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Memory systems: A cognitive construct for analysis and synthesis

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Memory system is a construct used to refer to the capacity for behavior, thought and emotion to change as a function of experience. It is assumed to be instantiated in biological mechanisms. Because the human memory system is complex, it is useful to think of it as consisting of parts that subserve classes of functions. Depending on an investigator's emphasis, hypothesized parts are defined in terms of conceptual structures (e.g. sensory registers, short-term memory, long-term memory), types of content (e.g. episodic versus semantic memory, habit versus memory, procedural versus declarative memory), types of processes (e.g. shallow versus deep, automatic versus effortful, familiarity versus recollection, perceptual versus reflective), and/or in terms of brain structures (e.g. hippocampus versus striatum). Like the blind men and the elephant, all of these approaches capture some of the truth, and the challenge is to construct the memory system elephant from the ideas and findings yielded by these different perspectives.

One effort—a *m*ultiple-*e*ntry, *m*odular memory system (MEM)—is shown in Fig. 60.1. MEM is a *process*-oriented system that specifies the types of component processes needed for the wide range of memory phenomena demonstrated in human thought and behavior. The MEM architecture organizes these component processes into four functional subsystems. Proposed subsystems P-1 and P-2 consist of perceptual component processes and they record the consequences of these processes. The reflective subsystems R-1 and R-2 consist of component processes of what we generally call 'thought' and 'imagination', allowing us to act mentally on the products of prior perception or reflection and record the consequences. The subsystems are proposed to be modular in the sense that they can engage in some functions without reference to other subsystems, but multiple subsystems are normally operating and interacting in any complex task or situation.

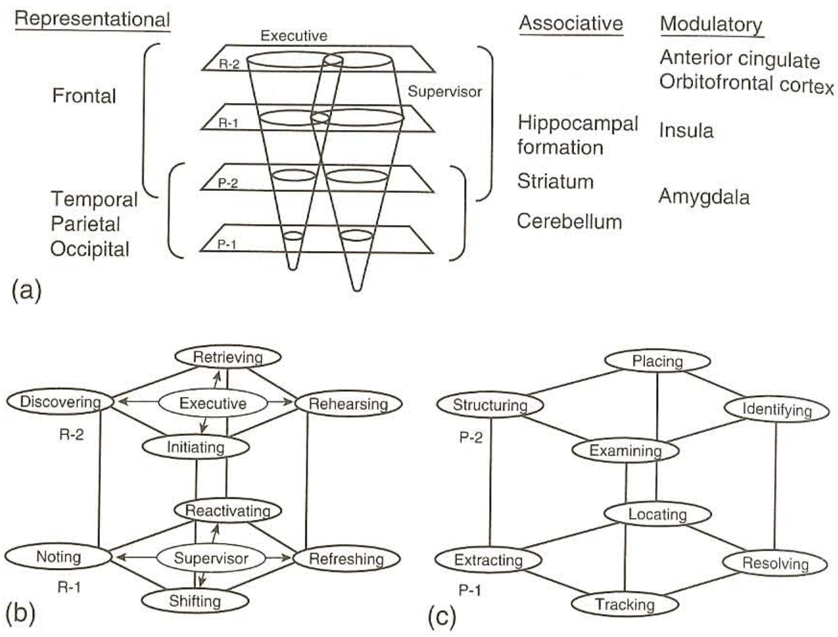

Fig. 60.1 Memory system as a cognitive construct for analysis and synthesis. (a) A multiple-entry, modular memory system composed of two reflective subsystems (R-1 and R-2) and two perceptual subsystems (P-1 and P-2). (b) Component processes of R-1 and R-2. (c) Component processes of P-1 and P-2. Component processes are realized by networks of brain regions: Various cortical regions (frontal, occipital, parietal, temporal) in interaction with each other and with regions in the hippocampal formation, cerebellum, and striatum, and modulated by anterior cingulate cortex, orbitofrontal cortex, insula and amygdala, account for variations in the types of memory that humans display. (From Johnson, M.K. (1991). Reflection, reality-monitoring, and the self. In R. Kunzendorf (Ed.), *Mental imagery* (pp. 3–16). NY: Plenum. Reprinted with permission from Springer Science and Business media.)

We are typically unaware of the perceptual information involved in P-1 processes, for instance 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 accent or to anticipate the trajectory of a baseball. In contrast, we use P-2 processes in learning about the conscious, phenomenal perceptual world of objects such as people, chairs and balls, events such as seeing a person sit down in a chair or catch a ball, and the relations among objects (e.g. a couch is to the left of a chair in the living room).

Reflection allows us to go beyond the immediate consequences of perception, allowing us to sustain, organize, manipulate and revive information. Similar to P-1 compared with P-2 processes, R-1 processes are more automatic than R-2 processes. R-1 processes allow us to refresh (foreground), shift to, note or reactivate relevant information. R-2 processes allow us to rehearse and initiate new strategies (e.g. generate cues) that help us discover relations or retrieve information. Reflective component processes are the mental activities that not only contribute to a sense of remembering but also allow us to anticipate future events, imagine possible alternative pasts and futures, and have the sense that we are taking an active role in our thought and behavior.

The idea of active control of the flow of cognition is often assigned to a central executive in cognitive theories. In MEM, there is no central executive. Rather, perceptual and reflective cognition is guided by agendas, which serve as virtual executives (or supervisors) when active. For example, with an R-1 agenda to listen attentively to a story, you might generate tacit implications of sentences, note relations between one part of the story and an earlier part of which you are reminded, and so forth. With an R-2 agenda to evaluate the story critically, you might generate objections to the logic of events, actively retrieve other stories for comparison, and so forth. That is, agendas (both well-learned and *ad hoc*) activate combinations of reflective and perceptual processes in the service of specific goals and motives, and monitor or evaluate outcomes with respect to these agendas. Agendas can coordinate activity across subsystems (reflected in the cones in Fig. 60.1), as when a goal activates retrieval of information along with related perceptual schemas (e.g. in driving to a party, trying to remember an address while looking for a specific style of house). In MEM, representing agendas separately in each of the two reflective subsystems provides a mechanism for (1) control and monitoring of complex thought and action; (2) self-observation and self-control; and (3) certain forms of consciousness.

The activity of any of these component processes generates changes in memory. Changes in memory can be expressed in behavior (e.g. seeing something that was seen before more easily under degraded conditions) or expressed as phenomenal experiences, such as experiencing a feeling of familiarity, remembering an autobiographical event or knowing a fact.

The component processes of MEM (see Fig. 60.1B and C) are described in terms of mid-level concepts. A component process represents a class of similar operations performed on different data types, for example similar operations occurring in different sensory modalities. Also, because component processes are transactions among brain regions or circuits of activity, they can be disrupted in multiple ways. Because different circuits likely instantiate different versions of a process (e.g. *refreshing* auditory/verbal information may involve a circuit different from *refreshing* visual/pictorial information), considerable specificity of disruption from highly localized brain lesions could occur, depending on where the lesion is located.

Cognitive neuroscience is providing evidence about the relation between proposed cognitive processes and neural mechanisms. For example, for visual information, findings are rapidly accumulating from many laboratories about the roles of different areas of occipital, temporal and parietal cortex in perceptual processing, and about the roles of different areas of frontal cortex in reflective processing (e.g. dorsolateral and ventrolateral prefrontal cortex in *refreshing* and *rehearsing*, respectively). Likewise, we are seeing progress in characterizing how cortical regions, interacting with hippocampal, cerebellar and striatal structures, contribute to memory, and how these circuits are modulated by activity in regions that are sensitive to conflict and emotional and motivational factors (anterior cingulate cortex, orbitofrontal cortex, insula, amygdala). In turn, activity in brain regions associated with motivation and emotion is modulated by past experience and current goals and cognitive contexts. Thus, even at a quite general level of description, the memory system is complex and highly interactive among brain regions and across putative subsystems. Specifying the relations among regions engaged in representing information (e.g. goals, criteria, relations, objects, features) and associative and modulatory regions is a major challenge for cognitive and affective neuroscience.

Science is an effort to understand by analysis and synthesis. MEM subsystems (like concepts such as implicit learning, episodic memory or reflection) are too complex to be the basic units of analysis. For analysis, component processes are a more tractable approach. Hypothesized component processes can be investigated experimentally, both behaviorally and with the tools of cognitive neuroscience that are currently available [e.g. functional magnetic resonance imaging (fMRI), event-related potentoal (ERP), transcranial magnetic stimulation (TMS)]. A cognitive neuroscience of *component processes* aims to: (1) provide operational definitions of processes; (2) identify brain regions subserving a process; (3) distinguish these regions or patterns of activation from regions or patterns of activation subserving other component processes; (4) identify functional correlates of component processes (e.g. impact on long-term memory); (5) demonstrate that disruption of putative function is associated with damage or dysfunction in the presumed brain regions subserving the process; and (6) specify how the process and its neural correlates vary with context (e.g. changes in the types of representations on which the process acts, or changes in the amount of potential interference). In short, understanding a complex psychological phenomenon such as memory involves a graceful alignment between biological perspectives (emphasizing, for example, brain structures) and cognitive perspectives (emphasizing, for example, processes).

As investigators identify more specific neural circuits associated with more specific component processes, and further explicate their interactions, some mid-level conceptual framework that proposes an architecture for component processes should be useful for synthesis. That is, subsystems such as those proposed in MEM help identify and organize relations among the many findings, such as the relation between working memory and long-term memory or why different kinds of brain damage selectively disrupt memory.

Such a general, synthetic framework for characterizing memory subsystems should try to address a number of key issues: (1) the wide range of functions that memory serves (e.g. perceptual learning, recognition, voluntary recall, autobiographical memory, knowledge, prediction); (2) the relation between memory and reality, i.e. the mechanisms that account for both accurate and distorted memory; (3) dissociations among memory measures and variation in phenomenal experience of memory; (4) selective effects of brain damage, aging, fatigue and stress; (5) how subsystems of memory interact; (6) the relation of memory to other cognitive concepts such as attention, perception and consciousness; (7) the relations among cognition, emotion and memory; (8) changes in memory with development; (9) the concept of 'self;' (10) the evolution of memory subsystems; and (11) brain structures and networks subserving memory processes. For further discussion of issues relating to the goals of analysis and synthesis from the MEM perspective, see Johnson (1983, 1990, 1991, 1992, 1997), Johnson *et al.* (1993, 2005), Johnson and Hirst (1991, 1993), Johnson and Chalfonte (1994), Johnson and Multhaup (1992) and Johnson and Reeder (1997).

Acknowledgments

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