MEM: Mechanisms of Recollection

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Abstract

■ The MEM framework (Johnson, 1991a, b; Johnson & Hirst, 1992; Johnson & Multhaup, 1992) consists of a relatively small set of component cognitive processes configured into memory subsystems. Here MEM is used to discuss "recollection," particularly the mechanisms by which aspects of experience become bound together to yield the phenomenal experience of contextually specific, event-like memories. I consider how central aspects of complex events are bound to each other and propose that these same cognitive activities operate to bind central and contextual elements into "episodic" memories. Attention is particularly focused on the role of *reactivation* in establishing complex memories and in strengthening or consolidating them over time. ■

INTRODUCTION

Recollection can be distinguished from other manifestations of memory such as knowing (e.g., Gardiner, 1988; Tulving, 1972), or transfer and priming effects (e.g., Richardson-Klavehn & Bjork, 1988; Schacter, 1987). Recollection implies an autobiographical past; the information remembered has contextual specificity and personal relevance. Often, but not always, we have voluntary access to the information as well. Knowing, transfer, and priming effects depend, of course, on past events, but such effects may occur without creating the phenomenology of particular, personally experienced past events and do not depend on our being able to voluntarily revive anything about them as past experiences. Contextual specificity, personal relevance, and voluntary access—by what processes do these characteristic features of recollection arise?

This paper discusses recollection in terms of the component subprocesses described in the Multiple-Entry, Modular Memory System framework (MEM). Other papers describe MEM in relation to other memory models (Johnson, 1983; Johnson & Hirst, 1992) and consider such topics as amnesia (Johnson, 1990; Johnson & Hirst, 1991), confabulation (Johnson, 1991a), emotion (Johnson & Multhaup, 1992), and source monitoring (Johnson, Hashtroudi, & Lindsay, 1992) from the point of view of this framework. Here I focus specifically on some of the mechanisms that may underlie recollection. The first section below provides a general overview of the analytic problem posed by recollection, the second section describes the MEM framework, and the third and fourth consider one aspect of the problem of recollection—how different elements of experience become bound together in complex records that are the basis of contextually specific, event-like or episodic memories characteristic of recollection.

THE ANALYTIC PROBLEM POSED BY RECOLLECTION

The issue of recollection is really composed of three related questions: the mechanisms by which cues access traces (e.g., associative search, direct access via feature match, synergistic ecphory, or holographic correlation); the mechanisms by which the aspects (e.g., content and context) of a recollection become associated in memory (the binding problem), and the mechanisms by which mental experiences are judged to be accurate recollections rather than, say, current or past imaginations (the source monitoring problem).

A simple and uncontroversial idea is that recollection, like all forms of memory, is cue dependent. Regardless of theoretical style and research domain, most investigators share the assumptions that experiences establish memory traces that include certain features or types of information and that the probability that memories are revived is a function of the amount of overlap in features shared by cues and traces (e.g., Anderson, 1983; Bower, 1967; Estes, 1955; Hintzman, 1986; Johnson & Raye, 1981; Kesner, 1990; Metcalfe Eich, 1982; Raaijmakers & Shiffrin, 1981; Rolls, 1990; Rovee-Collier, 1991; Spear, 1978; Tulving, 1983; Underwood, 1969). The following thought experiment points out that this simple idea requires elaboration. Suppose subjects see blue words on the left and red words on the right of a computer screen. The memory trace for each item then might include a semantic feature (e.g., dog) and contextual features such as color (e.g., blue) and spatial position (e.g., left). According to a simple cue/trace overlap model, presentation of the cue, "remember the blue words on the left" should cue the recollection of appropriate items through a match between the cue "blue/left" and various traces including those features. Such a cuing model is straightforward but the actual situation observed with human subjects is clearly more complicated. Under many circumstances, blue/left would be unlikely, by itself, to be a particularly good recall cue for words. Simply seeing words in blue on the left is not sufficient to establish the cue value of these features.

We could embellish the simple cue/trace overlap model with the idea that cue effectiveness is not established all-or-none; the strength of a cue improves with repetitions of cue/target pairings. The idea that the strength between cues and targets increases with repetition is an improvement incorporated in most models, but the picture is still incomplete. For example, there are limits to the number of items that can be retrieved via a particular cue (e.g., Anderson, 1983; Raaijmakers & Shiffrin, 1981; Watkins & Watkins, 1975). And some cues would still be more likely to provide access to particular traces than would others. The conditions that determine whether a "contextual" cue will work to revive a memory's "content" need to be specified, as do the conditions that determine whether memory for "content" is accompanied by memory for "context."

To specify the conditions of cue effectiveness for recollection, we need to consider how features get bound together to create complex traces of complex events. One possibility is that simply by virtue of cotemporal activation, features become bound or "glued" together in memory traces. Accordingly, time spent studying an item in a context might determine the strength of the item–context relation (e.g., Gillund & Shiffrin, 1984). Although association by contiguity may be a fundamental learning mechanism, by itself it is not going to be the whole story of contextual memory (e.g., see Bjork & Richardson-Klavehn, 1989). Even in basic perceptual processing, something more seems to be required to bind together a shape with a color than simple cotemporal activation (e.g., Treisman & Gelade, 1980; see also Johnson, Peterson, Chua Yap, & Rose, 1989). Furthermore, not all contiguities are equivalent; some associations are easier to acquire than others (e.g., Revusky & Garcia, 1970; Seligman, 1970). A failure of simple contiguity that is perhaps more critical for understanding recollection occurs in situations where subjects entertain hypotheses and sample from a set that does not include the correct hypothesis. In a concept learning task, after experiencing several problems with complex sequence solutions, subjects may miss the most obvious of contiguities, failing to learn that the experimenter says "right" every time the subject says "A" and "wrong" every time the subject says "B" (Levine, 1971). Minimally, we have to make a distinction between nominal and functional contiguity; what is functionally cotemporal depends on the hypotheses, schemas, and goals that are active at the time.

But suppose that, by whatever processes, learning mechanisms have established complex traces and determined the cue potential of various probes that might be presented later. Even when such cues work, what is revived does not come to mind with the tag "recollection" on it to tell us that it is a recollection. Recollections result from *judgment processes* that take particular mental experiences to be memories derived from particular sources (Johnson & Raye, 1981; Johnson et al., 1992). Knowing a bit of gossip is quite different from recollecting the occasion that you heard it. When you can attribute a memory to a source, it has some of the defining qualities of a recollection. It seems to be a memory for an actual event that you experienced personally. There is no fixed type or amount of information, however, that distinguishes knowing from remembering. Although the most prototypical recollections may be for specific, individual events (e.g., a particular party), several, similar events can result in a more broadly defined, yet still event-like, phenomenal experience (e.g., meetings of the 1991 memory seminar). Furthermore, given the same activated information, factors such as the purpose of the remembering and therefore the criteria used will affect whether or not the subject has the experience of recollecting (e.g., Lindsay & Johnson, 1989).

In short, to understand the mechanisms of recollecting, we have to explore two questions in addition to mechanisms of cue-target revival. How do memory records come to include more than one feature, that is, what are the conditions for establishing complex traces; in particular, how are context and content bound? And what are the processes that determine how what is revived is attributed to particular sources?

My colleagues and I have previously described some ideas about the second of these—the information and judgment processes involved in attributing memories to sources (e.g., Johnson, 1988a; Johnson et al., 1992; Johnson & Raye, 1981). In this paper, I focus on the first question—potential cognitive mechanisms by which attributes, features, or qualities of memories become bound together to establish their cue potential for personal recollection. The issue of how various cues become compounded, configured, or related is a fundamental problem for memory theory (e.g., Estes, 1976; Eichenbaum, Stewart, & Morris, 1990; Hirsh, 1974; Hirst, 1982; Mayes, 1988; Medin & Reynolds, 1985; O'Keefe & Nadel, 1978; Olton, Becker, & Handelmann, 1979; Rolls, 1991; Squire, Shimamura, & Amaral, 1989; Sutherland & Rudy, 1989; Teyler & DiScenna, 1986; Wickelgren, 1979). Here I begin to lay out a set of "functional specifications" for establishing complex traces using the MEM framework. To foreshadow, one set of critical mechanisms involves the interrelated functioning of components of reflection as described in MEM: *agendas*, *refreshing*, *reactivation*, and *noting*. I will argue that through the joint action of these reflective component processes, the incidental or contextual information that is necessary for a sense of personal experience can be bound to central aspects, thus creating events.

The next section briefly outlines the MEM framework. Following this, I will consider the question of how central elements of complex events are bound to each other and then propose that these same processes operate to bind central and contextual elements into "episodic" memories.

THE MEM FRAMEWORK

MEM is a process-oriented approach to memory subsystems (Johnson & Hirst, 1991, 1992); it is a working framework in which the primary descriptive units are cognitive actions. These activities are organized into four functional subsystems (Fig. 1): two perceptual subsystems (P-1 and P-2) and two reflective subsystems (R-1 and R-2). (See Johnson & Hirst, 1992, for a discussion of the way "subsystem" is used here.)

Component subprocesses of P-1 (Fig. 1c) 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 toward you). P-1 processes develop connections or associations involving perceptual information of which we are often unaware, such as 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. Learning that results from P-1 processes allows us to do things such as adjust to a person's foreign accent or anticipate the trajectory of a baseball.

Subprocesses of P-2 (Fig. 1c) include *placing* objects in spatial relation to each other, *identifying* objects, *examining* or perceptually investigating stimuli, and *structuring* or abstracting a pattern of organization from temporally extended stimuli (e.g., abstracting syntactic structure from a sentence). P-2 processes are involved in learning about the phenomenal perceptual world of objects such as chairs and balls and about events such as seeing a person sit down in a chair or catch a ball.

Both R-1 and R-2 involve component processes that allow people to sustain, organize, and revive information. The component processes in R-1 (Fig. 1b) 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 (Fig. 1b) are analogous but more deliberate; they include *discovering*, *initiating*, *rehearsing*, and *retrieving*. To illustrate, 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 pre-

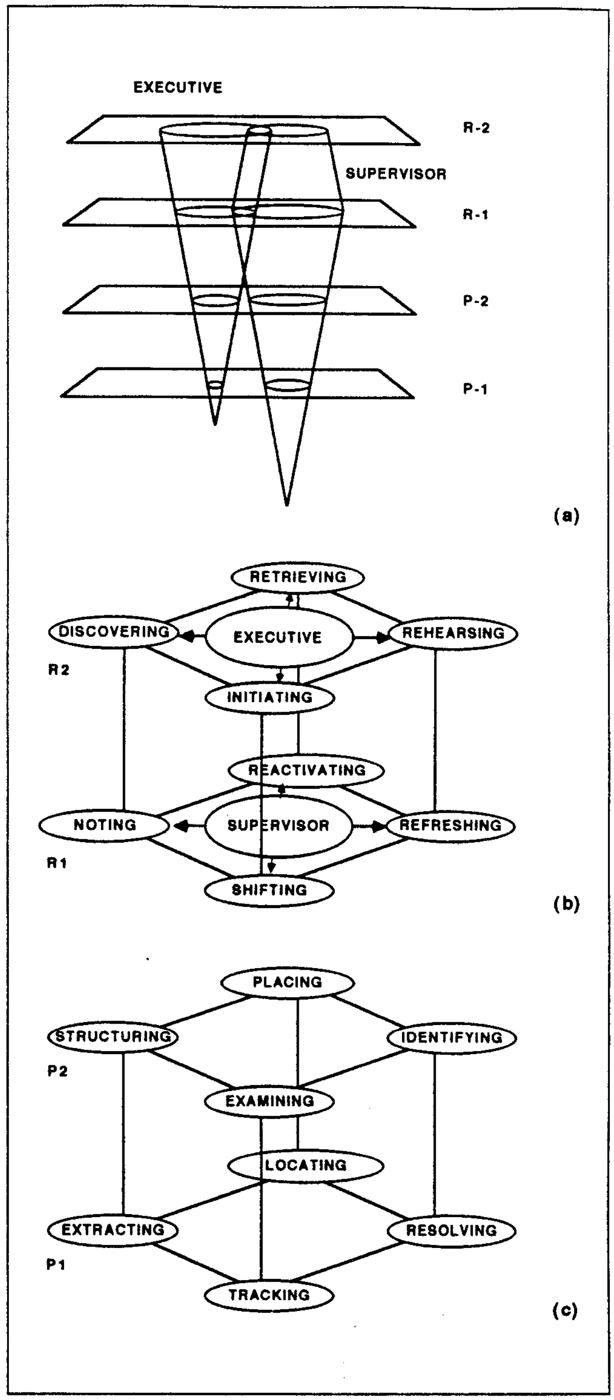

Figure 1. (**a**) A Multiple-Entry, Modular memory system, consisting of two reflective subsystems, R-1 and R-2, and two perceptual subsystems, P-1 and P-2. Reflective and perceptual subsystems can interact through control and monitoring processes (supervisor and executive processes of R-1 and R-2, respectively), which have relatively greater access to and control over reflective than perceptual subsystems. (**b**) Component subprocesses of R-1 and R-2. (**c**) Component subprocesses of P-1 and P-2. [Adapted from Johnson (1991b) with permission.]

vious reflection, for example, when a relation that is currently noted brings to mind an occasion when the same relation was previously noted (e.g., Faries & Reiser, 1988). An example of *retrieving* is when you use the strategy of self-presentation of cues, for example, in trying to think of the name of a restaurant to try to remember people who might have told you about it (Baddeley, 1982; Reiser, 1986).

The component processes in R-1 and R-2 are coordinated and monitored by *agendas* and criteria for evaluating outcomes with respect to these agendas. Agendas may be quite general (e.g., obtain, explain, persuade, recollect) or task-specific (say words starting with "F"). They may be relatively simple (identify each word in a perceptual identification task) 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 for learning a list of words). They may call up perceptual component processes or schemas (e.g., identify the letter *a* in this array). Ways for accomplishing routine goals become schematized (or compiled) into well-defined, cohesive agendas through practice (e.g., Anderson, 1987); thus calling up an agenda may be sufficient for sequencing component processes. Whether simple or complex and whether well-learned or only beginning to be formed, agendas include recipes or programs for cognitive action consisting of component subprocesses.

The control and monitoring processes that are active in R-1 are called *supervisor* processes, and the ones active in R-2 are called *executive* processes (cf. Miller, Galanter, & Pribram, 1960; Nelson & Narens, 1990; Stuss & Benson, 1986). Supervisor processes can handle simple, well-learned regulation and monitoring tasks, for example, setting simple criteria for old/new recognition judgments. Executive processes are necessary for more complex monitoring—tasks involving multiple rules, testing imagined alternatives against imagined consequences, such as in the Missionaries and Cannibals problem, embedded subgoals that are not routine, and so forth.

In Figure 1a, supervisor and executive processes are depicted as cones passing through planes representing the different subsystems. As implied in the figure, 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 have heard about restaurants in this part of town). As suggested by Figure 1a, activated agendas temporarily "group together" activation that is simultaneously occurring in various subsystems. In other words, one mechanism by which perceptual information can become bound (at least temporarily) with reflective thoughts about it is *through their mutual association with an agenda*. Such grouping of elements of experience through agendas helps create episodic memories.

The supervisor and executive processes can recruit and monitor each other, as depicted by their overlap in Figure 1a. This permits sequencing subgoals, gives rise to experiences such as thinking about thinking and self-control, and provides information about cognitive operations that is important for reality monitoring (Johnson, 1991b). Also, the idea that cognition varies in effort, will, or control (Hasher & Zacks, 1979; Norman & Shallice, 1986; Posner & Snyder, 1975; Shiffrin & Schneider, 1977) can be depicted in MEM in terms of the number of different component processes that are recruited and the number of recursions of the same component processes that are required (Johnson & Multhaup, 1992; Johnson & Hirst, 1992).

For heuristic purposes, the component processes in MEM are treated as if they were elementary computations; they could, however, be further decomposed. For example, Beiderman's (1987) recognition-by-components theory of object recognition could be viewed as a more complete specification of subprocesses contributing to *resolving* and *identifying* visual stimuli in P-1 and P-2, as could the work on structural descriptions by Schacter and Cooper and colleagues (e.g., Schacter, Cooper, Delaney, Peterson, & Tharan, 1991). Work on visual attention explores some of the mechanisms of *locating* (e.g., Weiskrantz, 1986; Yantis & Johnson, 1990) and *tracking* (Kowler & Martins, 1982; Pylyshyn, 1989). Baddeley and colleagues' (Baddeley, 1986; Baddeley & Hitch, 1974) theory of the phonological loop could be viewed as a characterization for language materials of *refreshing* and *rehearsing* processes in R-1 and R-2 (see also Naveh-Benjamin & Jonides, 1984). *Noting* could be further decomposed into processes required to compute possible relations, e.g., similarity, dissimilarity, part-whole, and attribute of (Chaffin & Kelly, 1991; Tversky, 1977; Tversky & Hemenway, 1984). Various process models of *reactivating* have been proposed (e.g., Hintzman, 1986; Metcalfe Eich, 1982; Raaijmakers & Shiffrin, 1981), and reactivating has been identified as a central problem in understanding transfer in problem-solving contexts as well (e.g., Gentner, 1988; Gick & Holyoak, 1980; Faries & Reiser, 1988). *Retrieving* has been considered by Baddeley (1982), Reiser (1986), and Kolodner (1984) among others. MEM provides a more general architectural framework for showing potential relations among such mechanisms.

P-1, P-2, R-1, and R-2 activities go on simultaneously and yield corresponding changes in memory that are the representations of experience. Dissociations among memory measures (e.g., Roediger, Weldon, & Challis, 1989; Schacter, 1987) can arise when different probes selectively activate records from different subsystems. These memory representations (or records, or traces) could be characterized in any number of ways—as associative networks, connectionist networks, episodes, cases, production rules, propositions, schemas, mental models. It may be that the type of representational format that is most useful for theoretical analysis at our current stage of knowledge depends on the subsystem in question; for example, connectionist networks may be more appropriate for characterizing the outcomes of perceptual processes, while propositional representations or mental models may be more appropriate for characterizing the outcomes of some types of reflective activities (Johnson & Multhaup, 1992), or the most tractable format may vary with knowledge domain (English phonemes vs. story narratives). One useful approach is to stipulate the nature of the representation of information and then develop predictions based on formal models of these representational formats (e.g., Metcalfe, 1991). The focus in MEM, in contrast, is to characterize component processes by which representations come about. Hence representations are referred to neutrally, as representations, records, or traces, without assuming any particular format. Here the main concern is to characterize some of the processes necessary to yield complex representations that are "event-like."

THE CREATION OF COMPLEX EVENT RECORDS

Many investigators have emphasized that associations between content and context play an important role in remembering (e.g., Bower, 1972; Estes, 1955; Hirst, 1982; McGeoch, 1932; McGovern, 1964; Mayes, 1988) and that explicit memory for context is the heart of recollection (e.g., Tulving, 1972). Yet, how contextual information binds with more central information in memory and the conditions under which context affects recollection (either by serving as a cue or by becoming available as a diagnostic sign of autobiography) remain vague (Bjork & Richardson-Klavehn, 1989; Humphreys, Bain, & Pike, 1989). In thinking about complex memories, we typically (but perhaps too readily) consider the content of the memory to be its semantic meaning and distinguish semantic content from contextual factors such as medium (e.g., person, modality), spatial location, or temporal information. This makes sense because, as Tulving (1983) pointed out, ordinarily we test subjects only for semantic content. If, however, subjects were inspecting various television sets with the idea of buying one, then sound and color quality and in which store each TV was located would be the content of the memories; the semantic information the TVs happened to have been displaying would be incidental or contextual information (cf. Morris, Bransford, & Franks, 1977). Thus the notion of content depends on activated agendas, and context is defined as features that seem incidental to the primary agenda (e.g., Allport, 1955).

Memory for Content

After a century of experimental work, we have a reasonably clear picture of what influences recall and recognition of information. The most critical acquisition factors are whether information has been comprehended and organized in terms of available schemas or cue structures (e.g., Bower, 1970; Bransford & Johnson, 1973; Chase & Simon, 1973; Mandler, 1967; Miller, 1956; Tulving, 1962), and the repetitions it has undergone (e.g., Bahrick, 1979; Ebbinghaus, 1885/1964; Linton, 1975; Rovee-Collier, 1991). Although much of the history of memory research can be seen as a debate about the relative importance of these two factors, organization and repetition, it is clear that both play key roles in determining recollective experience. In particular, organization allocates items to cues, and repetition strengthens the representations of items and the relations between targets and cues. Furthermore, these activities are critically determined by the agendas that define the interests and goals of the individual. That is, agendas help determine the content of memories by affecting what gets organized and repeated.

Memory for Context?

Although we have a relatively good picture of the mechanisms involved in the acquisition of agenda-related "content," we know much less about what binds agenda-related content information together with seemingly incidental information into memories with the kind of richness of detail that makes them seem like "events." One possibility is that perception does this binding work for us. After all, perception delivers up phenomenally bound experiences. We have a unified experience of hearing Endel, dressed in a gray suit, assert A in context Z. These are not isolated features but aspects of an event that make up a cohesive whole. Perception does a lot of work to put colors onto forms, forms into space, and so forth. Perhaps we just automatically remember combinations as they were phenomenally experienced. Hasher and Zacks (1979), for example, suggested we remember spatial information automatically, with no special effort required (see also O'Keefe & Nadel, 1978).

In addition to findings challenging the idea of automatic encoding of contextual information (e.g., Light & Zelinski, 1983), our common experience is that memories are frequently fragmented; often we have no idea where we heard or read something. If incidental or contextual aspects of events are fragile relative to the content or "gist" of events (Sachs, 1967), how does recollection come about? If memory for context separates recollection from knowing, there is much about our lives that we know but do not recollect. Memory is the record of the processes engaged (Johnson, 1983; Kolers, 1973; Kolers & Roediger, 1984); thus, the greater accessibility of agenda-relevant than contextual aspects of events derives from the processing they receive. The next subsection describes the processing that produces this accessibility. After first considering the role of repetition, organization, and agendas in memory for central content, we will return to the question of how incidental features become bound to central features.

Repetition and MEM

As already mentioned, a cornerstone in most analyses of memory is the idea that repetition has profound consequences in determining the probability of later recall. MEM distinguishes between repetitions of two types: *reinstatement* is repetition through perception; *reactivation* is repetition through reflectively regenerating a previous perception or reflection. Either type of repetition can produce *activation* of cognitive representations of item or relational information. Activation refers to the idea that representations can be made temporarily more accessible. (They can also be made accessible by initial perception or reflective generation, before any repetition has taken place, of course.) Either type of repetition can also produce *strengthening* of item and relational information (e.g., Gronlund & Ratcliff, 1989; Mandler, 1980).

To clarify the difference between reinstatement and reactivation, consider what happens in learning a word list. When an item occurs, there are a number of perceptual components of the event (the word's identity, color, location, features of the computer display, the room, etc.). Other components are given by reflective processes (e.g., noting a relation between this word and a previous one; refreshing contextual elements such as the item's color). When subsequent words occur, they will produce perceptual elements, and reflective elements may be generated as well. These reflective elements may include reactivated elements, for example, a match between a relation currently being noted and one previously noted (the items would make good birthday presents), or a reactivation of previous contextual information (e.g., reactivating a memory of a previous word printed in the same color). A particular word or particular word-context pairing might be repeated in the list (reinstated) or particular perceptual or reflective aspects of prior events might be reactivated. In general, reactivation occurs when elements of a prior episode are activated beyond those that are determined by the current perceptual information. Ordinarily, reactivation is an agenda-driven process that involves combining current perceptual cues with reflectively maintained or generated cues as described below. (The activation that is determined by perceptual information alone can, of course, change with experience. As new English words or novel objects become more familiar, for example, they activate underlying conceptual meanings, including certain associated relations, purely as a consequence of perception, without necessarily engaging reflective component processes.)

The distinction between reinstatement and reactivation is important because these two types of repetition play somewhat different roles in learning and memory. Many learning models primarily are directed at explaining situations that involve multiple reinstatements (the list is presented several times; the tone precedes the shock for several trials, etc.). These reinstatements presumably strenghten associative relations that support memory. For episodic memory of particular events, however, such models are problematic. A true "episode" occurs once only. How is it then that episodes are ever recollected after substantial retention intervals? What determines the relative "strength" of episodes? One possibility is that memory for "one time events" depends on repetition by reactivations. Without such reactivations, particular episodes may have little chance of being remembered (or even misremembered) later. Reactivations are also important for establishing and maintaining more "composite" but still event-like memories resulting from similar experiences.

A number of findings suggest that long-term memory for information such as face-name pairs (e.g., Landauer & Bjork, 1978) and autobiographical episodes (Linton, 1975; Rubin & Kozin, 1984; Suengas & Johnson, 1988) depend on reactivation. Reactivation determines the probability that a particular cue will work on subsequent occasions (Linton, 1975) and determines whether the memory will continue to have subjective perceptual clarity (Suengas & Johnson, 1988). Reactivation also plays a dramatic role in retention in human infants (Rovee-Collier & Hayne, 1987) and other animals (e.g., Spear, 1973); a single reminder may "reverse" weeks of forgetting (Rovee-Collier & Hayne, 1987). Spacing reminders so that they indeed involve reactivation appears to be critical in producing long-term retention benefits (e.g., Keppel, 1964; Landauer & Bjork, 1978; Rovee-Collier, 1991; Toppino, 1991). In summary, reactivations strengthen and bind information, increasing the probability that particular cues will work as later reminders and maintaining the qualitative detail characteristic of episodes. Furthermore, it appears that in anterograde amnesia, reinstatement effects are intact, but reactivation is disrupted. The consequence is a disproportionate disruption of performance in any memory tasks that normally involve reactivation (e.g., Johnson & Hirst, 1991; Phelps, 1989). Thus direct memory measures, which are more likely than indirect measures to draw on reflective reactivation, are more disrupted in amnesia.

Figure 2 summarizes the consequences of engaging various component processes of MEM. Perceptual processes are depicted in less detail than reflective processes because the latter are of primary concern here. When stimuli occur, several processes may be set in motion: Perceptual processes activate records and produce more permanent changes, that is, strengthening (in the sense of increasing memory performance measures) takes place. These temporary activations and more permanent

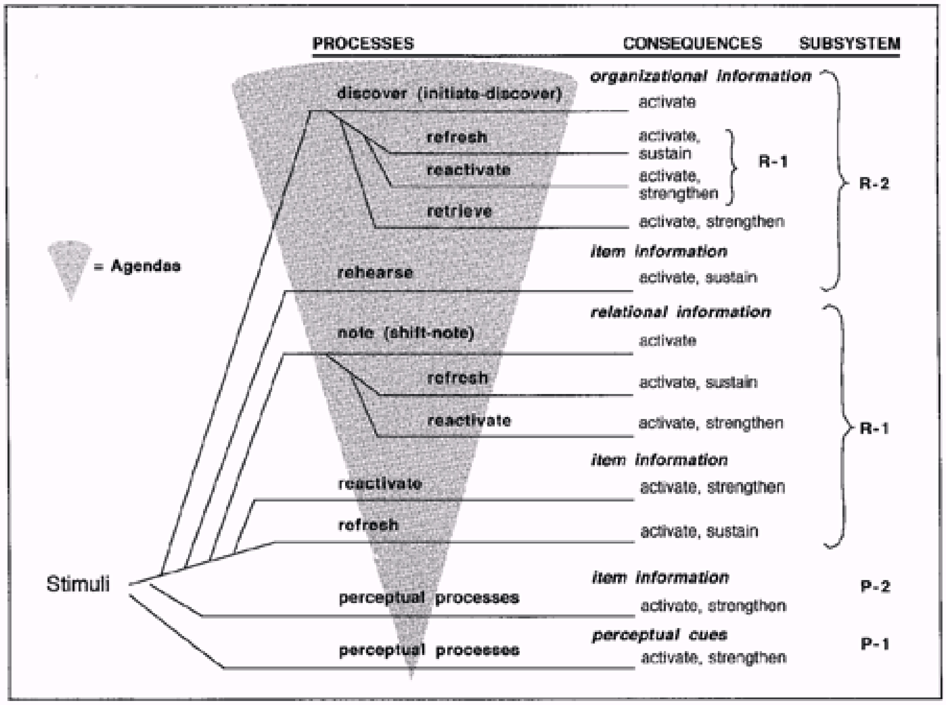

Figure 2. Schematic representation of reflective component processes in MEM and their consequences. Agendas (shaded cone) recruit processes that activate, sustain, and strengthen both item and relational information.

changes may facilitate perceptual processing of the same stimulus again. They also underlie acquisition of associations between the stimulus properties to which P-1 and P-2 are sensitive and certain responses that can take these properties as "conditions." For example, in learning to box, P-1 might associate moving to the left with *extracting* rapid expansion of a stimulus array coming from the right. P-2 processes may, among other things, result in the recording (or encoding) of object or "item" information in the P-2 system as a consequence of *identifying* operations. Such item records may produce word priming, be one basis for picture recognition, be relevant cues for discrimination learning, and so on. Both P-1 and P-2 records may contribute to all types of memory—priming, skill learning, conscious recollection—but the relative amounts of their contribution depend on the particular task in question. The main point here is that learning in these perceptual subsystems is occasioned by external stimulus conditions. Repetitions of the same or similar stimulus conditions in conjunction with performance of the relevant mental and behavioral reponses provide opportunities for strenghtening associative relations. Such learning may be under the general control of a perceptual schema (e.g., Hochberg, 1978) or a reflective agenda, but such schemas and agendas are "future directed." Their function is to set up expectations about and detect what comes next (Schwartz, 1978), not to inspect what came before. This is the kind of learning that has variously been called associative, horizontal, habit, procedural, route-like, perceptual, or data-driven learning.

Reflection introduces the capacity to prolong, reactivate, and inspect what came before and thus permits forms of learning, memory, and phenomenal experience that would not be possible with the perceptual memory system alone. The process of *reactivating*, along with the other R-1 processes (*noting*, *refreshing*, *shifting*), are necessary for this. Guided by agendas, R-1 processes of *refreshing* and *reactivating* reduce dependence on external stimulus conditions. *Refreshing* sustains temporary activation of either already active reflective or perceptual records. Refreshing's primary contribution is keeping information active so that it might be easily used when appropriately cued or related to previous or subsequent information via *noting* operations. Even if information is no longer active or being refreshed, reactivation processes may bring it back, thus allowing one to inspect what came before. Reactivation has strengthening effects analogous to the strengthening produced by perceptual repetition in the perceptual system. If an item is reactivated, item information is *strengthened* (see Fig. 2). The R-2 processes of *rehearsing* and *retrieving* are analogous to *refreshing* and *reactivating*, respectively, only are more strategic or deliberate (Johnson & Hirst, 1992). (Potential strengthening effects of refreshing and rehearsing are not discussed here; see, e.g., Glenberg, Smith, & Green, 1977; Naveh-Benjamin & Jonides, 1984.) Although repetitions through reactivation are critical for event memory, they alone cannot account for recollection of complex events or episodes; thus in the next subsection we explore the mechanisms of organization.

Organization and MEM

Organization, or the binding of previously separate elements of experience (e.g., two "items") into relational information, has many functions. Among other things, it allows one to build a cumulative representation, map, or model (e.g., Nadel, Willner, & Kurz, 1985; Johnson-Laird, 1983) of incoming information. Organization has two major enabling conditions—cognitive contiguity and noted relations. Once a candidate relation has been initially set up through contiguity or noting, it can be strengthened through reinstatement and/or reactivation. Thus the joint action of organization and repetition connects information to other information.

The importance of relational, organizational, or elaborative learning has been emphasized by many memory theorists (e.g., Bower, 1970; Craik & Lockhart, 1972; Mandler, 1967; Tulving, 1962; Wickelgren, 1979). In MEM, *noting* and *shifting* are the reflective components that work together to establish relations among disparate elements of experience (Johnson, 1990). If relations between an item (e.g., word, statement, picture) and other information are noted, or if there is a shift in the aspects of the item attended to and the resulting new relations are noted, a relation is generated, and this relation becomes a candidate for refreshing and reactivation (Fig. 2). Like item information, if relational information is only refreshed, its temporary activation is sustained for some period; if it undergoes reactivation, relational or associative information is strengthened. The item may also undergo strategic *rehearsing*, which would result in activation. Relations between this item and others may be strategically *discovered*, or new ways of looking at the item and its potential relations to other items or events may be *initiated* and *discovered*. The resulting set of relations is what we mean by an organization, a "mental model," or a cognitive map. In turn, these organizations, models, and maps may be refreshed, may be reactivated, or may be strategically retrieved (see Fig. 2). Retrieval would set the stage for refreshing and for a cycle of reactivation, which would contribute to the cohesiveness of the set of relations, or model, and so forth.

The Role of Agendas

Items get selected for *refreshing* and *reactivating* partly by chance occurrence of cues, for example, if present cognitive operations and content match prior ones, those will be activated. Perhaps more important than these chance remindings for understanding recollection, agendas play a critical role in determining what gets refreshed, reactivated, noted, and so forth. This idea is depicted by the shaded "cone" in Figure 2. R-1 and R-2 agendas determine what might be useful and hence gets refreshed or what types of relations are likely to be noted. Furthermore, an agenda, alone or in combination with other cues, has some capacity to cue the reactivation of records that have been previously active along with the agenda (see Fig. 1a) (e.g., Seifert, 1988). These occasions of combined action will further strengthen (bind) relations among agendas, cues, and targets.

Agendas determine what is content and what is context worth noting. For example, for animals or human infants a major ongoing agenda is to acquire information about what happens where (e.g., O'Keefe & Nadel, 1978). In classically conditioning animals, contextual cues from the conditioning chamber, as well as the designated CS, may become conditioned to a UCS (Bouton & Bolles, 1985; Phillips & LeDoux, 1992). Infants as young as 3 months old show acquisition of very specific contextual information about their crib in connection with learning a foot kick response to move a mobile (Rovee-Collier, 1991). It seems reasonable to speculate that in such situations, subjects actively note where they are when the critical events (shock; moving mobile) occur and that persisting agendas may continue to refresh and reactivate such relations for some time. And just as activation persists for some period for item and relational information, activation of agendas may persist for some time as well. When these weakly activated agendas combine with other cues, they may have ongoing and seemingly "unconscious" effects (e.g., producing incubation in problem solving).

The combined and repeated action of reactivation, organization, and agendas produces a kind of "consolidation" of memories (e.g., Milner, 1966; Spear & Mueller, 1984; see chapters in Weingartner & Parker, 1984). The period over which such consolidation occurs is indeterminate because it depends on factors such as which agendas are active and which reminder cues are present. Any time, even after very long retention intervals, a target is reactivated for any reason, its memory representation would be strengthened. We could think of this sequence of possible reactivations as a long-term consolidation process (e.g., Wickelgren, 1979; Squire, 1986; Squire, Cohen, & Nadel, 1984) that depends on the integrity of specific brain areas such as the hippocampus (e.g., Teyler & DiScenna, 1985; Zola-Morgan & Squire, 1990). Nevertheless, this kind of consolidation requires more than whatever biochemistry is set in motion by a single episode. A particular representation may never get reactivated because it may not fit any activated agendas, or other events may recruit the reactivation circuit. That is, "consolidation" of either item or relation information will not take place unless they are subsequently activated.

The gains from reactivation would diminish as any particular cue-target or agenda-target relation becomes stronger. Old memories that have been frequently reactivated will tend to be accessible with cues that do not need the extra boost that comes from combining them with other cues during cycles of reactivation. Thus normally there are two routes to reviving information from memory, one that involves the reactivation component (that functionally augments cues, including agendas, by combining them) and one that involves a more "direct" activation through individual, well-learned cue-target or agenda-target relations. Only the latter route appears to be available to anterograde amnesics. Loss of the cue-combining reactivation component could also produce temporally graded retrograde amnesia, assuming that older memories are more likely to have become over-learned (repeated and organizationally embedded) than newer memories. Although differing somewhat in details, this general idea is similar to other proposals regarding retrograde amnesia that emphasize differences in "strength" of remote memories of various ages (Squire et al., 1984; Teyler & DiScenna, 1986).

BINDING INCIDENTAL AND CENTRAL ASPECTS OF EVENTS

The previous section outlined a basic process model for how agenda-relevant information is built into cohesive relations or models that are available for voluntary recall or for recognition. How then do incidental aspects of events (e.g., spatial location, colors of objects), become bound together with the more central aspects of events to create records that we take to be specific episodes of personal experience? I propose that the same processes that operate to connect central aspects (C_1, C_2, etc.) of events operate to connect incidental aspects (I_1, I_2, etc.) of events with central aspects of events. Although there may be some small contribution made simply by contiguity between C_n and I_n, more critical is that incidental aspects and central aspects be active together in conjunction with an agenda and/or that the potential relations between incidental and central elements be noted or discovered (Bjork & Richardson-Klavehn, 1989) and subsequently reactivated.

Although I focus on the role of reflective processes in binding content and context, it should be pointed out that some aspects of the contextual information necessary to define events would be established by processing by MEM's perceptual system. For example, the component process of *placing* (see Fig. 1c) results in a representation of the relative locations of objects and this configuration would be strengthened through reinstatements, that is, through encountering the same stimulus conditions again.

To illustrate the role of reflective processes in binding content and context, suppose you heard a friend make a thoughtless comment at a party. This might activate an *agenda* to "explain" why he might do such a thing. Aspects of the experience might be kept *refreshed* for a brief time by the agenda "explain." From this refreshed information, you *note* a potential relation between your friend's location in the corner of the room and his statement: Perhaps he thought he couldn't be overheard. A subsequent *reactivation* of this noted relation, say, in offering it as an excuse to someone criticizing your friend, will strengthen the relation and thus seemingly incidental location information may remain a feature of a detailed event memory for some time. This cognitive activity (*agenda–refreshing–noting–reactivating*) will bind spatial location with the comment. In general, incidental aspects of events have an opportunity to become related and incorporated when a functional agenda is guiding thought and behavior; when incidental aspects of events undergo organization and repetition in conjunction with central aspects, they will be incorporated into the memory and create an episode.

One source of evidence that binding contextual and content cues may not be entirely perceptually driven or based on simple contiguity but may require the kind of reflective activity outlined above comes from a series of studies Shahin Hashtroudi and I are conducting on age differences in source monitoring. Our initial results suggest that elderly adults may actually do better at source monitoring when there is only one distinctive cue to source than when there are two redundant cues. For example, elderly subjects may remember who said what as well as younger subjects when the two speakers are quite distinctive, but perform more poorly than young adults when the speakers are also placed in distinctive locations or when the subjects are required to perform different orienting tasks on the words spoken by each speaker. These location and orienting task cues can, however, be used by elderly subjects when they are introduced singly. One possibility is that processing an additional contextual cue takes processing away from the first, processing that might otherwise have bound the first contextual cue (speaker) to content (word). This trade-off evidently is more costly for elderly than for young adults.

The most dramatic evidence that binding of context and content requires some particular processing step(s) comes from anterograde amnesics, who show very poor contextual memory even when procedures or item content have been retained (e.g., Mayes, 1988; Milner, Corkin, & Teuber, 1968; Shimamura, 1989). Remember, however, that amnesics not only have trouble binding incidental context to central content, they also have difficulty binding elements of central content to each other (e.g., the idea units from a narrative story) as we would expect if the same reactivation mechanism underlies both content–context and content–content relations. Hence, because of a disruption in reactivation (Johnson & Hirst, 1991) the memory representations of amnesics remain fragmentary and lack "coherence" (Hirst, 1990).

Other evidence that content–content and content–context relations may depend on similar mechanisms comes from animals with hippocampal lesions. Hippocampal animals appear to be able to acquire either an association between a "central" cue such as a tone and an overlapping unconditioned stimulus (UCS) such as shock, or an association between contextual cues from the conditioning chamber and the UCS, but not both (Penick & Solomon, 1991; Phillips & LeDoux, 1992; Winocur et al., 1987). In contrast, normal animals typically learn both types of associations. For normal animals, the tone presumably recruits activation that might otherwise be recruited by contextual cues and the simultaneously active tone and shock become associated. Once the tone and shock have ended, activation presumably is again recruited by contextual cues and, if memory for the shock is reactivated, the now overlapping reactivated shock and contextual cues have an opportunity to become associated. Hippocampal animals should show a deficit in conditioning whenever reactivation is required to connect either a specific CS or contextual cues to the UCS.

Finally, if reactivation has an impact not only on the probability of subsequently remembering an autobiographical event (e.g., Linton, 1978; Rubin & Kozin, 1984), but also on qualitative aspects of the memory (Suengas & Johnson, 1988) that make it seem autobiographical and event-like (Klatsky, 1984; Johnson, 1988b), then whether one habitually mentally reviews events, along with social opportunities for recollection and other reminders such as photographs, should affect how available and how richly detailed one's autobiographical memories are. There may be other factors (e.g., chronic stress, lung disease, drug abuse) that affect what people note and how often they review (overtly or covertly) past autobiographical events. Such factors affecting reactivation and resulting consolidation should put people differentially "at risk" for developing retrograde amnesia under certain conditions of brain damage and might help explain the variable relation observed between anterograde and retrograde amnesia (e.g., Salmon, Zola-Morgan, & Squire, 1987; Squire, 1987b).

CONCLUSIONS

The contextual specificity that yields a sense of recollection depends on the binding of various aspects of experience into complex memory traces whose elements or features have the capacity to cue each other. One way this binding arises is as a consequence of reflective activity in which relations among elements are noted and then strengthened either through repeated perceptual experiences or through reflective reactivations of prior experiences. Reactivations are the combined outcome of activated perceptual and reflective cues and reflective agendas. Reactivation can combine such cues, increasing the probability of revival of a target and further strengthening associations among various elements. Disruption of this reactivation component would thus reduce the opportunity for content and context to become bound in a reflective consolidation process that is critical for establishing and maintaining the kind of complex memory records, especially for "one-time events," that might later be judged to be recollections of episodic experience.

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