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CHAPTER NINE

MEM: Memory Subsystems as Processes

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INTRODUCTION

Memory supports an extraordinary range of functions such as remembering autobiographical events, learning concepts, finding your way home, driving cars, solving geometry problems, and developing emotional responses such as fear of dogs. In understanding this system, psychologists have developed individual "local" theories for each of these situations (e.g. a theory of concept learning). They have also tried to outline a set of functional specifications or a general cognitive architecture for a "global" system that could account for all these functions. This second approach provides an integrative frame- work for cumulating currently available knowledge as well as high- lighting potentially fruitful directions for research. Here we continue to expand a discussion of such a general cognitive architecture: MEM (a Multiple-Entry, Modular memory system).

This model provides a framework for understanding a large number of complex mnemonic phenomena. It offers a small set of putatively basic or primitive processes that can serve to guide the analysis of different memory tasks. In doing so, it provides a vocabulary for clarifying many of the problems that exist in the field of memory. Some readers may find such a set vocabulary for dissecting the demands of encoding, retrieval, and storage somewhat limiting, but we hope to show that it serves as an efficient tool for describing the dynamics of memory, including aspects of memory that structural/systems approaches have so far not given much attention to. The present rendition of MEM is intended only as a working model. As we understand more about the phenomena of memory, MEM will evolve and could be transformed significantly.

The first section of this paper describes the basic MEM framework, drawing on previous presentations (Johnson, 1983, 1990, 1991a, 1992; Johnson & Hirst, 1991; Johnson & Multhaup, 1992). The next section illustrates how the MEM architecture explicates complex issues surrounding source monitoring (Johnson, 1991a; Johnson, Hashtroudi, & Lindsay, in press). Subsequent sections discuss MEM's relation to theoretical ideas about consciousness and control (Schacter, 1989; Tulving, 1985b) and the distinction between bottom-up and top-down, or between data-driven and conceptually-driven, processing (Jacoby, 1983; Roediger & Blaxton, 1987).

The last two sections consider characteristics of subsystems (Sherry & Schacter, 1987) and suggest that the vocabulary of subsystems may not capture the natural units of breakdown of the cognitive/memory system. Problems encountered by accounts of amnesia in terms of a disrupted episodic (Tulving, 1983) or declarative (Squire, 1987a) memory system are used to argue against the idea that entire subsystems devoted to a broadly defined type of content are the most useful units of analysis for memory disorders. An alternative strategy focuses on partial breakdowns within functional processing subsystems. This is illustrated with some suggestions about how disruption of different component processes in MEM could produce identifiable patterns of cognition (Johnson & Hirst, 1991).

THE MEM FRAMEWORK

MEM is a process oriented approach; the primary descriptive units are cognitive actions. MEM specifies a set of actions that, working together in various combinations, have memorial consequences. These mental actions (or component processes or computations) could simply be listed as attributes of a memory system; however, organising them into classes can help us identify and highlight functionally important combinations and relations, and frame questions about potential interactions and limits on interactions among processes. We will treat these classes as processing structures or subsystems. Postulating such structure reflects an assumption that particular mental processes did not simply appear out of "whole cloth" in evolution, but rather were variations on basic cognitive themes (see p. 252). Such a structured system can also be helpful in characterising the differences in cognitive functions that come with development, disruption (stress, multiple tasks, etc.), or brain damage (e.g. amnesia, confabulation). MEM does not as yet include specific hypotheses about the nature of memory representations (e.g. networks, episodes, vectors; see p. 250). Rather, our focus has been on developing hypotheses about the cognitive processes required to establish, maintain, access and use memory representations.

A schematic view of MEM is shown in Fig. 9.1. MEM distinguishes a perceptual memory system from a reflective memory system. The perceptual system can be thought of as containing two subsystems, P-1 and P-2, and the reflective system another two subsystems, R-1, R-2. We are typically unaware of the perceptual information involved in associations established by P-1 processes. For instance, we are unaware of the cues in a speech signal that specify a particular vowel, or the aspects of a moving stimulus that specify when it is likely to reach a given point in space. Yet, learning via P-1 processes allows us to adjust to a person's foreign accent, or to anticipate the trajectory of a baseball. Subprocesses of P-1 include *locating* stimuli, *resolving* stimulus configurations, *tracking* stimuli, and *extracting* invariants from perceptual arrays (e.g. cues specifying the rapid expansion of features in the visual field that indicate a stimulus is coming towards you).

In contrast, we use P-2 processes when learning about the phenomenal perceptual world of objects such as chairs and balls, or events such as seeing a person sit down in a chair or catch a ball. Subprocesses of P-2 include *placing* objects in spatial relation to each other, *identifying* objects, *examining* or perceptually investigating stimuli, and *structuring* or abstracting a pattern of organisation across temporally extended stimuli (e.g. abstracting syntactic structure from a sentence).

As has been suggested previously (Johnson, 1983), P-1 component processes are likely to be especially important in pursuit rotor (Corkin, 1968) and mirror reading (Cohen & Squire, 1980; Kolers, 1976), and P-2 processes in the development of perceptual categories (Posner & Keele, 1968). However, as yet we do not really know the relative contributions of P-1 and P-2 processes to these and other situations with heavy perceptual processing demands—tasks such as identifying degraded stimuli (Warrington & Weiskrantz, 1968) and random dot stereograms (Benzing & Squire, 1989), old/new picture recognition (Shepard, 1967), and frequency judgements (Johnson, Peterson, Chua-Yap, & Rose, 1989). A useful approach would be to vary the processing requirements within a single type of task rather than trying to make comparisons across tasks. As an example of this approach, see Johnson et al. (1989) for evidence that frequency judgements require P-2 processing and are unlikely to be based on stored outcomes of P-1 processes alone.

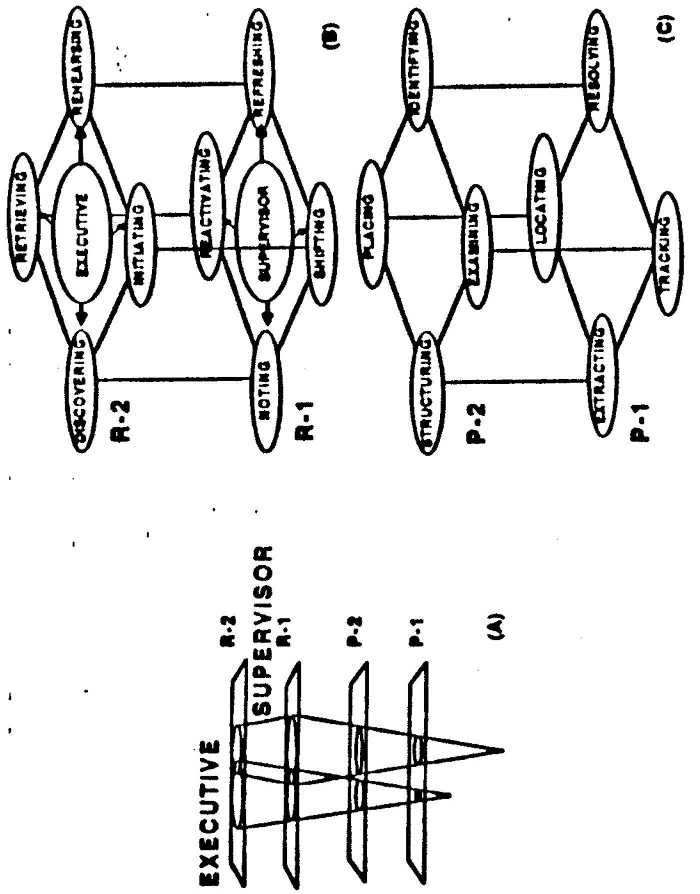

FIG. 9.1. (A) A Multiple-Entry, Modular memory system, consisting of two reflective subsystems, R-1 and R-2, and two perceptual subsystems, P-1 and P-2. Reflective and perceptual subsystems can interact through control and monitoring processes (supervisor and executive processes of R-1 and R-2, respectively), which have relatively greater access to and control over reflective than perceptual sub-systems. (B) Component sub-processes of R-1 and R-2, and (C) Component sub-processes of P-1 and P-2. Adapted from Johnson (1991b) with permission.

The reflective system and its component processes are illustrated in Fig. 9.1B. Both R-1 and R-2 reflective processes allow one to go beyond the immediate consequences of perception in order to do such things as manipulate information and memories, anticipate events, imagine possible alternatives, compare these alternatives, etc. R-2 processes are more deliberate and are important for more complex tasks than are R-1 processes. For example, R-1 processes might note that two acquaintances both like food and generate the idea of having a dinner party to introduce them. R-2 processes would then be used in planning a dinner party—retrieving names of potential guests, sequencing activities such as sending invitations, buying food, determining the order in which dishes are prepared, and so forth.

Both R-1 and R-2 involve component processes that allow people to sustain, organise, and revive information. Component processes in R-1 are *noting* relations, *shifting* attention to something potentially more useful, *refreshing* information so that it remains active and one can easily shift back to it, and *reactivating* information that has dropped out of consciousness. Component processes in R-2 include *discovering, initiating, rehearsing*, and *retrieving* (Johnson, 1990; Johnson & Hirst, 1991). To illustrate the difference between R-1 and R-2 activities, consider the difference between *reactivating* and *retrieving*. An example of *reactivating* is when a memory record is activated by a partial match between ongoing reflection and records of previous reflection, for example, when the steps one goes through in solving a problem remind one of a similar problem (e.g. Faries & Reiser, 1988). An example of *retrieving* is when a person deliberately uses the strategy of self-presentation of cues; for example, in trying to think of the name of a restaurant, you might try to remember people who might have told you about it (Baddeley, 1982; Reiser, 1986).

Activities resulting in memory (e.g. attention, comprehension, learning, problem solving) are made up of combinations of these perceptual and reflective component processes. As an example of how the components within a system might work together, consider the use of organising strategies in free recall experiments (e.g. Bower, 1970; Mandler, 1967; Miller, 1956; Tulving, 1962; see also Figure 9.2, adapted from Johnson, 1990). A subject studies the words PIG, DOG, WEED, DINNER, etc., with the idea of later recalling them. As each word (e.g. PIG) is presented, the subject perceptually *identifies* the word, activating memory representations such as the idea of a pink, plump animal. After hearing DOG the subject might *note* that PIG and DOG are both ANIMALS. If WEED activates DRIED and DINNER activates TABLE, the subject might also *note* that dried weeds could be used as a table CENTREPIECE. This *noting* activity would establish two small

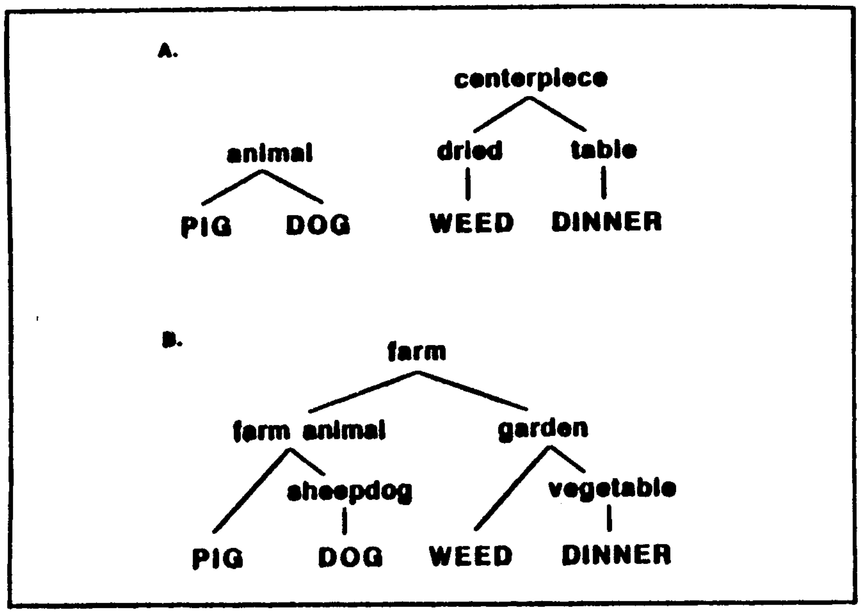

FIG. 9.2. Hypothetical activation patterns and noted relations for four items (pig, dog, weed, dinner) from a tree recall list: (A) Initial activation and noted relations, and (B) Activation and noted relations after a shift in perspective. Adapted from Johnson, M.K. (1990) with permission.

units, the unit PIG/DOG and the unit WEED/DINNER. Driven by an *agenda* to look for larger organisational units, the subject might *shift* activation in order to change what is given in the current activation pattern. Our hypothetical subject might *shift* to PIGS and DOGS as FOUND ON FARMS and WEEDS as unwanted plants in a DINNER VEGETABLE GARDEN. Now garden and farm animals are both related through FARM, creating a single unit of four items rather than the previous two, two-item units. *Refreshing* keeps items such as PIG and DINNER active during *shifting* and *noting*. *Reactivating* brings back information that has dropped below some critical level of activation; it strengthens or consolidates relations established through *shifting* and *noting* (Johnson, 1992).

The free-recall example illustrated in Figure 9.2 involves a relatively simple organisational activity. A more complex organisational scheme might require postulating the use of R-2 processes. For example, the subject might also decide to organise the to-be-remembered items alphabetically within semantic subgroupings (e.g. DOG, PIG; DINNER, WEED). This strategy would require (R-1) *refreshing* of the semantic

organisation while (R-2) *initiating* a search for first letter cues and (R-2) *discovering* the alphabetical ordering within groups. These new groups might be (R-2) *rehearsed* in order to increase their probability of later recall. (R-2) *Retrieval* would be accomplished later by voluntarily using semantic and alphabetical cues to facilitate search. The point here is not that semantic organisation is done via R-1 processes and alphabetic organisation through R-2 processes, but that mentally organising information may require the coordination of at least two levels of reflective activity. One of these may begin relatively easily as a consequence of accidental factors, an initial set, or instructions, but adding in a second dimension would require more complex coordination and control. On the other hand, if the subject had started with a set to alphabetise, then this goal might have been accomplished via R-1 processes. If, in addition, the subject decided to elaborate (e.g. Anderson & Reder, 1979; Stein & Bransford, 1979) on this basic alphabetical scheme by forming semantic links between successive items, the elaboration would probably involve a combination of *initiating* and *discovering* (e.g. taking the alphabetical pair DOG–DINNER and initiating a search of DOG's properties until one that links it to DINNER is *discovered*, e.g. edible in some cultures). Even more complex organisation could be accomplished by having R-1 and R-2 operate alternately, using the relations activated and generated by each other.

As indicated from this hypothetical example, the component processes in R-1 and R-2 must be controlled or coordinated and monitored. Control and monitoring involve *agendas* (or goals, intentions, purposes), and criteria for evaluating outcomes with respect to these agendas. Agendas may be relatively simple (identify each word), or may include relatively complex schemas or scripts that specify which processes to engage and in which order (e.g. apply the Method of Loci). Ways of accomplishing routine goals become schematised (or compiled) through practice (e.g. Anderson, 1987); thus calling up an agenda may be sufficient for sequencing component reflective processes.

We call the control and monitoring processes (including the relevant agendas) that are active in R-1 *supervisor* processes, and the ones active in R-2 *executive* processes. Both refer to the sorts of activities discussed by Miller, Galanter, and Pribram (1960), Nelson and Narens (1990), Norman and Shallice (1986), Stuss and Benson (1986), and others. R-1 processes can be characterised as more holistic, global, and schematised, and R-2 more deliberate and analytic, and more likely to be generated on-line. Supervisor processes account for simple, well-learned regulation and monitoring tasks, for example, setting simple criteria for old/new recognition judgements. Executive processes account for more complex monitoring: tasks involving multiple rules; testing imagined alternatives against imagined consequences, such as are involved in the Missionaries and Cannibals problem; embedded subgoals that are not routine, etc. The idea that executive and supervisor processes consist in part of activated *learned* agendas (or compiled sequences) is one reason for viewing executive functions as part of the memory system itself. Control is a function of experience and improves with practice; hence it may be misleading to conceptualise an "executive" as somehow standing apart from the entire memory system.

In Fig. 9.1A, supervisor and executive processes are depicted as cones passing through planes representing different subsystems. The sizes of the ellipses at the intersects of cones and planes reflect the relative degree of involvement of supervisor and executive processes in each subsystem's activities. Interactions between perceptual and reflective memory may take place through supervisor and executive components. For example, an agenda initiated by the R-2 executive, such as "look for a restaurant", might activate relevant perceptual schemas from perceptual memory (e.g. "look for building with ground level window, tables visible, menu in window"). It might also activate reflective plans adapted to the current situation (e.g. "try to retrieve what you've heard about restaurants in this part of town"). Typically, executive functions have greater access to reflective memory than to perceptual memory, and greater access to P-2 than to P-1 subsystems.

An especially important aspect of reflection is that the supervisor and executive processes in R-1 and R-2 can recruit and monitor each other, as depicted by their overlap in Fig. 9.1A. For example, an R-2 agenda to *retrieve restaurant information* can initiate an R-1 goal to *note the source of the information*. Interaction between R-1 and R-2 provides a mechanism for sequencing subgoals. It also gives rise to the phenomenal experience of reflecting on reflection (or thinking about thinking) which is intrinsic to our sense of *self* (Johnson, 1991b). Interactions between R-1 and R-2 also give rise to the experience of control, including self-control, another factor important to our sense of self. Access to information about one's own cognitive operations provides a salient cue for identifying oneself as the origin of information as well (Johnson, Raye, Foley, & Foley, 1981).

Cognition varies in the effort, will, or control it seems to require (Hasher & Zacks, 1979; Norman & Shallice, 1986; Posner & Snyder, 1975; Shiffrin & Schneider, 1977), an idea captured by contrasts such as non-analytic versus analytic processing (Jacoby & Brooks, 1984), automatic versus intentional processing (Jacoby, 1991) and heuristic versus systematic processing (Chaiken, Lieberman, & Eagly, 1989). The idea of control is central to most current conceptions of cognition. Although terms such as automatic and controlled suggest a sharp

dichotomy in processes and strict criteria for defining automatic (e.g. Posner & Snyder, 1975), most investigators now think in terms of degrees of automaticity or degrees of control. This approach implies a single underlying dimension of cognition that varies in "amount", such as amount of "cognitive capacity" required (e.g. Kahneman, 1973). Following this line of thinking, one direction for future work is to treat "control" as a primitive quantitative concept and to try to develop measures of the amount of control operating in various situations (e.g. Jacoby, 1991). A complementary direction, represented by MEM, is to attempt to describe control in terms of yet more primitive concepts such as the component cognitive activities postulated in MEM. Thus in MEM, increased effort, will, or control would be associated with R-2 compared to R-1 processing. Effort would increase with the number of different processes engaged or the number of recursions of the same component processes engaged. Whether we should think of all the component processes within a subsystem as equal in "effort" remains to be answered, as does the relative contribution of various components to increasing the probability of long-term retention using various memory measures (see Johnson, 1992).

The component processes shown in Fig. 9.1 are the elementary computations in MEM. They provide a useful conceptual level for integrating across a range of phenomena. These processes could, however, be further decomposed. Biederman's (1987) recognition-by-components theory of object recognition could be viewed as a more complete analysis specific to vision of subprocesses that contribute to *resolving* and *identifying* in P-1 and P-2, as could the work on structural descriptions by Schacter and Cooper and colleagues (e.g. Schacter et al., 1991). The mechanisms of *locating* (e.g. Weiskrantz, 1986; Yantis & Johnson, 1990) and *tracking* (Kowler & Martins, 1982; Pylyshyn, 1989) are investigated in work on visual attention. Baddeley and colleagues' (Baddeley, 1986; Baddeley & Hitch, 1974) theory of the phonological loop could be viewed as a characterisation for language materials of *refreshing* and *rehearsing* processes in R-1 and R-2 (see also Naveh-Benjamin & Jonides, 1984). Various process models of *reactivating* have been proposed (e.g. Hintzman, 1986; Metcalfe Eich, 1982; Raaijmakers & Shiffrin, 1981) and reactivating is a central issue in understanding problem solving (Faries & Reiser, 1988; Gentner, 1988; Gick & Holyoak, 1980). *Retrieving* has been investigated as well (Baddeley, 1982; Kolodner, 1984; Reiser, 1986). *Noting* could be further decomposed into processes required to compute possible relations, e.g. similar, dissimilar, part–whole, attribute of, etc. (Chaffin & Kelly, 1991; Tversky, 1977; Tversky & Hemenway, 1984). Although MEM does not suggest a detailed description of each particular component of the overall system, it provides a relatively comprehensive framework for incorporating the results of analyses focusing more directly on those parts.

As noted earlier, the representations (or records, or traces) of experience that result from MEM's component processes could be characterised in any number of ways, for example, as associative networks, connectionist networks, episodes, cases, production rules, propositions, vectors, schemas, or mental models. The type of representational format that is most useful for theoretical analysis at our current stage of knowledge may depend on the subsystem in question; for example, connectionist networks may be more appropriate for characterising outcomes of perceptual processes, and propositional representations or mental models more appropriate for outcomes of some types of reflective activities (Johnson & Multhaup, 1992). Some theoretical approaches assume a particular representational format and then make predictions based on a formal model of this representational format (e.g. Metcalfe, 1991). MEM, in contrast, characterises component processes. The terms representations, records, or traces, are used here interchangeably without implying anything in particular about format.

Dissociations among memory measures arise naturally from the MEM framework (Johnson, 1983). At some future time, exactly which of the various records established during an experience are activated will depend on the kind of task probing memory. Suppose you met many new people at a dinner party. The next day, you might be tested in any of several ways. For example, you might be asked to identify, against a background of white noise, random syllables isolated from the speech of the foreigner who sat next to you. This identification would draw primarily on representations formed by P-1. A recognition task in which you had to discriminate pictures of people who were and were not at the dinner party should draw primarily on representations formed in P-2. Recall of your dinner companion's story would draw on R-1 and R-2 records. Reactivation in all subsystems depends on the encoding specificity principle (or transfer appropriate processing), as emphasised by Tulving (1983), Roediger, Weldon, and Challis (1989), Morris, Bransford, and Franks (1977) and others. It is important to note, however, that typically there is no "pure" one-to-one correspondence between tasks and subsystems (Johnson, 1983; Moscovitch, Winocur, & McLachlan, 1986). Consequently, identifying which tasks should show dissociations among memory measures depends on specifying the processing subsystems that underlie the tasks.

Although laboratory and practical everyday tasks usually involve multiple systems, it is still useful to consider in broad terms the significance of multiple systems. The subsystems in MEM perform

different functions or solve different problems (e.g. Sherry & Schacter, 1987); they also allow more than one type of problem to be worked on more or less simultaneously. For example, the P-1 and P-2 systems deal, respectively, with the "thatness" and "whatness" of external stimuli. For some aspects of the learned skill of catching something, it does not matter exactly what the object to be caught is. The P-1 system can learn to respond to certain invariants or cues in a perceptual array while the P-2 system is learning to identify particular objects and to make adjustments for object identity. One benefit resulting from separating these functions is a kind of constant conservatism; certain responses (e.g. chase, flight, defense) can be prepared in case they are needed, and quickly initiated. If the information from P-2 can affect the behavioural output from P-1 (i.e. if a P-1 response is not "ballistic" once initiated), this would be one type of evidence that the P-1 and P-2 systems interact.

The functional importance of adding reflective processes to perceptual processes is enormous. Other proposed multiple-system memory models, such as the distinctions between declarative vs. procedural knowledge (Cohen & Squire, 1980), habits vs. memories (Mishkin, Malamut, & Bachevalier, 1984), System I vs. System II (Sherry & Schacter, 1987), and episodic vs. semantic memory (Tulving, 1983) are directed primarily at explaining how different types of externally-derived information might be encoded or stored, but they neglect our capacity to be the source of information as well as the recipient. The evolution of self-generated, reflective processes greatly expanded the range of environmental problems that could be solved. R-1 processes allow us to set up simple plans and monitor events with respect to goals, reactivate representations of prior events and compare them with present events; they provide basic processes necessary for abstract thought, allow us to dissociate responses appropriate to perceived objects (e.g. fear and flight) from those appropriate to imagined objects, and so forth. R-2 processes permit additional substantial advances in mental manipulation of information, and hence regulation and control of ourselves and the environment. With R-2 processes, in true "executive" fashion, we can deal with conditionals and embedded goals, and we can manipulate complex mental models (e.g. Johnson-Laird, 1983). R-1 and R-2 together yield the experience of thinking about thinking; they are each other's "homunculus". R-1 or R-2 activities could not be done by a system designed only for efficiently handling perceptual information. To be useful to us, to coordinate us with our environment, perception requires a high degree of veridicality. In contrast, to be useful to us in creating new possibilities, reflection must be freed from the constraints of perceptual veridicality.

Although MEM postulates four subsystems with meaningful functional differences, there is continuity across subsystems as well. That is, there is "vertical" as well as "horizontal" structure in MEM. Processes along corresponding edges of the two cubes in Figs. 9.1B and 9.1C are related: The edge that includes *resolving*, *identifying*, *refreshing*, and *rehearsing* functions to identify and maintain active the objects of perception and thought. The edge that includes *extracting*, *structuring*, *noting*, and *discovering* functions to create relations across time and/or events; the edge that includes *tracking*, *examining*, *shifting*, and *initiating* provides ways of introducing changes in activation pattern to the system; the edge that includes *locating*, *placing*, *reactivating*, and *retrieving* provides mechanisms for "going back" to earlier objects of perception and thought. It may be that through evolution, the "higher" instantiations of a function built on the mechanisms of the "lower" instantiations (e.g. *rehearsing* may grow out of *identifying*). And it may be that components along each edge may share some overlapping underlying brain regions (cf. O'Keefe & Nadel, 1978). In any event, one could think of cognition as consisting of a small set of "themes" (e.g. identifying, relating, introducing change, going back) represented at multiple levels or at various levels of complexity in an overall cognitive system. In short, memory includes mechanisms for identifying elements of experience and organising them, and for capitalising on both novelty and continuity in experience.

Taking an evolutionary perspective, it seems reasonable to postulate that the general evolution of subsystems was in the order P-1, P-2, R-1, and R-2. Similarly, these subsystems appear to develop in the same order within an individual. Thus infants show certain forms of perceptual learning (e.g. increased skill in visual tracking) before they appear to recognise something as familiar. Both of these skills appear to develop before children recall episodic events spontaneously. They strategically execute plans to remember even later (e.g. Bower, 1989; Flavell & Wellman, 1977; Kail, 1984; Ornstein, 1978). Although the general "richness" of application of the subsystems seems to follow a developmental course (also see Schacter & Moscovitch, 1984), it would probably be a mistake simply to characterise a human infant as "having" only P-1 and P-2 subsystems, or to characterise a young child as "getting" R-2 processes at some particular age. For example, some aspects of reflective processing (e.g. *reactivation*) may operate from quite early on (Rovee-Collier, 1991). Furthermore, specific learning occurs in all subsystems throughout the lifespan. Acquisition of new information in any particular subsystem depends on acquisition of prior information. Consequently, differences in "sophistication" of the subsystems at a given age are partly the consequence of what has already been learned

by the different subsystems. One might have a knowledgeable P-1 system and a less educated R-2 system or vice versa. Sophistication within a subsystem might be greater in certain domains (e.g. baseball) than others (e.g. tennis).

As already noted, MEM provides a framework for understanding a wide range of mnemonic phenomena. In the next few sections, we offer several examples, beginning with the phenomenon of source monitoring.

SOURCE MONITORING

The mechanisms through which people monitor the origin of information in memory (Johnson et al., in press) play a central role in cognition, and a full understanding of these mechanisms would touch on issues as diverse as what distinguishes autobiographical from other information (Tulving, 1972), the nature of "unconscious" effects of past experience on present action (Jacoby & Kelley, 1990), and the dynamics of delusions and confabulation (Baddeley & Wilson, 1986; Johnson, 1988a, 1991a; Moscovitch, 1989). Source is an attribution people make based on various characteristics of memories. Particularly important memory characteristics include perceptual information, contextual information, semantic detail, affective information, and information about cognitive operations engaged when the memory was established. These characteristics are shorthand ways of referring to outcomes of combinations of component subprocesses in MEM. For example, suppose you ate lobster for the first time last week. Memory for the shape, colour, taste, and sounds associated with eating the lobster arises from perceptual records generated in the perceptual memory system as a consequence of combinations of perceptual component processes, such activities as *identifying* objects and *placing* them in spatial relation to each other. Memory that it was Friday night would be the result of reflective activity that generates such temporal information. For example, you might remember that as you drove to the restaurant that night you *retrieved* an earlier experience when the traffic was bad and *noted* that was also a Friday night (e.g. Johnson, 1983; Tzeng, Lee, & Wetzel, 1979). Subsequent *reactivation* of these noted relations strengthens them (Johnson, 1992).

Studies from our lab and from other labs support the general idea that these memory characteristics are important for source attributions. For example, increasing perceptual detail of internal events makes them harder to discriminate from external events (Johnson, Foley, & Leach, 1988; Johnson, Raye, Wang, & Taylor, 1979). Reducing the cognitive operations that go into generating information also reduces the accuracy of reality monitoring (Durso & Johnson, 1980; Finke, Johnson, & Shyi, 1988). Increasing the semantic overlap between two external sources also makes it more difficult to discriminate between them (Lindsay, Johnson, & Kwon, 1991).

Source monitoring involves attribution or judgement processes. If an interviewer asked you whether you have ever eaten lobster, you would probably easily answer "yes". Although it may seem that this answer only depends on retrieving information from your "lobster dinner memory", it also involves evaluating the memory using tacit criteria for claiming something to be true. Is what you retrieved a genuine memory or only an imagination or a plausible inference? How much of the lobster memory must be reinstated for it to be taken as knowledge? To be taken as an event memory? Similarly, if we asked you when the last time you had lobster was, your answer "last Friday" may seem at first glance only to be based on retrieval processes. Again, however, this answer also involves judgement processes applied to the activated information. What types and how much information do you need to be confident it was Friday? In MEM, such judgements are functions of reflective supervisor and executive processes. That is, supervisor and executive processes set the goal or agenda for judgement (e.g. did this happen?), set the criteria for judgement (e.g. the type and amount of information required to claim something happened), and engage whatever processes might be necessary to satisfy the agenda (e.g. *noting* relations between memory characteristics and criteria, *retrieving* additional information).

Two types of judgement or decision processes may be engaged in making attributions about source, characterisable in terms of the two reflective subsystems in MEM, R-1 and R-2 (Johnson, 1991a). The relatively quick, nondeliberative, or heuristic R-1 processes set up decision criteria for what will be required in the way of various memory characteristics in order to attribute a memory to a source. R-1 processes also carry out such evaluations on the basis of the features of the memory, using various rules and schemas about what features might be expected from which source. For example, memories derived from perception tend to have more perceptual detail than memories derived from imagination and less information about cognitive operations. Consequently, an activated memory will be judged to have been perceived rather than imagined if it has rich perceptual detail and impoverished levels of information about cognitive operations.

The more deliberative, R-2 processes are required for going beyond the phenomenal characteristics of activated information. They evaluate the plausibility of a source. For example, you might decide that a vivid memory of a colleague's remark at a faculty meeting is only the residue of an earlier fantasy because you retrieve the information that your colleague was in Spain at the time of the faculty meeting.

For normally functioning adults, most source monitoring involves R-1 processes; R-2 processes tend to be engaged less often, to be slower, and to be more susceptible to disruption. When both R-1 and R-2 processes are working normally, they provide potential checks on each other. A perceptually detailed memory that Alan told you a certain fact can be ruled out on the basis of, say, plausibility. Conversely, the certainty that comes from plausibility can be questioned if the qualitative characteristics of the memory do not support a judgement based solely on plausibility.

Experimental work demonstrates that source monitoring involves such judgement processes and is not simply a matter of "reading a source tag". For example, misattributions of source depend on the criteria subjects adopt in making source attributions. In eyewitness memory paradigms, misattributions can be greatly reduced by inducing subjects to adopt more stringent criteria about what constitutes a memory for visually derived information (Lindsay & Johnson, 1989; Zaragoza & Koshmider, 1989). R-1 type judgements surface when subjects tell experimenters how they know that certain autobiographical memories actually happened and others were only imagined. Comments like "I remember the colour of his shirt" are common. R-2 type reasoning is also evident, as in the comment "This must have been a fantasy because I was too young to be a doctor" (Johnson, Foley, Suengas, & Raye, 1988). In the confabulation of patients with brain damage, the most dramatic deficits of reality monitoring appear to come from disruption in R-2 reasoning processes, a disruption often attributed to certain types of frontal damage (Baddeley & Wilson, 1986; Johnson, 1991a; Moscovitch, 1989; Stuss, Alexander, Lieberman, & Levine, 1978).

These source judgements figure in all aspects of memory, not only in "remembering" but in "knowing" (e.g. Johnson, 1988a,b; Kelley & Lindsay, in press). The information needed for accurate judgements may not be available or accessible (Tulving, 1983), nor may all potential processes be engaged. The information necessary for, say, certain temporal judgements may not have been generated if the requisite reflective activity was not initially engaged. For example, if, in driving to the restaurant to eat lobster, you did not *note* the similarity in traffic from the previous Friday night drive, the record of this noted relationship would not be available as information about "when". Reactivated perceptual information, such as that it was dark outside, might indicate that it was night, but not that it was Friday night. Even if reflective activity establishing such information had taken place, its record may not be accessed and/or used. The rememberer may be faced with inappropriate retrieval cues, or may fail to engage a judgement process that involves retrieval of the appropriate prior reflective activity.

Because of the complexity of source monitoring, it can be disrupted in various ways (e.g. Johnson, 1988a, 1991a; Johnson et al., in press). Initial processing of events might be disrupted by limiting encoding or consolidation of some types of perceptual, contextual, affective, semantic, and cognitive operations information (see Johnson, 1992). Retrieval of supporting memories might also be disrupted. Disruption of encoding, consolidation, or retrieval would result from disruption of component processes in MEM such as *placing* or *noting* or *reactivation*. There could be disruption in R-1 (*supervisor*) or R-2 (*executive*) judgement processes—subjects may use lax or inappropriate criteria for making source decisions, or may not use R-1 and R-2 processes to check each other. Such disruptions in reflective processing can come about when subjects at either acquisition or test are pressed for time, stressed, depressed, distracted, under the influence of alcohol or other drugs, or if they have suffered damage to certain areas of the brain. Anything that reduces motivation to be accurate would also disrupt source monitoring by affecting the *agendas* that control source monitoring, including the criteria used.

In general, the disruption in source monitoring associated with ageing (e.g. Cohen & Faulkner, 1989; Hashtroudi, Johnson, & Chrosniak, 1989, 1990; McIntyre & Craik, 1987), amnesia (e.g. Huppert & Piercy, 1982; Mayes, 1988; Schacter, Harbluk, & McLachlan, 1984; Shimamura & Squire, 1988), confabulating patients (Baddeley & Wilson, 1986; Johnson, 1991a; Moscovitch, 1989; Stuss et al., 1978), delusional syndromes (Johnson, 1988a), schizophrenia and mania (Harvey, 1985) may reflect interesting differences in which source monitoring processes are disrupted. It is unlikely that source monitoring is a single function served by a single brain area (cf. Nadel, Willner, & Kurz, 1985). As MEM has guided us in our discussion of source monitoring so far, it may provide the complexity needed to understand such differences.

ATTENTION AND CONSCIOUSNESS

The terms attention and consciousness are related, but each suggests a somewhat different focus. Consciousness implies phenomenal experience, whereas attention points to underlying processes (e.g. selection) guiding conscious experience. As Tulving (1985b, p. 2) suggests, attention connotes control over the direction of consciousness. Attention is usually treated as a system external to memory (e.g. Norman & Shallice, 1986; Posner & Petersen, 1990). In contrast, in MEM, attentional processes are embedded within memory systems;

that is, attention involves activities or operations (e.g. Posner, Petersen, Fox, & Raichle, 1988) with memorial consequences (e.g. Shiffrin & Schneider, 1977). Specifically, attending is a shorthand term for engaging in the component processes shown in Fig. 9.1. As the figure suggests, attention is a consequence of both perceptual and reflective processes. Visual/spatial attention can be commanded or "triggered", for example, by the onset of a light (e.g. Yantis & Johnson, 1990) that engages a *locating* process. Furthermore, a subject might locate more quickly over trials a stimulus with high probability of being in a particular location, demonstrating learning via P-1 processes. In a recall experiment, an activated agenda to critically evaluate an argument might engage a *noting* process that identifies inconsistencies between parts of the argument. In both cases, the subject is "attending", but *locating* and *noting* are distinct cognitive processes; disrupting each individually would result in quite different attentional deficits.

All activation in MEM produces changes in memory (Johnson, 1977; 1983), but not all activation results in consciousness (e.g. see Bowers, 1984; Kihlstrom, 1984) or becomes the basis of recollection (e.g. Johnson, 1992; Tulving, 1989). For example, we might observe priming effects from prior activation in any subsystem without the subject having a conscious recollection of the information (e.g. Eich, 1984; Schacter, 1987). In MEM, consciousness or awareness is a phenomenal experience that is an emergent property of ongoing processes. Whether a particular activation pattern becomes conscious depends on factors discussed by Norman and Shallice (1986) and others, such as the amount of mutual activation among elements (pattern "cohesiveness"), the extent to which component processes such as *refreshing* or *reactivating* are engaged based on current agendas, and inhibition among patterns involving common elements or processing structures.

In MEM, one aspect of the phenomenology of consciousness arises when agendas trigger between-system monitoring. For example, if you are driving with, say, an R-1 agenda to appreciate the scenery, you are conscious of perceptual stimuli because you are mentally *noting*, *refreshing*, and *retrieving* experiences related to this agenda. If you are driving only with the purpose of getting somewhere, and are mentally planning what you will do at your destination, you may arrive at your destination, notice that you remember nothing from the drive, and marvel at how practised perceptual-motor routines can serve us so well. Such examples suggest that consciousness often involves the operation of two subsystems, for example, R-1 monitoring P-2, or R-2 monitoring R-1. The control that occurs *within* subsystems through agendas helps organise thought and behaviour but does not alone yield "consciousness" *that* one is consciously experiencing.

Tulving (1985b) distinguished between three types of consciousness: consciousness restricted to present stimulation (anoetic), consciousness associated with manipulation of abstract symbols from semantic memory (noetic), and consciousness associated with remembering personally experienced events (autonoetic). Tulving is right to emphasise that consciousness has a different "flavour" depending on the particular combination of mental activities currently taking place—but there are probably more than three flavours. Tulving (1985b, p. 3) makes consciousness a causal agent in his framework—e.g. autonoetic consciousness "is necessary for the remembering of personally experienced events ... autonoetic consciousness ... confers the special phenomenal flavour to the remembering of past events". In contrast, in MEM, the phenomenal experience of consciousness emerges from component cognitive activities—that is, cognitive activities involved in perceiving and reflecting confer consciousness rather than the other way around. If you disrupt some of these activities, you disrupt consciousness, but it is not possible to disrupt consciousness without inhibiting or disrupting at least some aspects of these activities. The apparent causal properties of consciousness come from the fact that the elements of cohesive patterns (those most likely to become conscious) promote their own further activation, which makes that pattern particularly effective in mental life (e.g. as a candidate for *noting*, use in an executive routine, or later *reactivation*).

Schacter's (1989) Dissociable Interactions and Conscious Experience (DICE) framework provides another approach to conceptualising consciousness that can be compared with the view of consciousness represented in MEM. A central concept in Schacter's DICE framework is a Conscious Awareness System (CAS), which is a mechanism that is distinct from mechanisms that process and represent various types of information. For awareness, information must activate not only a memory system, but also CAS. CAS, in turn, can activate an executive system "that is involved in regulation of attention and initiation of such voluntary activities as memory search, planning, and so forth" (Schacter, 1989, p. 365). Thus DICE, like MEM, distinguishes the idea of phenomenal consciousness from attentional control. The DICE model includes three memory systems: a procedural/habit system and two declarative systems—episodic and semantic. The terms episodic and semantic are not used in the usual way (Tulving, 1983, to be discussed later), however. Information in the episodic system may or may not have time and place cues associated with it; the critical feature is that it is *new* information. The semantic system includes both non autobiographical and autobiographical information; the critical feature is that it is *old*, overlearned, and unitised information. The procedural/habit system "does not send input to CAS under *any* circumstances" (Schacter, 1989, p. 365). Ordinarily, both declarative systems are connected to CAS and hence activation in them produces awareness, although only input from the new declarative/episodic memory system produces explicit remembering.

If this model is adopted, one might be tempted to treat the conscious quality of memory as all-or-none. Thus people are consciously aware that an episodic memory occurred in their past, whereas they do not have conscious awareness for procedural memories. Yet the conscious quality of memory does not seem to have this all-or-none quality. An old event that is remembered many times does not necessarily lose its phenomenal episodic quality (although it might); depending on how an event is thought about, rehearsal may maintain aspects of memories, such as perceptual clarity, that signal their episodic quality (Suengas & Johnson, 1988). Conversely, not all recent memories that we consciously believe occurred in our recent past are "fully" episodic. The experience of recently having learned something but not remembering (or misremembering) where you heard it is quite common (i.e. the problem of source monitoring). Moreover, states of consciousness may be associated with skilled procedural activity. It seems as reasonable to suppose that there is consciousnes of *doing* that results from activation of the procedural/habit system, as that there is consciousness of *knowing* that comes from activation in the old (semantic) information system. It seems to us that both doing and knowing produce consciousness (of different "flavours"), although neither has an episodic or autobiographical flavour. In fact, as mentioned earlier, Tulving gives a special term to the consciousness associated with his procedural system—anoetic consciousness. The idea that procedural/habit memory is unconscious mistakenly equates our ability to make propositional ("declarative") statements with the idea of consciousness.

We can only begin to outline a MEM account of consciousness. It would include the idea that there are several interesting aspects of consciousness to be captured. One is the phenomenal experience created by the processing and representations engaged in MEM. This experiential aspect includes one's awareness of perceptual sensations (tasting wine) and of engaging in skills (swimming), as well as one's experience of the content of semantic facts (canaries are yellow) or of autobiographical recollections (we had a good time in Lancaster). Another aspect of consciousness, the capacity for wilful, deliberate action or control, would (as discussed previously) arise from processes serving agendas, along with the R-1/R-2 interaction that permits us to "reflect" on the fact that we have engaged an agenda. Yet another aspect of consciousness has to do with analytic capability, for example, bringing information to bear on some decision. Again, in terms of MEM, this would involve combined workings of *agendas*, and component processes such as *retrieving* and *noting*. Consciousness can occur in various combinations of these aspects or dimensions. For example, one can be aware but not in control (e.g. as with hypnagogic images), in control but not especially analytic (as when one uses quick heuristics to make decisions), analytic but not in control (as when one notes a flaw in an argument even when one has no strategic agenda to evaluate), and so forth. Considering these and other aspects of consciousness in terms of MEM is a project for the future. In short, unlike DICE, MEM does not have a single consciousness module. Rather, consciousness emerges out of the individual component processes in their various combinations. Depending on which processes were engaged, one would have different consciousnesses.

PERCEPTION/REFLECTION vs. DATA-DRIVEN/CONCEPT-DRIVEN

Useful distinctions have been made between top-down and bottom-up (or between conceptually-driven and data-driven) processing (e.g. Ashcraft, 1989). *Bottom-up* or *data-driven* processes are hard-wired, do not depend on learning or context, and rely on structural perceptual features of stimuli, not the stimuli's meaning. Prior learning, context, and meaning presumably make their contribution through *top-down* or *conceptually-driven* processing. Although reflection and perception in the MEM framework may seem to be the same as, respectively, top-down (conceptually-driven) or bottom-up (data-driven) processing, there is not a one-to-one correspondence. MEM offers a more fine-grained division of learning and memory than do the top-down/bottom-up and conceptually-driven/data-driven distinctions and consequently may prove more analytically useful.

Top-down (conceptually-driven) processes figure in a wide range of situations. For example, top-down or conceptually-driven processes may allow one to see the same carelessly written stimulus as an "A" in the word CAT and an "H" in the word HAT. Top-down or conceptually-driven processes also govern memory-based effects that clearly go beyond those implicated in immediate perception, effects of elaboration, question answering, comprehension of complex passages, etc. (e.g. Blaxton, 1989; Jacoby, 1983).

The terms *top-down* or *conceptually-driven* cover processing ranging across MEM's perceptual and reflective subsystems. Grouping such diverse processes as context effects on letter interpretation, generating

antonyms, and elaborative processing in free recall learning under one term such as top-down or conceptually-driven may be useful for some purposes, but finer distinctions will be required for others. Along these lines, MEM distinguishes "top-down" processes, by which prior experience and current context affect phenomenal perception, from "top-down" reflective mental activities, those that go beyond the phenomenal consequences of perception.

That is, according to the present view, reflection refers to centrally-generated processes that may operate in the absence of perceptual input. Reflection may also take discontinuous but internally cohesive perceptions (and their immediate consequences) and work them into cohesive frames of relations, narratives, or plans. For example, if you watch a horror movie, certain concepts such as DANGER, DEATH, BURGLAR, and MURDERER may be primed. Later, as a consequence of perceptual *top-down* processing, you may "see" a burglar lurking in the corner when, in fact, it is only the laundry bag. After you "see" the burglar, you might reflectively think back over the evening and retrieve a memory of an unusual sound. With further *reflective* processing, you may then jump to the conclusion that the burglar must have been in the house all evening. Reflection here bridges perceptual events.

Reflection is flexible because it can generate and manipulate information without perceptual support. Unfortunately, this beneficial capacity for reflection can create a "reality monitoring" problem (Johnson, 1985, 1988a; Johnson & Raye, 1981). Reflectively generated information that we know full well at the time is being self-generated, when later remembered may be mistaken for perceived information. In contrast, top-down perceptual processing is not as flexible. We cannot volitionally control it as easily as we can control top-down reflective processing. Moreover, unlike reflection, we are not usually aware at the time that our perception mixes stimulus information with perceptual expectancies and perceptual inferences. (There are exceptions, e.g. we may be aware that illusory contours are illusions at the time we experience them.)

MEM, then, challenges psychologists to separate complex perception of meaningful objects and events from reflective thought. According to one research strategy, investigators could explore the conditions under which subjects can and cannot discriminate perceived from imagined events (e.g. Johnson & Raye, 1981; Perky, 1910). Alternatively, researchers could explore the relative impact of perceived and reflectively generated information on event memory, knowledge, and beliefs (e.g. Hogan & Kintsch, 1971; Raye, Johnson, & Taylor, 1980; Slusher & Anderson, 1987). Whatever the adopted strategy, the challenge must be addressed both conceptually and empirically.

In summary, there is much elegant work unequivocally showing that a match between test and acquisition processing requirements is critical for assessing memory (e.g. Blaxton, 1989; Jacoby, 1983; Roediger & Blaxton, 1987). This work was based on distinctions between top-down and bottom-up processing and conceptually-driven and data-driven processing. As useful as these distinctions have been, they are too general to account for the complexity and variety of human memory functions. For example, not all types of conceptual processing have equivalent effects on all types of memory tests. A more specific component process account is needed to clarify which processes figure in which tasks. A framework such as MEM is needed to specify the contributions of individual and particular combinations of component processes to task performance.

WHAT KINDS OF SUBSYSTEMS?

Controversy has surfaced between accounts of memory based on "subsystems" models (e.g. Sherry & Schacter, 1987; Squire, 1987a; Tulving, 1983) versus accounts based on "processing" models (Craik, 1986; Jacoby, 1983; Roediger & Blaxton, 1987). Subsystem accounts propose distinct memory systems that encode, retrieve, and store different types of content such as procedures, episodes, or semantic knowledge. Process accounts tend to be associated with unitary memory models and with arguments against the need for postulating subsystems responsible for encoding, retrieving, and storing particular kinds of information. MEM could be viewed as a compromise (thus, perhaps unsatisfactory to both camps): it is a subsystems account where subsystems are described as sets of processes. In this view, subsystems may interact and all subsystems may contribute to procedural, episodic, and semantic memories, depending on specific task requirements.

Sherry and Schacter (1987) distinguish between "strong" and "weak" views of memory systems. According to a "strong" view, the components of a memory system interact exclusively with one another and not with the components of the other systems. According to a "weak" view, components from one system may interact with components from another system. In MEM it is possible for a subsystem to be "stronger" or "weaker", depending on the particular other subsystem with which it is compared. For example, the two reflection systems are closely related and highly interactive, as are the two perceptual systems; the R-1 system may interact relatively more with the P-2 system than the P-1 system, and so on. Note also that MEM's "modularity" is not the same as that described by Fodor (1983). According to MEM, memory has a modular capability in that organised/functional modules or groupings of processes might on some occasions operate without drawing on or being influenced by other modules; for example, P-1 can operate without R-2 and vice versa. MEM does not, however, define modules as units that are non-interacting or "impenetrable". Specifying the ways various subsystems interrelate and how they communicate is a continuing theoretical task, as is specifying the minimal number and type of subsystems and component processes necessary to account for available empirical results.

The exact structure in which cognitive processes are organised will depend on the goals of the researcher (e.g. Stuss & Benson, 1986). For example, one might concentrate on decomposing control and monitoring functions (e.g. Nelson & Narens, 1990), attention (Posner & Peterson, 1990), working memory (Baddeley, 1986), or problem solving (Newell & Simon, 1972). In MEM, a focal interest in learning and memory dictates the selection of processes and specification of functional relations among them—the architecture.

Given our current knowledge, it might seem premature to postulate subsystems at all. Nevertheless, thinking in terms of different constellations of processes, whether or not they are called "subsystems", helps us to think systematically about dissociations among measures of memory, ways in which the memory system can be disrupted (as in amnesia and other deficits), or functions that can take place in the absence of other functions (accounting perhaps for certain developmental trends, effects of normal ageing, performance in certain divided-attention situations, etc.).

The construction of subsystems should not be constrained by too rigid or formal criteria for subsystems. In addition to Sherry and Schacter's (1987) paper, other recent discussions of criteria for subsystems (e.g Dunn & Kirsner, 1988; Hintzman, 1990; Roediger, 1984; Shimamura, 1990; Tulving, 1985a) have also usefully clarified the nature of assumptions, limitations in the available data, and problems in the logic we use to make theoretical claims. Nevertheless, the criteria discussed in these papers must be placed in perspective. Premature rigidity or formality may cost more than being too lax (cf. Schacter, 1989).

Although we do not want to be overly restricted about thinking in terms of subsystems, any particular approach needs constraints to avoid generating a subsystem for each empirical fact. (All approaches do not necessarily need the same constraints, however.) MEM avoids such proliferation by defining subsystems in terms of processes and not in terms of content. Thus, someone working within the MEM framework would not posit a separate face system, space system, or language system. To account for the selective disruption of some of these capacities (McCarthy & Warrington, 1990; Shallice, 1988), the MEM worker might describe well-learned bundles of information in which elements mutually activate each other, which have a high degree of neural localisation of representation, for which there might be restricted entry and exit routes to and from the representational area, and so forth. According to this approach, *domains* could be formed around many topics (e.g. professional expertise) and are not necessarily predetermined or hard-wired although some, such as language or face processing, may be. These domains are orthogonal to MEM's subsystems, and thus MEM's architecture may be replicated across particular domains. This point has important consequences. For example, all of MEM's subsystems participate in language processing (e.g. Caplan & Hildebrandt, 1988): P-1 in learning to segregate a speech signal into units, P-2 in extracting syntax and meanings of familiar words, R-1 in generating simple implications, R-2 in developing representations of complex text (e.g. van Dijk & Kintsch, 1983), and so forth. MEM then suggests that a particular domain of knowledge—such as language or faces—could be disrupted in a variety of ways.

Subsystems as Units of Breakdown?

Although it is useful to think of the memory system as composed of functional subsystems, breakdowns in cognition would not be expected to correspond all-or-none to MEM subsystems. Functional subsystems in MEM are complex, with each composed of several component processes. Any particular subsystem could be disrupted in various ways, yielding different patterns of deficit all of which might be attributed to disruption of the same subsystem. The section that follows on "Alternative Patterns of Reflection" illustrates this point. But first, consider problems encountered by an alternative view, namely that subsystems are defined in terms of types of memory content and that breakdowns "honour" subsystems so defined. Two prominent analyses of this sort have been accounts of amnesia in terms of a general breakdown in either episodic or declarative memory.

Breakdowns and the Episodic/Semantic Distinction. Tulving (1972, 1983) drew attention to a fundamental problem: How should we conceptualise the difference between memories that feel autobiographical (my summer vacation) and memories that do not (knowing the sorts of things people generally do on summer vacations)? Tulving proposed that these two types of memories are mediated by two different systems, episodic memory and semantic memory. Tulving (1983; see also Cermak, 1984; Kinsbourne & Wood, 1982; Schacter & Tulving, 1982)

maintained that anterograde amnesia disrupts the episodic memory system while leaving the semantic system intact.

There have been a number of criticisms of the episodic/semantic distinction, on both conceptual and empirical grounds (e.g. see comments following Tulving, 1984). For example, as Tulving himself (1983) has pointed out, certain effects in amnesics, such as intact enhanced tachistoscopic identification from prior presentation of a word, are not easy to handle within the episodic/semantic framework. Adding a procedural memory to the system (Cermak, 1986; Tulving, 1983) may seem to solve this problem, but it also creates new ones (discussed in the next section). Another problem is that amnesics are disrupted in learning semantic information as well as episodic information (Squire, 1987b).

In contrast to the episodic/semantic distinction, in the MEM framework there is no separate store for autobiographical events. In MEM, semantic and episodic memories do not constitute different subsystems of memory; rather the sense of knowing and the sense of remembering associated with episodic memories reflect attributions made on the basis of subjective qualities of mental experiences (Johnson, 1988a, 1988b; Klatzky, 1984). Analysis of what differentiates a "recollected" autobiographical memory from a more generic memory would proceed along lines similar to those we have used for an analysis of reality monitoring (Johnson & Raye, 1981) and source monitoring in general (Johnson, 1988a; Johnson et al., in press). Attributing a memory to our personal past is the result of a judgement or attribution process applied to phenomenal characteristics of activated information.

Whereas Tulving emphasised time and place information as defining features of personal memory, in MEM such details are not regarded as defining features of a subsystem, but as important evidence (along with other evidence such as perceptual and emotional detail) for a judgement or attribution. The process of *reactivating* is important for maintaining over time qualitative characteristics of memories such as contextual or perceptual detail (Johnson, 1992; Suengas & Johnson, 1988). Disruption of *reactivation* in amnesia (Johnson, 1990; Johnson & Hirst, 1991) would severely limit the specificity of memories. Even for individuals with completely intact memory systems, remembering in MEM is not either autobiographical or nonautobiographical. Rather, while remembering, we experience degrees of specificity, clarity, confidence in veridicality, and so on.

In addition to qualitative characteristics of a memory, another factor in autobiographical attribution is that people judge remembered information as autobiographical in part because earlier reflective activity tied the information to other personal experiences. For example, anticipating an event in advance, and later reflecting back on it, create supporting memories that become evidence for the specificity and personal relevance of the event (Johnson, Foley, Suengas, & Raye, 1988). Because amnesics cannot retrieve prior events, they are doubly penalised (Johnson, 1988b). Even if a memory record is subsequently activated via external cues, it will not have supporting memories from prior reflection. Because of disrupted reflective processes, the phenomenal experience that amnesics have typically lacks specificity and embeddedness, the qualities of episodic or autobiographical memories.

Just as MEM does not assume a special store for autobiographical memory, neither is there a separate store for semantic or generic memory. In MEM, semantic or generic memories are built out of processes distributed throughout all subsystems. Consequently, not all generic information need be alike. For example, the generic knowledge we use to segregate sounds in listening to a foreign language may differ in interesting ways from the generic knowledge we have about how to behave at cocktail parties. That is, some generic knowledge is largely perceptually derived, whereas other generic knowledge is largely reflectively generated.

Breakdowns and the Procedural/Declarative Distinction. Amnesia does not disrupt certain forms of perceptual/motor skill learning, even though memory for the events involved is severely disrupted (Cohen & Squire, 1980; Milner, 1966). This dissociation led to the proposal that there are two memory systems: procedural (involved in skill learning) and declarative (involved in memory for factual information). Proponents of this distinction maintain that the procedural system is spared in amnesia, whereas the declarative memory system is disrupted (Cohen, 1984; Cohen & Squire, 1980; Squire, 1987a). The procedural/declarative distinction has been widely adopted, but in spite of its clear heuristic usefulness, it faces a number of problems as the basis of a general learning and memory framework.

In particular, all procedures may not naturally group together. The type of procedural knowledge involved in reading mirror text may differ from the type of procedural knowledge involved in crocheting or in knowing how to perform routine surgical operations. Learning surgery may depend on much more reflective activity than does mirror reading. Although amnesics may be able to learn mirror-reading procedures, which are largely supported by P-1 and P-2 processes, they should have much more difficulty learning other, more highly reflective procedures.

A report that amnesics learn the Tower of Hanoi problem at a normal rate seemed dramatically to support the idea of a unitary procedural system that included both perceptual/motor and cognitive skills (Cohen, 1984; Cohen & Corkin, 1981). This finding now appears to be limited to certain types of amnesics or special acquisition conditions. For instance, Korsakoff patients have profound difficulty with the Tower of Hanoi (Butters et al., 1985; Kim, 1985) and the Missionaries and Cannibals task (Kim, 1985). Although Korsakoff's might have deficits other than those included in some definitions of amnesia (e.g. Squire, 1982), Phelps, Johnson, and Hirst (unpublished data) found severe disruption on the Tower of Hanoi with non-alcoholic, mixed-aetiology amnesic patients. Furthermore, Gabrieli, Keane, and Corkin (1987) reported that H.M. (a subject in the original Cohen & Corkin, 1981, study) failed to improve on this task in a follow-up study. Gabrieli et al. suggest that H.M. may have performed as well as he did in the original study because the original procedure provided extensive experimenter cueing.

It will take more research to specify the kinds of procedures and problems various types of memory disordered patients can master, and under what conditions (e.g. Milberg et al., 1988; Phelps, 1989; Squire & Frambach, 1990). The point here is that different subsystems very likely support different types of skills or procedures (or components of complex skills or procedures). MEM describes the conditions (e.g. perceptual control) under which some procedures can be learned without strategic intervention or declarative representation, but it does not free the learning and remembering of procedures from the possibility of 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 the same apparent task. That is, skill acquisition is not always just a matter of learning to do the same thing "automatically" (Hirst, 1986). Rather, we learn to do different things as different cues (and perhaps different subsystems) come to control the performance.

As heuristic categories, declarative and procedural knowledge make intuitive sense, but the idea that procedural knowledge as a system is intact in amnesics made it tempting to define as procedural any task that amnesics can do. Thus priming and classical conditioning have been assumed to reflect procedural knowledge (e.g. Cohen, 1984), although what processes they share with tasks like mirror reading is not obvious. A clear definition of procedural memory has "proved elusive" (Butters, Salmon, Heindel, & Granholm, 1988).

More recently, Squire and colleagues (Benzing & Squire, 1989; Shimamura, 1990) replaced the procedural/declarative distinction with a declarative/nondeclarative distinction. The nondeclarative category encompasses a heterogeneous group of tasks operating "without the neural systems damaged in amnesia" (Shimamura, 1990, p. 163).

Declarative memory mediates memories disrupted by diencephalic or medial temporal damage (Shimamura, 1990, p. 164). Although this new taxonomy reflects the sensitivity of these researchers to some of the issues discussed here, it implies that declarative tasks are reasonably well-defined and homogeneous in their cognitive requirements. Moreover, it maintains that whereas the relations among tasks such as skill learning and classical conditioning remain unclear, they at least do not involve declarative information (although see Shimamura & Squire, 1988).

Even as a non-theoretical taxonomy, however, this scheme may lead to problems. Skill learning tasks, presumably mediated by non declarative memory, may involve "declarative" knowledge and hence also engage declarative memory (e.g. Anderson, 1982). Conversely, subjects may take perceptual "skill" as evidence for "declarative knowledge", as when they use perceptual fluency to make old/new recognition judgements (Johnston, Dark, & Jacoby, 1985).

The procedural/declarative (or the declarative/nondeclarative) distinction also does not by itself provide much guidance about how to analyse further the presumed disruption in the declarative system. The declarative system encodes, retrieves, and stores factual or propositional knowledge to which we have conscious access. The more detailed architecture of MEM provides a more comprehensive framework (based on a wide range of findings from basic memory research; see Morton, 1985) for considering potential differences in severity of amnesia or other types of learning and memory deficits (see the next section) and suggests why memory disordered patients' performance may vary across declarative tasks (e.g. recall vs. recognition: Hirst et al., 1986; Hirst, Johnson, Phelps, & Volpe, 1988; Weinstein, 1987), across procedural tasks (e.g. Phelps, 1989), and across tasks not obviously procedural or declarative, such as the acquisition of affect (Johnson, Kim, & Risse, 1985; Johnson & Multhaup, 1992).

Although the present discussion is intended to clarify the difference between MEM and the procedural/declarative distinction, like the episodic/semantic distinction, the procedural/declarative distinction can also be viewed as orthogonal to MEM's subsystems. As mentioned earlier, all MEM subsystems are very likely involved in "procedural" learning (typically of different types); whether all subsystems contribute to declarative knowledge is an open question. For instance, the P-1 subsystem may not alone produce declarative memory, but functioning of the P-1 system may promote access to factual information. Undertaking a P-1 activity may bring to mind memories of specific events from the past involving that same activity. Playing tennis may cue memories of other occasions of playing tennis. Or the declarative or propositional representation of a telephone number may be cued by dialling the number. Such interdependence between P-1 records and declarative information makes it difficult to draw a clear distinction between P-1 process and declarative memory. MEM could be viewed as a potential framework for further explicating the processing components of procedural and declarative knowledge.

Although the episodic/semantic and procedural/declarative distinctions have generated valuable insights and research, by adopting a more detailed process approach such as MEM, we should be able to build on these insights to develop a more complete understanding of why "episodic" or "declarative" information creates such a problem for amnesics. Processing ideas about episodic memory are described in Tulving's (1983) GAPS model, and processing ideas about declarative and procedural memory in Anderson's (1983) ACT* model. However, researchers, especially in characterising memory disorders, have for the most part focused on the structural rather than the process aspects of models, reflecting the field's tendency to gravitate towards simpler distinctions. MEM is an attempt to hold issues about process in central focus while at the same time searching for functional organisation (subsystems) among processes.

According to MEM, amnesics should have difficulty acquiring any kind of information—affective, semantic, episodic, or procedural—insofar as reflective processes are required and performance is not supported by ongoing sensory or perceptual cues (Johnson, 1983). We have further suggested that a disruption in *reactivating* could produce an amnesic pattern of deficits (Johnson, 1990; Johnson & Hirst, 1991). This account of amnesia encompasses a number of ideas about amnesia with a strong family resemblance: that amnesia reflects a "premature closure of function" (Talland, 1965), failure of consolidation (Milner, 1966; Squire, 1982), disruption of vertical processes (Wickelgren, 1979) or mediated learning (Warrington & Weiskrantz, 1982), an encoding deficit (Butters & Cermak, 1980; Cermak, 1979), a deficit in initial learning (Huppert & Piercy, 1982), or a contextual encoding deficit (Hirst, 1982; Mayes, 1988). These ideas focus attention on the fact that amnesic mnemonic processing is somehow attenuated (Johnson, 1990). MEM can be seen as an attempt to make some of these ideas more explicit and to give them a clearer statement within a more comprehensive framework.

A major question is what the "primitive terms" should be in such an effort. There is no obvious right answer: we are assuming that "consolidation" is not a primitive concept, but something to be explained in terms of basic cognitive processes postulated in MEM (e.g. Johnson, 1992). Similarly, "encoding", "vertical processes", and "cognitive mediation" would not be primitive concepts. Nor, for that matter, is "reflection". In developing the MEM framework, we have tried to decompose perceptual and reflective memory processes into component subprocesses. In general, we should expect that what we accept as primitive concepts will change as we are increasingly able to imagine and empirically investigate component parts of processes. By looking more closely at subcomponents of reflection and perception, we might eventually be able to account for degrees of amnesia and other learning and memory deficits (Weiskrantz, 1987). The next section outlines some preliminary ideas along these lines (Johnson & Hirst, 1991).

Alternative Patterns of Reflection. Eventually, we hope to be able to specify various normal and abnormal mental phenomena in terms of the patterns of functioning and nonfunctioning component processes within MEM's perceptual and reflective subsystems. To illustrate this approach (Johnson & Hirst, 1991), consider the situations depicted in Fig. 9.3. Each panel includes the R-1 and R-2 subsystems; to simplify, executive and supervisor processes are omitted. Active processes are indicated by solid lines, and inactive by dotted lines. This simple schema allows us to characterise several cognitive activities involving memory as well as certain deficits (Johnson & Hirst, 1991). For instance, as illustrated in Fig. 9.3A, when all R-1 and R-2 processes are intact, memory is working normally, and both unintentional and strategic learning can be accomplished with no apparent cognitive deficiencies. In Fig. 9.3B, R-2 has been deactivated or suppressed. Here, noting, shifting, refreshing, and reactivating are still operating. This pattern would yield unintentional learning or, guided by R-1 executive processes, relatively simple intentional learning. However, the disruption of R-2 processing would severely limit the complexity of the possible learning.

Figure 9.3C highlights the combination of shifting, initiating, refreshing, and rehearsing. This configuration would yield something like the phenomenal experience of free association or stream of consciousness. In Fig. 9.3D, we have the combination of refreshing, rehearsing, reactivating, and retrieving. This pattern yields goal-directed rote rehearsal and, if poorly controlled, perseveration or even compulsions. In Fig. 9.3E, we have the combination of noting, discovering, reactivating, and retrieving. This combination mediates rationalised (relations are noted) but rigid rote rehearsal (something like some professor's lectures). In Fig. 9.3F, the combination of shifting, initiating, noting, and discovering act together to produce the kind of creative organisational activities found, for example, in problem solving or brainstorming. The ideas generated would not be remembered well, however, with other component processes deactivated. Furthermore, a

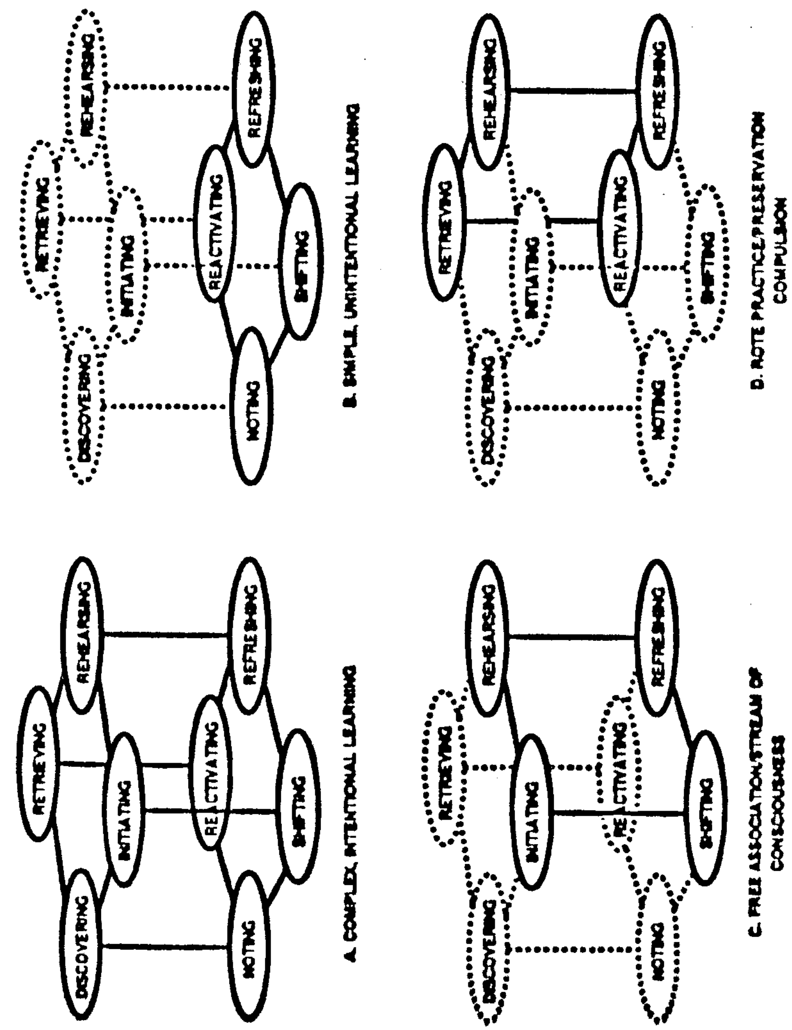

FIG. 9.3. (A–D) Schematic representation of the consequences of different combinations of reflective component processes. Adapted from Johnson & Hirst (1991) with permission.

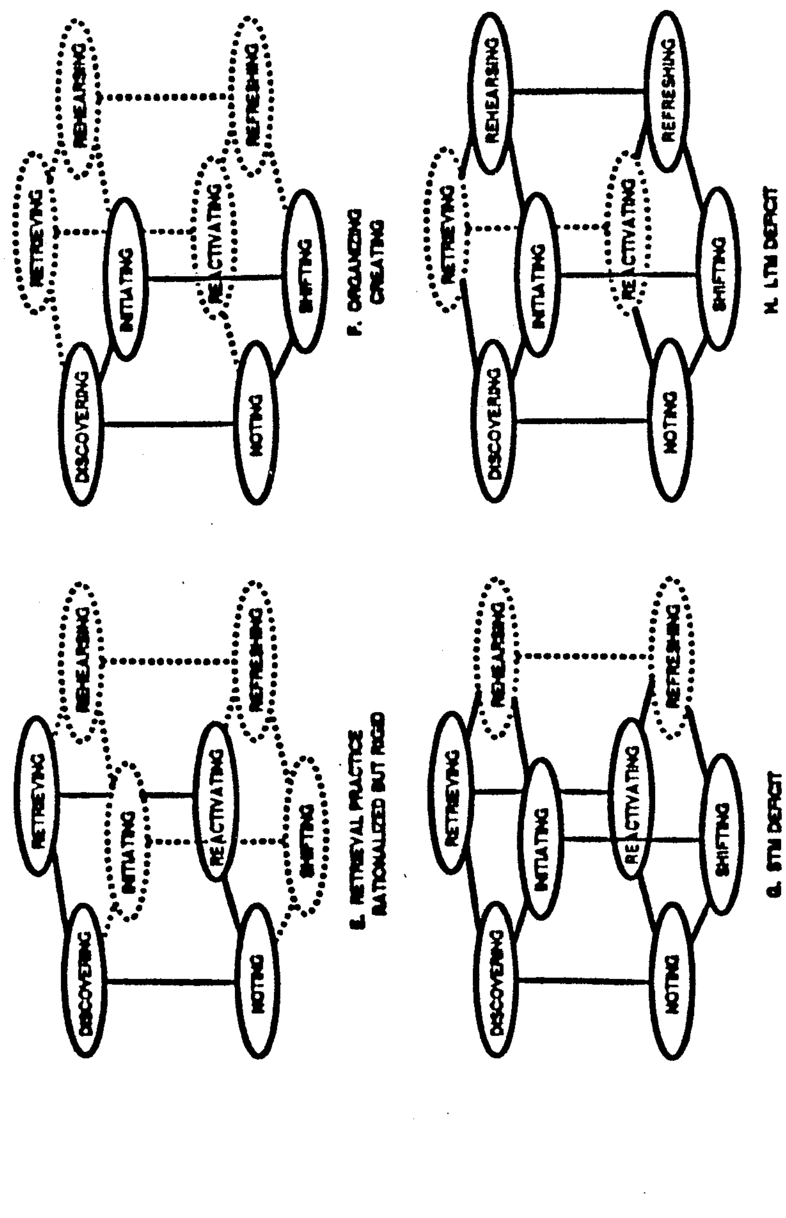

FIG. 9.3. (E–H) Schematic representation of the consequences of different combinations of reflective component processes. Adapted from Johnson & Hirst (1991) with permission.

nonfunctional reactivation component, as in Fig. 9.3F, would limit the nature of past knowledge that could be drawn on for making analogies (e.g. Faries & Reiser, 1988). A short-term memory deficit (e.g. Vallar & Baddeley, 1984; Warrington, 1982) could arise when all components except refreshing and rehearsal are intact (Fig. 9.3G). When all components are intact except reactivating and retrieval (Fig. 9.3H), a long-term memory deficit very much like core anterograde amnesia might be observed (Hirst, 1982; Parkin, 1982; Schacter, 1985; Squire, 1986).

Figures 9.3I, 9.3J, and 9.3K show various ways in which the relation between supervisor and executive processes associated with R-1 and R-2 subsystems might be disrupted. For example, Figure 9.3K depicts a situation in which both R-1 and R-2 judgement processes are intact, but in which R-1 and R-2 supervisor and executive processes no longer exchange information about each other's functioning. This disconnection would reduce the availability of cognitive operations as a discriminative cue for origin to either R-2 executive or R-1 supervisor processes.

Although here we have focused on the impact on learning and memory of disrupting reflective processes, disruption in the P-1 and P-2 subsystems (or component processes within these subsystems) in MEM could produce learning and memory deficits as well (see Fig. 9.1C). For example, patients with Huntington's disease are more impaired in learning to read mirror-reflected word triads (Butters, 1984; Martone et al., 1984) or in a pursuit rotor task (Heindel, Butters, & Salmon, 1988) than on recognition tests. Such findings may reflect the selective disruption of the P-1 system. Selective disruption of P-2 processes may produce visual agnosias as in the case of "the man who mistook his wife for a hat" (Sacks, 1985). This patient cannot integrate visual stimuli into organised, patterned percepts, but can evidently learn to recognise people from their movements.

CONCLUSIONS

People confront a range of memory tasks every day. These tasks differ in complexity, process demands, and the chance for success. No system could be designed with each of these tasks in mind. New situations will engender new memory tasks. Human memory did not evolve to learn the Pledge of Allegiance or to report autobiographical events to a therapist. Whatever the processes underlying these tasks, they spring from the resources developed to meet quite different task demands figuring earlier in evolution. Psychologists have tried to develop experimental tasks that capture what might be considered quite general

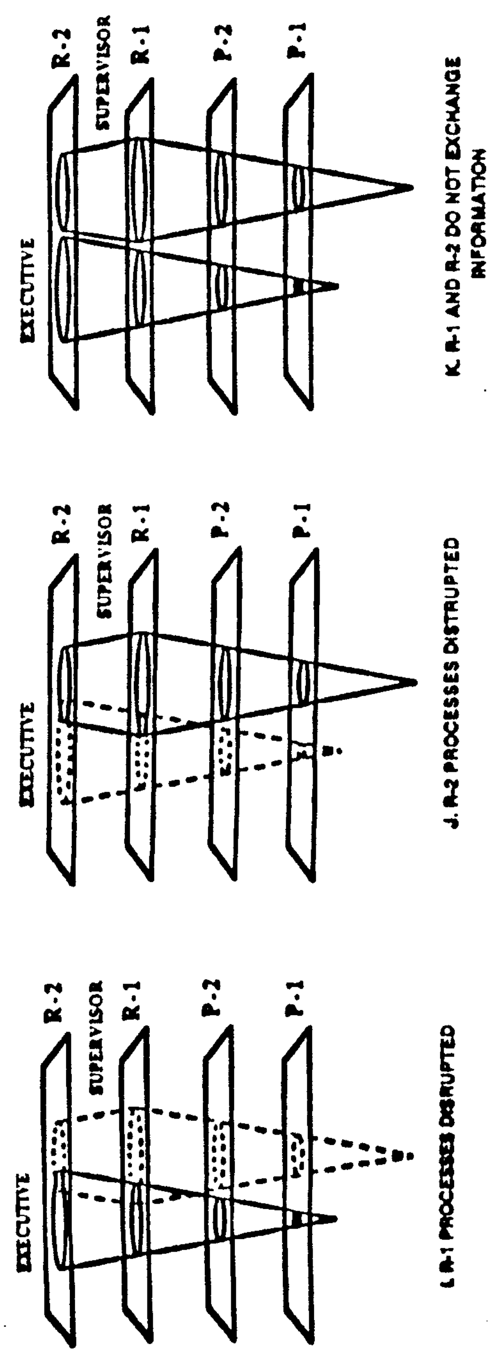

FIG. 9.3. (I–K) Schematic representation of the consequences of different combinations of reflective component processes. Adapted from Johnson & Hirst (1991) with permission.

memory demands: tasks such as serial learning, free recall, cued recall, recognition, source monitoring, stimulus identification under degraded conditions, and so on. These tasks are useful constructs but each is complex and thus no single one is likely to reveal some single primordial process.

No matter what task they use, psychologists are faced with the gargantuan problem of ferreting out the underlying primitive processes involved. The processes can rarely if ever be observed in isolation or on the surface of behaviour. Rather, as memory researchers increasingly appreciate, basic processes can only be discovered through a careful analysis of a range of tasks. The challenge is to construct a coherent picture from the jigsaw puzzle of evidence derived from many tasks. The hidden quality of the basic elements of human information processing, the complexity of requirements in even relatively simple tasks, and the variety of tasks, together suggest that the models we need will be relatively complex and will not exactly mirror the surface features of tasks expressed in categories such as episodic, semantic, procedural, and declarative.

Clearly, what is needed is a vocabulary of basic processes that will guide and constrain psychological discussion of memory tasks and processes. MEM offers a first approximation of just such a language. Although at first glance it may seem complex, it articulates only 16 basic processes, most based on prior findings or concepts from the cognitive literature. These are augmented by some proposals about how these component processes might be configured into functional subsystems, including two (R-1 and R-2) with the capability of executive control and monitoring functions. These processes and their proposed structure serve as a basis for modelling a host of different memory phenomena discussed here and in earlier papers (Johnson, 1983, 1990, 1991a, 1991b; Johnson & Hirst, 1991; Johnson & Multhaup, 1992), including dissociations among memory measures, autobiographical memory, source monitoring, mnemonic aspects of attention and consciousness, the relation of cognition to emotion, and the relation between recall and recognition. MEM not only offers parsimonious language for describing a range of phenomena, it also provides rich enough detail to make solid predictions about the breakdown of functioning with brain damage and psychological distress, and the course of the development of memory. We hope that the diversity of the phenomena discussed, and the fact that their complexity can be straightforwardly described using the MEM framework, will persuade the reader that MEM is as useful as we find it.

Finally, the language of MEM provides a means of clarifying problems with some alternative general frameworks—such as those proposing distinctions between episodic and semantic memory, between procedural and declarative memory, and between conceptual processing and data-driven processing. Minimally, MEM provides some much needed processing vocabulary for describing how episodic, semantic, procedural, and declarative memory come about—a vocabulary that is often missing from uses of structural models. That is, MEM suggests that analyses framed in terms of processes will be at least as useful as analyses framed in terms of outcomes. At the same time, MEM provides some ideas about functional groupings of processes (i.e. subsystems) missing from models based primarily on the distinction between data-driven and conceptually-driven processing.

There are at least three strategies for the further development of working frameworks such as MEM, and we are pursuing them all. One is to try to create and investigate tasks and measures that isolate and independently manipulate the proposed component processes to observe their separate impact on memory. A second is to explore a particular problem (e.g. source monitoring) in detail in order to reveal its complexity and to attempt to characterise the processes involved within the MEM framework. The third strategy is to pursue the integrative approach. By attempting to apply the current MEM framework to findings in as broad a range of domains as possible, the framework will undoubtedly continue to be challenged and modified. In our view, these three approaches provide complementary and equally valuable ways of "testing" and clarifying a theoretical framework.

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CHAPTER TEN

Problems and Solutions in Memory and Cognition

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INTRODUCTION

The Lancaster International Conference on Memory provided an opportunity to reflect on some general aspects of the way in which we investigate human memory. Indeed, it tempted one to be not merely descriptive but prescriptive as well. Such temptation is probably best resisted, however. It is always possible that there is a single, royal road to all that we wish to know about memory. However, in the absence of consensus among mnemonic cartographers, it is no doubt more conservative to pursue a variety of paths instead. It is with this proviso that I draw attention here to one of these paths into the domain of Mnemosyne. Mnemosyne, goddess of memory, was mother of the nine Muses personifying artistic and intellectual achievement. Greek mythology reminds us therefore that memory also relates to most other aspects of the intellect. It is likely that what can be said of the investigation of memory can also be said for cognition in general. What, then, is the present suggestion for exploring human memory and cognition? In principle, it is a simple one. It is that in exploring memory and cognition we should proceed by formulating problems or solving problems.

It might be objected that to formulate and solve problems is a relatively anodyne recommendation because, in general terms at least, it would appear to exclude few possibilities in research. However, such