their expectations and beliefs. In either case, the processing that yields depth perception or lexical access would not have occurred at that time if information had not impinged upon the sensorium in the first place. Such processing, which is *dependent* on the external world, constitutes perceptual processing. Other processing, of course, can occur independent of sensory stimulation. People can imagine, plan, develop beliefs, and solve problems without continuous guidance from external cues. Such independent internal processes are what we are referring to as reflective.

Memory here is assumed to record the processing underlying cognitive activities, not some further consequence of the processing (Kolers & Roediger, 1984). Memory is treated as an integral part of certain cognitive processes and not a separate mechanism. Recent work on connectionist networks illustrates the point. In a connectionist network, perception or categorization is a function of the weights of the connections, but the act of perceiving or categorizing also changes the weights (Rumelhart & McClelland, 1986). Thus, the processes that yield a perception or categorization also change the nature of subsequent processing by changing the weights on which this processing depends. A close tie between process and memory suggests that it may not make much sense to talk separately about process and memory. To claim that two processes involve different processing systems is equivalent to claiming that two different memory subsystems exist. Therefore, if we want to understand the nature of different memory subsystems, we must understand the processing these memory systems record.

A Working Framework

The framework we describe is an expansion of Johnson's multiple entry, modular memory system, or MEM (Johnson, 1983, 1990, 1991a). In developing this framework, we have been guided by introspection, a large body of evidence and theorizing from experimental cognitive psychology, and neuropsychological findings. We adopt the following terms to refer to different levels of analysis: The term *component* refers to the most primitive concepts in the present framework (these may be further decomposed in the future or for other purposes). *Subsystem* refers to the coordinated activities of two or more component processes; a *system* coordinates activities from two or more subsystems; and *memory* is a summary term for the coordinated activity of all memory systems. Of course, which level of analysis in this scheme is identified as a memory "system" is somewhat arbitrary. For example, even individual components may be considered systems in the "weak" sense (see Sherry & Schacter, 1987).

According to MEM, memory contains distinguishable perceptual and reflective memory systems. Positing these distinct memory systems has heuristic value, in that it has provided a means of organizing empirical facts obtained from cognitive/behavioral studies of normal memory (Johnson, 1983), a framework for interpreting observations about patients suffering from amnesia (Johnson, 1990), delusions (Johnson, 1988a), and confabulation (Johnson, 1991a), and has also generated new research (Hirst, Johnson, Kim, Phelps, Risse, & Volpe, 1986; Hirst, Johnson, Phelps, & Volpe, 1988; Johnson & Kim, 1985; Johnson, Kim, & Risse, 1985; Johnson, Peterson, Chua-Yap, & Rose, 1989; Weinstein, 1987; see also Johnson, 1990). The division between perceptual and reflective memories may capture functional organizations within the nervous system as well. Several behavioral dissociations support this claim. For example, reflective processing develops later than perceptual processes (e.g., Flavell, 1985; Moscovitch, 1985; Perlmutter, 1984; Schacter & Moscovitch, 1984). Moreover, reflective processes are more likely to be disrupted by stress, depression, aging, and the use of alcohol and other drugs than are perceptual processes (Craik, 1986; Eich, 1975; Hasher & Zacks, 1979, 1984; Hashtroudi & Parker, 1986). Furthermore, the breakdown in memory functioning found in patients with anterograde amnesia appears to fall disproportionately on reflective memory (Johnson, 1983; chapters in Cermak, 1982; Hirst, 1988). Conversely, reflective processes may be relatively intact while perceptually guided processes are disrupted, as in agnosias or certain cases of disrupted perceptual–motor skill learning. For example, there is evidence that Huntington's disease patients are impaired relative to Alzheimer's disease patients on a perceptual–motor skill task but Alzheimer's patients show the greater impairment on a recall task (Heindel, Butters, & Salmon, 1988).

Perceptual Memory

A closer analysis of perceptual memory suggests several divisions within the perceptual memory system. Perceptual processing can be divided along the lines of different perceptual modalities (seeing, hearing, etc.), but it can also be divided along amodal dimensions. For example, much of what people learn, regardless of modality, requires the processing of invariants in a complex stimulus array. People are not necessarily aware of this processing or of these invariants. In order to understand a speaker with an unusual accent, people must learn to distinguish cues in the speech signal that specify various phonemes, yet they may be unable to consciously isolate the relevant information or to tell someone what it is. Similarly, in learning to catch a ball, people have to coordinate their activity with changes in aspects of the stimulus array such as the rate of change in the size of the stimulus as a function of time. The memory system involved in recording these kinds of perceptual learning is called P-1.

On the other hand, other products of perceptual processing, namely, the phenomenal experiences of objects and events, are consciously accessible. Listeners may not know how they have adapted to a speaker's accent, but they know what words they have just heard. Ballplayers may not know what aspects of the changing stimulus array allowed them to catch a ball, but they know it is a ball they have caught. Such differences suggest that memory for perceptual phenomenal experience may involve a system other than P-1, which we call P-2.[1]

The postulation of P-1 and P-2 memory subsystems corresponds to the claim that there are interesting, functionally important differences in the memorial consequences of P-1 and P-2 perceptual processing. Recent neuropsychological studies provide dramatic examples of such a division in perceptual processes. Several studies have demonstrated that P-1 processing may take place although P-2 processing is disrupted. For instance, agnosic patients have a conscious awareness that an object is in front of them, but cannot identify it. Rather they claim that they see individual features without being able to assemble them into a whole (Luria, 1973; Marcel, 1983). In studies of other patients with brain damage, some patients can make perceptual discriminations without being aware of the object itself. Patients suffering from prosopagnosia may show a galvanic skin response to familiar faces even when they cannot consciously recognize the face (Damasio, 1985). Volpe, LeDoux, and Gazzaniga (1979) found that patients with extinction, who cannot identify an object if simultaneously presented with another object in the contralateral field, could nevertheless indicate whether the two simultaneously presented objects were the same. Blindsight patients can point to objects that they claim not to see (Weiskrantz, 1986).

Reflective Memory

Reflective processing can be sustained by internal events and can be independent of external events. The evolutionary development of reflective capabilities produced an explosion of mental possibilities: People can consider analogues of perception (images) in the absence of the corresponding object or event; they can plan, solve problems, generate alternative futures, concoct beliefs, and come to doubt these beliefs. Although we cannot yet list all the component subprocesses involved in reflection, much less the relations among them, a modest and, it is hoped, tractable beginning is to consider a minimum set of components that could, in principle, yield reflection approaching the complexity we observe in normally functioning adult humans.

A reasonably powerful reflective system would include at least four types of component subprocesses, which might be called *noting, shifting, refreshing,* and *reactivating* (Johnson, 1990). These processes activate or affect the activation of already established memories or concepts and thereby establish new memories. *Noting* involves identifying relations among activated objects or events; *shifting* involves a change in perspective that activates alternative aspects of objects or events; *refreshing* prolongs ongoing activation through attentional processes; *reactivating* brings information that has dropped out of consciousness back to an active (though not necessarily conscious) state. To these four components of reflection, we need to add *supervisor functions* that set agendas or goals and monitor outcomes (Miller, Galanter, & Pribram, 1960; Nelson & Narens, 1990).

These four processes can vary in the extent to which they are strategically driven or deliberate. To mark this deliberative dimension of reflection, when noting, shifting, refreshing, and reactivating are carried out under strategic control, they might be called *discovering, initiating, rehearsing,* and *retrieving,* respectively. The control processes that set agendas and monitor outcomes in the case of strategic reflection might be called *executive functions.*

In sum, a simple but powerful reflective system has to have several component processes, including supervisor and executive functions, for sustaining, organizing, and reviving events. These processes must be represented by at least two levels of reflection that differ in degree of deliberation. The two organized groupings of reflective component processes corresponding to these two levels can be thought of as two reflective subsystems, R-1 and R-2 (see Figure 12.1). The component processes within and between

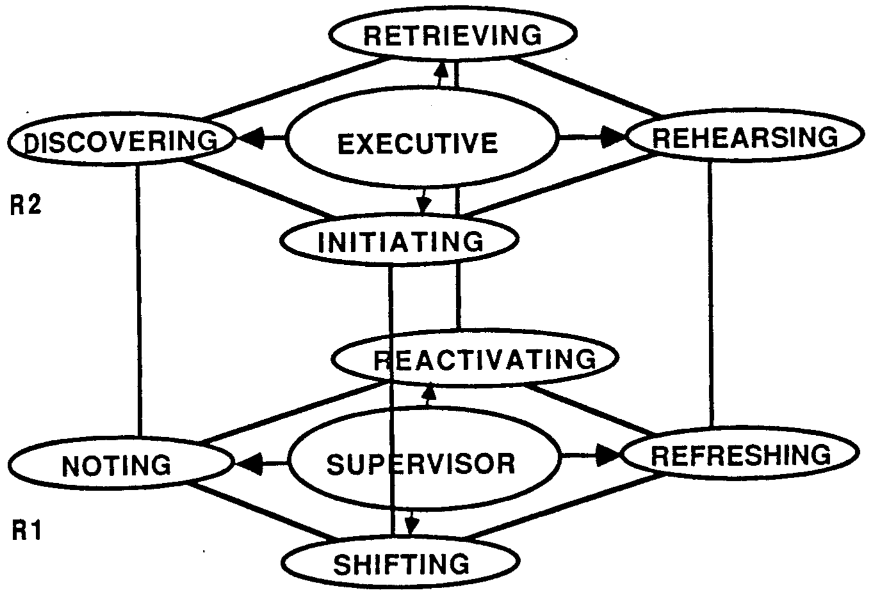

Figure 12.1 Reflective processes differ in degree of deliberation. Basic reflective processes (noting, shifting, refreshing, reactivating, and supervisor functions) are represented on the bottom of the cube and corresponding but more strategic reflective functions (discovering, initiating, rehearsal, retrieval, and executive functions) are represented on the top of the cube.

levels work together to allow mental activity to go beyond immediate perception.

Like the perceptual memory system, the reflective memory system is a record of prior processing. The distinction between R-1 and R-2 processes yields distinguishable reflective memory subsystems, also called R-1 and R-2. In theory, manipulations of reflective memory could differentially affect the various component processes in R-1 and R-2.

Activation of Memories

The processing at any point in time is recorded in the perceptual and reflective memory subsystem(s) that are active. At some future time, these records may be activated. By activation, we mean that the processing record is being replayed, so to speak (Kolers & Roediger, 1984). Exactly what is activated will depend on the kind of task probing memory. Complex experiences typically elicit a host of processes, and these complex mental events will yield memorial representations distributed across various memory subsystems. A task that probes memory may activate all or only some of this multiple and complex representation. Evidence of memory depends on an appropriate match between earlier processing and processing produced by the memory probe (e.g., Morris, Bransford, & Franks, 1977; Tulving &

Thompson, 1973). A perceptual identification task, for instance, may rely relatively more on representations formed by P-1, and a recognition task relatively more on representations formed by P-2 (e.g., Jacoby & Dallas, 1981). Recall, on the other hand, may depend critically on the reflective system (e.g., Hirst, Johnson, Kim, Phelps, & Volpe, 1986). A full understanding of different memory tasks would involve a clear articulation of the different subsystems the tasks call upon (also see Moscovitch, Winocur, & McLachlan, 1986).

The extent to which an individual is aware of the activation of a process will vary as a function of what kinds of processes and corresponding memory subsystems are involved and the kinds of interactions among activated processes. Thus consciousness is an emergent property of activation. Not all activated processes result in consciousness (e.g., see Kihlstrom, 1984). For instance, people are more likely to be conscious of R-2 processes than of P-1 processes even if both are activated. Moreover, one activated process may prevent another from becoming conscious, as in a divided attention experiment. In this regard, an activated process of which we ordinarily are not conscious may become conscious if activation of other processing is eliminated. Finally, consciousness may be determined by such factors as the degree of mutual activation among related elements, success in recruiting attention, and inhibition among patterns involving common elements or processing structures (e.g., Norman & Shallice, 1986).

Interaction Between Perceptual and Reflective Memory

In addition to specifying the component processes of perceptual and reflective memory, how perceptual and reflective subsystems interact must be specified. For example, representations from one subsystem may directly activate related representations from another, or interactions between perceptual and reflective memory may take place through supervisor and executive components (see Figure 12.2). A goal such as *look for a restaurant* might activate relevant perceptual schemas from perceptual memory as well as reflective plans adapted to the current situation (find a parking place, check the restaurant guide for this part of town, etc.). Typically, supervisor and executive functions have greater access to reflective memory than to perceptual memory, and greater access to P-2 than to P-1 subsystems. Also, through supervisor and executive functions, other component reflective processes (e.g., refreshing, reactivating) can be applied to representations in P-2, and perhaps in P-1.

It is important to emphasize that we do not define subsystems in terms of their complete independence or lack of interaction with each other. Rather, it seems more likely that subsystems must interact to support complex cognition and action. Characterizing this interaction remains a major challenge.

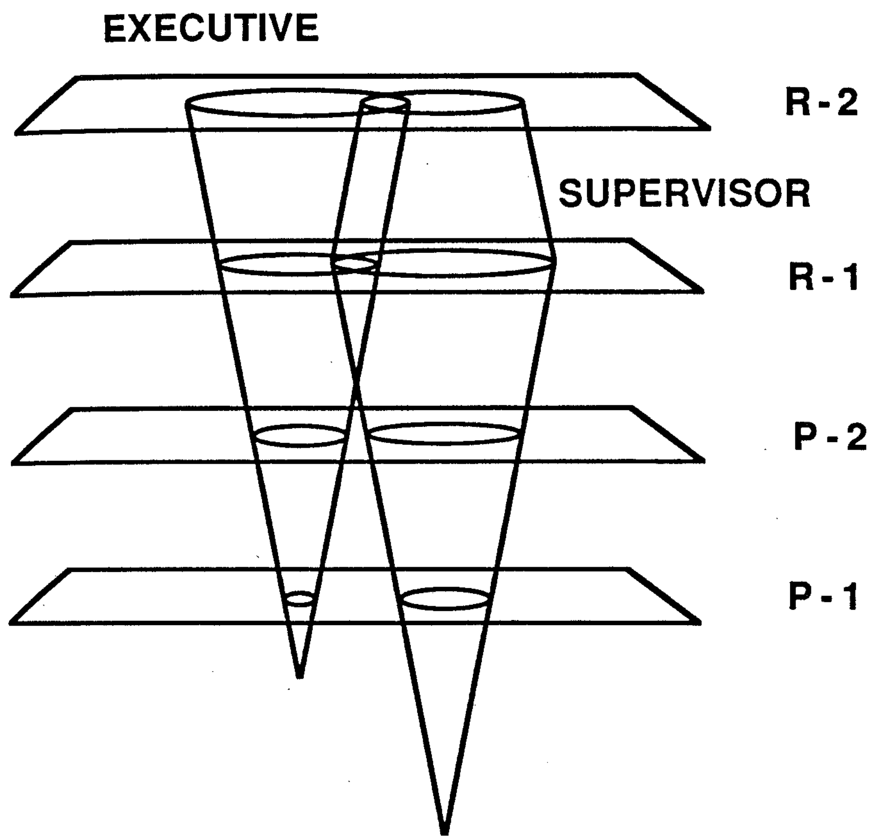

Figure 12.2 Reflective and perceptual subsystems interact through supervisor and executive processes, which have relatively greater access to and control over reflective than perceptual subsystems.

Relation of MEM to Other Concepts

The conception of memory outlined in the last section draws on (and in some cases expands) a number of related ideas in the memory literature. For example, the concepts of *shifting* and *noting* are based on the demonstrated critical importance of organizational processes for recall (e.g., Mandler, 1967; Tulving, 1962). To further clarify the present framework, a brief discussion of its relation to several other ideas follows:

Supervisor and Executive Processes

One could represent monitoring and control functions as a single executive system that is separate from memory (e.g., Stuss & Benson, 1986), but in the present conceptualization, supervisor and executive functions are embedded within the reflection subsystems because learning and remembering depend critically on such functions. Supervisor and executive processes direct and monitor other processes (e.g., rehearsal) that have memorial consequences and new combinations of supervisor and executive processes themselves can be learned and remembered (e.g., a new learning strategy).

Automatic versus Effortful Processes

The distinction between automatic and effortful, or automatic and controlled processes (e.g., Hasher & Zacks, 1979, 1984; Shiffrin & Schneider, 1977) easily fits within the present framework. Automatic processes are those that seem to require no (or only minimal) executive functions; the most controlled processes require R-2 functions involving deliberate, conscious activity. Varying degrees of control would depend on how many or which reflective components are involved. The distinction between P-1 and P-2 and between R-1 and R-2 memory subsystems emphasizes that controlled processes are intimately involved in memory (Shiffrin & Schneider, 1977), yet also allow for the possibility that some types of memory depend less than others on deliberate processing (e.g., Eich, 1984; Hasher & Zacks, 1979; Jacoby, Woloshyn, & Kelley, 1989).

Short-Term versus Long-Term Memory

The distinction between short-term memory (STM) and long-term memory (LTM) can also be represented in MEM. In MEM, short-term memory (or working memory) as "capacity" could be identified either with the set of activated information with functional consequences or with the even more restricted subset of activated information of which we are aware. STM as "process" could be identified with the refreshing and rehearsing components of reflection. In any event, in MEM there is not a single STM buffer; rather, STM or working memory is distributed throughout the subsystems (Baddeley, 1983; Baddeley & Hitch, 1974). LTM would be the records of prior processing represented in all subsystems.

Episodic versus Semantic (or Generic) Memory

It has been proposed that general knowledge or semantic memory and specific incidents or episodic memory are different subsystems of memory (Tulving, 1983). In contrast, in MEM, knowing and remembering reflect attributions made on the basis of subjective qualities of mental experiences (Johnson, 1988a, 1988b; Klatsky, 1984). Remembering is not *either* autobiographical *or* nonautobiographical (i.e., semantic); rather, while remembering, we experience degrees of specificity, clarity, confidence in veridicality, and so on, and the greater the clarity and specificity, the more likely a memory will seem to refer to a distinct episode. Time and place information (Tulving, 1983) contribute greatly to this specificity, but probably should not be taken as defining features of autobiographical memory. For example, an especially important factor determining whether remembered information is felt to be autobiographical is whether it was the object of earlier reflective activity that would tie it in with other personal experiences. For example, anticipating an event, and reflecting back on it, create supporting memories that become evidence for the specificity and personal relevance of the event (Johnson, Foley, Suengas, & Raye, 1988, Study 2).

Similarly, there is no separate store for semantic memory; generic knowledge is represented in all subsystems. Furthermore, the types of generic knowledge represented in various subsystems might be quite different from each other (for example, that involved in learned eye movements for reading in P-1 and learned strategies for taking notes in R-2). Given that there are potential differences in appropriate cognitive models of the representation of different types of generic knowledge, and in the corresponding underlying neurobiological systems, the idea of a single generic memory system may be misleading.

Procedural versus Declarative Memory

It has also been proposed that memory consists of procedural and declarative memory systems (Cohen & Squire, 1980). In MEM, procedural knowledge (like generic knowledge) is distributed throughout the subsystems, but different types of skills or procedures (or components of complex skills or procedures) are very likely supported by different subsystems. Thus, we might not expect the procedure for threading a needle and that for counterbalancing lists in a learning experiment to be represented in the same way or supported by exactly the same structures. In addition, some procedures can be learned without strategic intervention or declarative representation; the learning and remembering of others may require strategic intervention or declarative representation (in fact, Anderson, 1982, suggests that procedural knowledge may start out as declarative knowledge). Furthermore, as learning occurs, control may pass from reflective to perceptual subsystems and vice versa for what might superficially appear to be the same task. Acquiring the skills necessary to complete a task efficiently is not always just a matter of learning to do the same skill "automatically" (Hirst, 1986). Skill acquisition can involve the use of different cues and subsystems as the task becomes restructured. Finally, not only may "declarative" information be implicated in learning and reactivating procedures, but the reverse is sometimes the case as well. For example, in order to tell someone a phone number, you may need to start to dial it as a cue to revive its declarative representation.

Various Combinations of Reflective Subprocesses

Useful insights and data have been generated by thinking about memory in terms of dichotomies such as STM/LTM, episodic/semantic, automatic/effortful, procedural/declarative. Here we are suggesting that new insights and data might be generated by considering memory as the consequence of perceptually initiated and reflectively generated processes, and by attempting to specify the subsystems and component processes involved in establishing memory for perception and reflection. To illustrate the potential usefulness of this framework for thinking about similarities and differences among various cognitive activities, consider different combinations of reflective subprocesses. In Figure 12.3, the components of the reflective system are represented as either active, as indicated by solid lines, or as inactive, as indicated by dotted lines (to simplify the discussion, supervisor and executive functions have been omitted). This simple schema allows us to characterize various cognitive activities involving memory, as well as certain deficits.

For instance, as illustrated in Figure 12.3A, when discovering, initiating, rehearsing, and retrieving act in combination, the resulting activity is often characterized as intentional (i.e., strategy-driven) learning. If all R-1 processes are working as well, a wide range of memory tasks can be accomplished with no apparent cognitive deficiencies. However, as illustrated in Figure 12.3B, mental activity consisting only of noting, shifting, refreshing, and reactivating would yield unintentional learning alone—or, with guidance by R-1 supervisor processes, only relatively simple intentional learning. Consequently, the disruption of R-2 processing would severely limit the complexity of memory activities and thus would limit the complexity of what could be learned and remembered.

The pattern in Figure 12.3C, which highlights the combination of shifting, initiating, refreshing, and rehearsing, illustrates how the phenomenal experience of something like free association or stream of consciousness is realized. Goal-directed rote rehearsal and, if poorly controlled, perseveration or even compulsions, may arise from the combination of refreshing, rehearsing, reactivating, and retrieving (Figure 12.3D). The combination of noting, discovering, reactivating, and retrieving (Figure 12.3E) could produce a rigid type of rote rehearsal as well, resulting in a well-rationalized, well-remembered, but inflexible product. Shifting, initiating, noting, and discovering operating together would produce creative organizational possibilities useful in, for example, problem solving or brainstorming (Figure 12.3F).

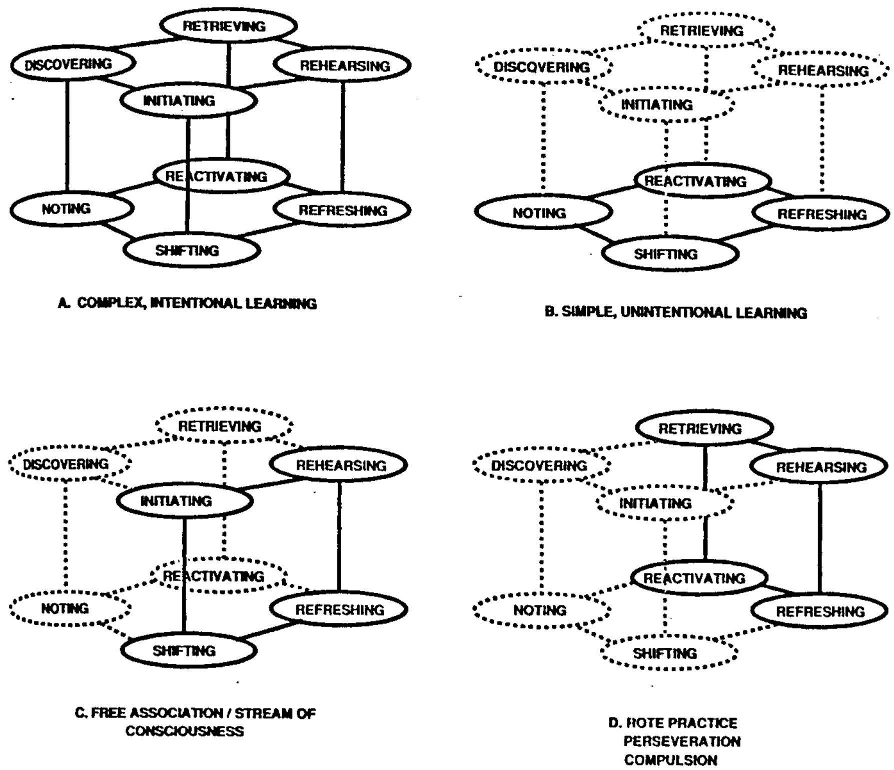

Figure 12.3 Schematic representation of the consequences of different combinations of reflective component processes.

A short-term memory deficit could arise when all components but refreshing and rehearsing are intact (Figure 12.3G). When all components are intact but reactivating and retrieving, a long-term memory deficit very much like "core" anterograde amnesia might be observed (Figure 12.3H; see next section). Disruption of R-1 supervisor processes (Figure 12.3I) would eliminate the relatively "automatic" reflective control of activities, such as keeping active a set to note certain kinds of relations while engaged in some other memory task controlled by R-2. The consequence would be that reflective activities that usually seem "automatic" would require "effort." Alternatively, the complete deactivation of executive functions in R-2 (Figure 12.3J) may lead to an inability to voluntarily initiate schemas in P-1 or P-2. Here such disruption may prevent people from willfully undertaking well-learned, perceptually based actions (such as demonstrating how to use a hammer) in the absence of external cues (such as the hammer itself). Disruption of the relation between supervisor and executive processes

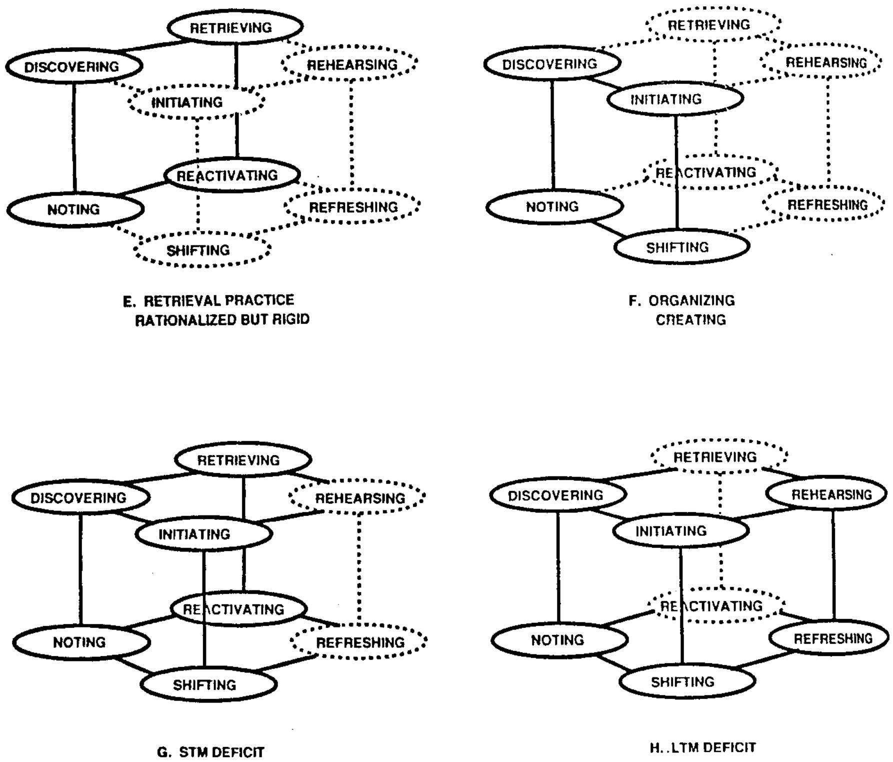

Figure 12.3 (Continued)

associated with R-1 and R-2 subsystems (Figure 12.3K) would, among other things, affect a person's ability to monitor the thoughts generated in R-1. When such disruptions occur, events imagined as a consequence of R-1 processes, for instance, might seem to have come from P-2 (see Johnson, 1991a).

Amnesia as a Reactivation Deficit

This section focuses on the way in which a particular memory deficit, "classic" anterograde amnesia, might be conceptualized in MEM. Available evidence suggests that perceptual memory processes (P-1 and P-2) are relatively intact in amnesics whereas some aspect(s) of reflection are disrupted (Johnson, 1983, 1990). A number of observations support this

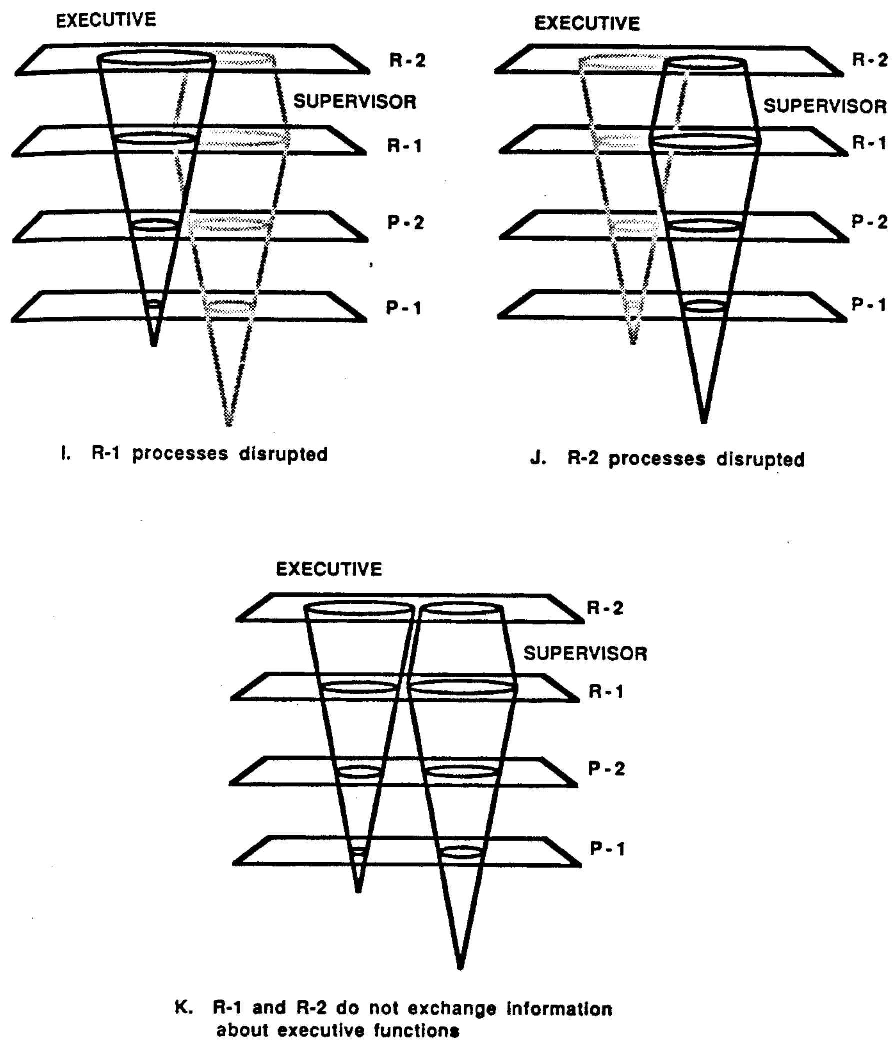

Figure 12.3 (Continued)

characterization. In amnesics, some cognitive/perceptual and motor skills appear preserved (Cohen & Squire, 1980; Corkin, 1968), and these skills seem to be largely under perceptual control of P-1 and P-2 processes. The recall of amnesics is always profoundly disrupted, but recognition memory appears to be less disrupted (Hirst et al., 1986, 1988; Johnson & Kim, 1985; Weinstein, 1987). Such a pattern is predicted in the MEM framework because recognition often draws on entries resulting from perceptual processes whereas recall draws more on reflective entries. Furthermore, the degree of disruption that amnesics show in recognition memory (Weinstein, 1987), and in the acquisition of affective responses (Johnson, Kim, & Risse, 1985), depends on the degree to which reflection is required in the task.

As we have highlighted, reflection is a complex system involving a number of different components that interact in various ways, depending on task demands and on an individual's reflective capabilities. Many components of the reflective system appear to be largely intact in amnesics. The fact that amnesics' intellectual functions seem to be remarkably intact (Butters & Cermak, 1980; Milner, Corkin, & Teuber, 1968) suggests that executive functions may often be unaffected. Many amnesics can plan for the future, adopt and use complex mnemonics (Hirst & Volpe, 1988), and generally appear to be able to recruit what mnemonic resources they have to accomplish a task. There are exceptions to this characterization. For instance, Korsakoffs may have deficient metamemory (Hirst & Volpe, 1988; Shimamura & Squire, 1986). Nevertheless, in many amnesic patients, severe memory problems can be observed in the presence of what appears to be intact supervisor and executive functions.

Observations of normal short-term memory in at least some amnesics (Baddeley & Warrington, 1970) suggest that refreshing may be intact. Amnesics profit from contexts that clarify meaning (e.g., BAGPIPES—*The notes went sour when the seams split,* Johnson et al., described in Johnson, 1990; McAndrews, Glisky, & Schacter, 1987), suggesting that noting relations among simultaneously active concepts is intact. As for shifting, although some amnesics, particularly Korsakoffs, show perseveration (usually taken to be a sign of frontal lobe damage), other amnesics do not show signs of perseveration (Moscovitch, 1982). They easily shift from one perspective to another. Nevertheless, even with refreshing, noting, shifting, and supervisor component processes intact, severe amnesia could result from a disruption in the reactivating component of reflection.

Reactivating

Reactivating provides an opportunity for noting relations between perceptually noncontiguous elements. It is essential for establishing relational information that bridges individual items or events. These bridges can initiate further reactivations. And with each reactivation, the strength of the memory improves, thereby increasing the availability of a memory and extending the retention interval over which the memory can be detected (Ebbinghaus, 1885/1964; Linton, 1978). The resulting memory is a complex, cohesive representation of past experience and consists of both relational and item information (e.g., Hunt, Ausley, & Schultz, 1986; Mandler, 1980).

Memories become reactivated with the appropriate externally provided and internally generated cues (e.g., McGeoch, 1942; Tulving, 1983). Cues can reactivate relational information, item information, or both. Different underlying mechanisms may be responsible for item and relational reactivation. Furthermore, cues from different sources combine so that a memory may be reactivated when no single cue would be sufficient. One especially important kind of cue combination is when specific external and internal cues combine with "agendas" to increase the probability of reactivation of a memory. In MEM, *agendas* are goals or plans that govern through supervisor and executive functions the actions and mental activities of an individual. An agenda might be fairly global ("Eat dinner") or more specific ("Get the waitress's attention and order a meal"). In many instances, an agenda might specifically call on the use of memory, as in "Remember list A." These memory agendas can also be quite general ("Remember what you did when you were a kid") or quite specific ("Remember the animal words in the list that you studied five minutes ago"). Whether an agenda explicitly probes memory or only makes an implicit use of memory (Schacter, 1987), it will interact with memory by activating relevant information. An agenda about "ordering a meal" may activate a restaurant script, whereas an agenda about eating may activate a script about etiquette and, in the appropriate context, a restaurant script as well. This activated information need not be "conscious." However, it may facilitate the reactivation of a memory so that it does become conscious in the appropriate circumstances. This capacity of ongoing agendas to keep information in a state of increased susceptibility to appropriate cues may account not only for phenomena such as incubation effects in problem solving, but also for why explicit retrieval cues can often elicit memories when more general cues could not. A general probe such as "Remember the list of words studied five minutes ago" may activate a great deal of information relevant to the spatio-temporal frame "five minutes ago." This activation, however, may not be sufficient to raise the desired information to consciousness. With an additional, more explicit cue of "animal," the convergence of activations may become sufficient to produce a conscious recollection.

Reactivation can produce a special kind of "consolidation" of memories. *Consolidation* has been used to refer to a variety of types of processes (see Squire, 1987, and chapters in Weingartner & Parker, 1984). Often what investigators seem to mean by consolidation is an automatic, time-dependent, endogenously driven process that is nonselective in that all memories undergo consolidation unless a disruptive event occurs (see, e.g., discussions about this issue by Gold & McGaugh, 1984, Keppel, 1984, and Spear & Mueller, 1984). In contrast, in the present formulation, reactivation plays a consolidative role that is neither automatic nor nonselective. Reactivation is not a "stand alone" process, but rather an aspect of an integrated reflective system. Reactivation is partially driven by supervisor and executive functions. Moreover, the noting, shifting, and refreshing initiated by the reactivation of information contribute to the impact of reactivation on memory and the probability of further cycles of reactivation. Information that does not satisfy an ongoing agenda is unlikely to be reactivated unless prompted by a specific, strong external cue. Agenda-relevant information is more likely to be reactivated, and this newly activated information is likely to lead to the reactivation of additional agenda-relevant information. This idea of reactivation is similar to Spear and Mueller's (1984) notion of retrieval-based consolidation (see also Squire, 1987).

If the reactivating component of reflective memory is deficient in amnesics, then several things should follow. Amnesics may not be able to form and subsequently use relational information beyond that contained in concurrently available elements (i.e., through noting and refreshing). The resulting impoverished memory should make it difficult for agendas to activate and access information related to but not directly described in the agenda. In particular, an agenda such as "Recall the list that you just studied" provides little information about the material to be remembered. One must access this information through the relations connecting the present circumstances with the previous study session and the spatio-temporal memories of the study session with the particular items learned in the study session. If relational information is not formed and cannot be activated by the cue "the list you just studied," then recall of the list should be difficult, if not impossible, for an amnesic. On the other hand, if the agenda is "Determine whether you saw the word 'hat' in the list just studied," the cues provide quite specific item information, which is often enough to produce a familiarity response. Of course, such item-specific reactivation cannot alone make up for the absence of reflectively generated reactivation. Consequently, both recognition and recall are depressed with amnesia, although recall is disproportionately depressed when compared with recognition.

Summary

According to the present framework, memory is created by an intricate interplay of processes that are organized at the most global functional level into perceptual and reflective systems. Each of these systems consists of more specific functional subsystems that, in turn, are made up of yet more specific functional components. Perceptual and reflective subsystems are differentially involved in various learning and memory tasks: for example, the perceptual subsystems are more important in certain types of skill acquisition, and the reflective subsystems are more important in strategic memorization for the purposes of later recall. Our goal is to begin to specify the component processes in perceptual and reflective subsystems, to understand tasks in terms of the contributions of these component processes, and, eventually, to link such processes to neurobiological systems.

As a step in this direction, we have described some possible components and organizations of two reflective subsystems, R-1 and R-2. These subsystems are critical for what is sometimes called *declarative, episodic,* or *direct* memory, and for problem solving and other forms of productive thinking. Certain cognitive activities as well as deficits in cognitive functioning can be described in terms of the operation of components or combinations of components within the R-1 and R-2 subsystems. For example, we suggest that "classic" anterograde amnesia could result from the disruption of reactivation and retrieval components within the reflective subsystems. These components are critical for creating and strengthening connections between cognitive/behavioral agendas and events and establishing relations among perceptually noncontiguous events. Various other memory or cognitive deficits, and a variety of distinguishable normal cognitive activities (e.g., stream of consciousness, strategic learning) as well, can be specified in terms of patterns of reflective components that are active and disrupted or suppressed. Hopefully, efforts to more clearly specify processes at a cognitive level of description will make it easier to link cognitive functions to underlying brain structures and systems.

Note

1. P-1 and P-2 correspond to what was called "sensory" and "perceptual" subsystems in previous papers (e.g., Johnson, 1983, 1990). P-1 and P-2 can be further broken down into component subprocesses (see Johnson, 1991b).

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