MEMORY IS MORE THAN JUST REMEMBERING: STRATEGIC CONTROL OF ENCODING, ACCESSING MEMORY, AND MAKING DECISIONS

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I. Introduction

The goal of this chapter and this volume in general is to provide a beginning sketch of the view that the successes and failures of memory are a reflection of skill in interacting with memory effectively rather than an expression of inherent qualities or liabilities of memory itself. In this chapter, I review examples of how particular capacities of memory can be conceptualized as interactions between a quite simple memory system and a set of higher-level control processes that are diverse and varied. In such a theoretical perspective, memory capacities reflect the myriad ways in which learners strategically engage encoding processes and successfully accommodate memory queries to the task at hand, as well as how the products of memory are flexibly aligned, recombined, and operated upon in the service of behavior and action.

Much of what we think of as "memory" is thus actually the efficient action of higher-level decision making on the inputs to and the outputs from memory stores themselves. This perspective contrasts with current views of memory, which appeal to an ever-increasing number of distinct memory systems (Schacter & Tulving, 1994) or separable memory processes (Roediger, Weldon, & Challis, 1989). I do not confront those perspectives directly here; nor do I deny levels of explanation (such as neurobiological ones) in which

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those perspectives may be particularly apt. I present the memory-as-skilled-cognition perspective as an alternate theoretical basis from which to make sense out of interesting human memory behavior, noting that, in most experiments, "... the most common approach is to treat subject-controlled processing as a nuisance factor ..." (Koriat & Goldsmith, 1996, p. 509) and that "investigators go to ... great lengths to design experiments that eliminate or hold ... self-directed processes constant ..." (Nelson & Narens, 1994, p. 8). The overarching message of this chapter is that those attitudes underlie unnecessary and artificial experimental constraints, and have led to an inappropriate partition between research on memory and research on metamemory and related decision processes.

This is not to claim that the current perspective is historically unprecedented or particularly revolutionary. The tremendous emphasis on control processes in the late 1960s and 1970s generated a wealth of research that fits neatly with the present claims. In fact, the groundbreaking model of memory proposed by Atkinson and Shiffrin (1968, 1971) presumed that long-term storage of memories was permanent and impervious to forgetting and interference—in that model, variance in recall performance was attributed entirely to control processes that governed the entry of information into long-term storage and the generation of retrieval cues and strategies sufficient for later access. This chapter espouses the same general principle as Atkinson and Shiffrin (1971): that "memory ... is best described in terms of the flow of information into and out of short-term storage and the subject's control of that flow ..." (p. 83). Whereas their work principally addressed free recall in shorter-term memory tasks, the current chapter applies more recent research in recognition, recall, metamemory, and decision making to understanding memory control in longer-term, more ecologically valid, and more diverse memory tasks. Similar arguments have been made by Koriat and Goldsmith (1996; see also Barnes, Nelson, Dunlosky, Mazzoni, & Narens, 1999) with respect to memory retrieval and Nelson and Narens (1990) with a somewhat greater emphasis on encoding.

To understand the goals of this chapter, the reader must temporarily appreciate, if not sympathize with, two concurrent goals. The first goal is to expand the purview of memory research by considering the cognitive contexts in which memory behavior is situated. It is possible to take an ecological (Neisser, 1976, 1982) or an embodiment (Glenberg, 1997) perspective on this issue, but those points of view force the theorizer to consider behavior at a more aggregate and complex level than I plan to here, and it loads the task with the additional difficulty of intuiting "real-world" memory demands. Instead, I take as a starting point the simple fact that memory use exists in the larger cognitive context of servicing intellectual and behavioral goals, and that part of using memory effectively involves knowing not just how to increase access to useful information from the past, but also how to decrease the costs of doing so (see also Anderson & Milson, 1989).

The second and concurrent goal of the chapter is to achieve the first goal with as minimal a set of assumptions as are necessary about the nature of memory itself. This goal represents an explicit attempt to reduce the proliferation of memory systems and memory processes. By decreasing the degrees of freedom available to theorists of memory *qua* memory, I hope to increase consideration of how extramnemonic processes might yield the wide variety of memory behavior that is reviewed here.

II. Interacting with Memory

The approach of this chapter will be to characterize ways in which nonmemorial processes interact with the inputs and outputs of memory in order to produce memory behavior that is realistically but only approximately suited to the demands of a student facing the end of the semester. During upcoming examinations, she will be queried on all manner of material from different courses, most of which she has not yet mastered. A rough characterization of this situation and the routes of access to memory are sketched in Fig. 1. Memory storage is depicted in the center of the diagram; there is one route in

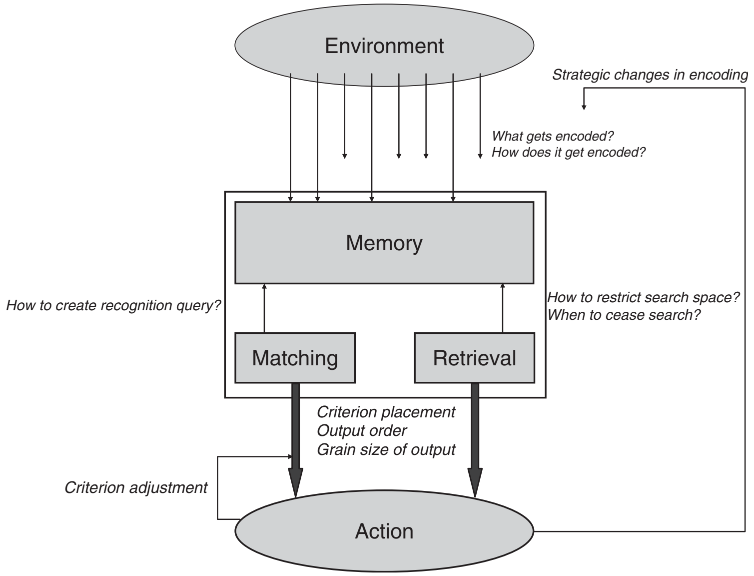

Fig. 1. A characterization of memory and memory control.

and two routes out of this store. Information can be attended to and committed to memory, or not, and additional decisions can be made about how to commit it to memory—by what means and under what scheduling regimen, for example.

To access information in memory, two processes are available. The matching process takes as its input a putative match for a memory trace and rapidly provides a measure of how well that trace resonates with a large portion of memory. The retrieval process takes as its input a partial memory trace and returns in response a noisy pattern-completed full trace. This chapter takes these two processes as a starting point and does not attempt to defend their necessity or sufficiency from first principles. I shall return to describe these processes in greater detail at a later point in this chapter, but here I call attention to the fact that the output of these processes are the impetus to behavioral action—for example, answering a question in class, continuing or discontinuing study of test-relevant material, or deciding to stop studying and spend more time with friends.

In Fig. 1, memory is encapsulated by the box in the center of the diagram. It consists of a store and the two access processes which act upon it. This chapter will deal almost exclusively in cognitive processes outside of that box, and how those extramnemonic processes yield behavior that we typically think of as within the province of memory.

Control of memory is a particularly important skill in light of the current and future potential for offloading aspects of memory onto systems with digital memory. Software like Nokia's Lifeblog and InSense (Blum, Pentland, & Troster, 2006) allow users to encode arbitrary and copious amounts of data from their everyday lives with the goal of reducing the burden on their pitiable brain-based memory system. The implied division of labor between carbon and silicon appears to play to the strengths of all parties: The human mind can do what it uniquely does—*control* memory. And the hard drives to do what they do best—*retain* information. However, users must still confront the problems of recovering information from their voluminous artificial memory, and what to do with it if and when they recover it. Throughout this chapter, it will be useful to consider as a benchmark exactly what advantages, and disadvantages, the prospect of "life logging" affords to users.

III. Strategic Decisions About Encoding

During study, learners often attempt to tackle a greater amount of information than can be easily mastered in the limited time available. They must thus make decisions about how to limit their intake of material, and how to engage in effective learning during the limited time period. Even subjects in the highly artificial context of traditional laboratory memory experiments are attempting to balance multiple goals: They may want to do well because they believe that their performance reflects well upon their intelligence, but they may also want to exert a minimal amount of effort and time before returning to their other responsibilities that have greater consequence in their lives. Clearly, personal motivation (Wolters, Yu, & Pintrich, 1996) and expectations of evaluators (Nolen & Haladyna, 1990) influence this trade-off for the average student, and the trade-off function may differ considerably across subjects. For some subjects under some conditions, the most effective encoding strategy might be not to encode at all.

Examples are reviewed in this section that reveal how learners effectively use encoding strategies to enhance memory performance by catering their encoding to the demands of the material and the task. Other examples are provided that reveal failures to do so effectively. The important lesson of these results is that they reveal ways in which one subject may show superior memory over another because of better encoding decisions, rather than better memory. Making smart decisions about encoding necessitates two skills: accurate monitoring of learning (Benjamin & Bjork, 1996) and reasonable knowledge about how various encoding schemes translate into long-term retention, both of which will be considered in this section.

Some early reports claimed little or no relationship between learners' abilities to monitor their own learning and actual memory performance (Begg, Martin, & Needham, 1992; Cull & Zechmeister, 1994; Kelly, Scholnick, Travers, & Johnson, 1976). However, studies that systematically investigated individual differences (Maki & Berry, 1984) or provided learners an opportunity to guide their own encoding through self-paced study regimens (Thiede, 1999) or to restudy self-selected subsets of items (Nelson, Dunlosky, Graf, & Narens, 1994) revealed clear evidence for superior memory performance in groups of learners with superior monitoring and metacognitive skills.

A. What Gets Encoded?

Learners can reduce the burden on memory by divising a plan for how to allocate their time among study items. Two candidate theories of how learners do so appear to have merit. The discrepancy-reduction theory (Dunlosky & Hertzog, 1998) suggests that time is allocated across items in accordance with each item's proximity to a desired level of learning, which is presumed to typically be equivalent across items (Le Ny, Denhiere, & Le Taillanter, 1972; Nelson & Narens, 1990). A review (Son & Metcalfe, 2000) provided good support for this theory: Under most conditions, subjects allocated more study time to items that were either normatively more difficult or that they rated as idiosyncratically more difficult (see also Mazzoni, Cornoldi, & Marchitelli, 1990; Zacks, 1969). Even children allocate more study time to items previously unrecalled or unrecognized—and thus presumably more poorly learned—than successfully remembered items (Masur, McIntyre, & Flavell, 1973; Rogoff, Newcombe, & Kagan, 1974).

There are limiting conditions on this generality, however. When a memory task places low performance demands on the subject by requiring mastery of only a small proportion of the total material, subjects allocate more study time to the easier, rather than the harder items (Thiede & Dunlosky, 1999). Similarly, if learning takes place under conditions of considerable time pressure (i.e., short study times), subjects primarily allocate that limited time to easier items (Son & Metcalfe, 2000). These results are consistent with the claim that subjects devote their study time to materials that are just beyond their current level of mastery, or in their region of proximal learning (Metcalfe, 2002; Metcalfe & Kornell, 2003). This second theory of study allocation appears to qualify in important ways the simple predictions of the discrepancy-reduction approach.

Other evidence for strategic influences on encoding is available in paradigms in which task instructions discount the value of remembering certain items over others. For example, in directed forgetting tasks (MacLeod, 1998), subjects are provided instructions about which items are necessary to remember and which can be forgotten. The relevant finding for present purposes is that subjects show poorer memory for the to-be-forgotten material (Bjork, LaBerge, & Legrand, 1968; Davis & Okada, 1971). Although some have postulated that memory inhibition plays a role in such effects (Bjork & Bjork, 1996), differences in encoding strategies and subsequent rehearsal appear to account for the data more coherently (Benjamin, 2006; Sahakyan & Kelley, 2002).

Other related findings support the general claim that learners selectively encode material of greater interest or value. Higher incentives for retention lead to superior memory than do lower incentives in both shorter-term (Weiner & Walker, 1966) and longer-term (Heyer & O'Kelly, 1949) memory tasks. Other results show that subjects achieve this effect in part by either shirking concomitant goals, such as a secondary task performance (Wickens & Simpson, 1968) or by deliberately avoid encoding potentially interfering and irrelevant information. Castel, Benjamin, Craik, and Watkins (2002) reported a task in which subjects were awarded a memory score based not on the total number of items recalled, but rather the total "point" value of the recalled words. During study, words were assigned an arbitrary point value ranging from one to 12. The results revealed that subjects were clearly able to selectively retain the highly valued items, and that older adults—for whom declining memory ability places an even greater value on the ability to selectively encode important and ignore unimportant details—were even more effective than younger subjects in doing so. This success was due in part to a strategy of willfully ignoring or failing to encode items of low value, a strategy they acquired over the course of repeated testing (see also the chapter by Castel, this volume).

B. How Does Information Get Encoded?

Once learners make a decision that some piece of information is worthy of learning, they must make additional choices about how to do so. Two ways in which learners appear to control the means of encoding is by actively varying the processing they engage in and by controlling the scheduling of study events.

1. Controlling Processing at Study

One of the major achievements of research on human memory from the last 50 years is an impressive catalogue of encoding variables and manipulations that affect memory. An informed and intuitive student should be able to take advantage of such a wealth of knowledge by using effective encoding strategies. However, the evidence on learners' abilities to successfully control encoding at study is mixed, and the recent literature is somewhat sparse.

One domain in which to look for such evidence is in the effects of test expectancy on memory performance. If knowledge of the nature of the upcoming memory test elicits superior performance relative to a group that lacks such knowledge, then learners must be catering their study strategy somewhat effectively to the demands of the test. Neely and Balota (1981; see also Balota & Neely, 1980) have shown that subjects who expect a test of recall (as opposed to a test of recognition) exhibit superior performance on either recall or recognition. Subjects expecting recall even demonstrate better memory for the order of studied items (Leonard & Whitten, 1983), suggesting that they simply work harder to learn the material when they expect the demands of the test to be greater, as they are on a test of recall. This pattern illustrates satisficing behavior (Simon, 1957): learners distribute resources to achieve at least (but no more than) some predetermined standard for performance; they do not attempt to maximize performance under all conditions.

The preceding results suggest that subjects optimize encoding by selectively attending to important materials and ignoring irrelevant stimuli, and by deliberately engaging in encoding suited to the difficulty demands of the material and the upcoming test. However, other data reveal failures to do so effectively. For example, there are conditions in which a simple orienting instruction to perform "deep" processing on to-be-learned names can lead to superior memory than self-guided learning, at least in older adults

(Troyer, Hafliger, Cadieux, & Craik, 2006). Clearly, the choices learners make in committing information to memory are suboptimal if retention can be improved by a simple orienting task that could have been implemented with little cost.

A similar conclusion can be drawn from studies of the *generation effect*, in which subjects who self-generate portions of a to-be-remembered stimulus show superior memory than subjects who merely read that stimulus passively. Instructions to engage in active imagery during encoding eliminate the generation effect by increasing performance for read items up to the level of generated items (Begg, Vinski, Frankovich, & Holgate, 1991; see also McDaniel, Waddill, & Einstein, 1988), as do instructions about the nature of the memory test and how best to prepare for it (deWinstanley & Bjork, 1997). These data reveal that the typical disadvantage of reading can be offset by employing more active processing during reading (see also Bjork, deWinstanley, & Storm, in press)—something learners do not, apparently, spontaneously do.

The apparent inability of learners to strategically use generation as a means to ensure effective encoding must be qualified by experiments examining the relationship between manipulations of encoding and judgments of learning (JOLs). If subjects provide higher JOLs for encoding conditions that actually elicit superior performance, it suggests that learners appreciate the advantages afforded by the superior encoding condition, and it would stand to reason that they would implement it for materials that they desired strongly to learn. Yet, despite the fact that they do not spontaneously engage in those activities during reading that elevate performance, they do give higher JOLs for generated than read items (Begg et al., 1991; Mazzoni & Nelson, 1995). It thus appears as though learners appreciate the advantages of generative processing but are either unable or unwilling to utilize such processing in the absence of instruction. Other data weigh in favor of a motivational over a cognitive interpretation to the disadvantage of reading: The generation advantage is considerably greater under incidental than intentional learning conditions (Watkins & Sechler, 1988), revealing that subjects are able to engage in processing that eliminates at least a portion of the difference between generating and reading when they know that their memory will be tested.

A similar pattern may be evident with respect to the effect of depth-of-processing variables on retention (Craik & Lockhart, 1972). Subjects correctly predict higher levels of recall for more deeply processed materials (although they do underestimate the magnitude of the effect considerably; Shaw & Craik, 1989), even though they do not appear to always use it to their advantage, as suggested earlier. Spontaneously implemented deeper processing does appear to account for the superior retention of words in intentional over incidental learning conditions (Hyde & Jenkins, 1969), however. Overall, data from manipulations of processing depth and generation appear to reveal differences in what subjects report—as assessed by experiments in which their predictions about encoding strategies are queried—and what they are able or willing to implement.

Organization of material at the time of encoding can also have a profound effect on memory, as exemplified by the seminal concepts of chunking (Miller, 1956; Simon, 1974) and clustering (Bousfield, 1953) in memory. Allen (1968) provided a particularly good example of the functional value of organizational processes at encoding by comparing recall in a group of subjects that were instructed only to rehearse the current item being studied with a group given standard instructions to learn a list of words. The latter group had a large advantage on the later test, supporting the view that learners were using the intervals between items to selectively rehearse and relate materials from across the list, not just the current item.

It is clear from these results and others that learners strategically employ organizational and mnemonic schemes in order to increase the effectiveness of memory encoding. However, there are important limits to this generality in behavior, both intellectual and ecological. On the intellectual side, metamnemonic skill limits knowledge of the effectiveness of strategies, and thereby influences choices. On the ecological side, subjects may be unwilling to engage processes that will not yield memories that are accessible under realistic time demands (Benjamin & Bjork, 2000; Lea, 1975). They also are in the position of balancing the demands of our experiments with the ongoing, much more relevant demands of their lives as college students. Overall, it appears as though students are often willing to satisfice on memory tasks, and thus make choices that achieve a desired level of performance without expending more effort or resources than are necessary.

2. *Self-Scheduling of Study Events*

Learners also typically have control over the scheduling of events when many things need to be learned. A student may decide to study the material relevant for a final examination in one session or distribute study for multiple examinations throughout that time. They may decide to study immediately prior to an examination or long before.

Spacing apart multiple presentations of to-be-learned material is one of the most effective ways of enhancing retention (Crowder, 1976). From a metacognitive perspective, it is doubly efficacious, as it incurs little cost to implement: Performance can be enhanced while keeping total study time constant. What does the literature reveal about learners using self-spacing as a means to enhance their memory? Again, the evidence is somewhat mixed.

Experiments in which subjects are exposed to both spaced study and massed study tend to report a preference for massing (Baddeley & Longman, 1978) and a sense of superior acquisition during massing (Simon & Bjork, 2001). These data might seem to suggest a false belief in the superiority of massing over spacing, but several caveats are in order. First, preferences about study strategy reflect more than its estimated efficaciousness; they reflect the desirability of implementation as well. Learners may be somewhat unwilling to go to the trouble of coscheduling multiple tasks. Second, subjects may choose to satisfice, rather than maximize, especially because performance on examinations and other real-world assessments are typically on an absolute scale. If learners feel that they can master the material sufficiently to meet their goals without imposing on them the burden of scheduling, they may desire to do so, even if they could perform even better under other conditions. Third, providing ratings and making explicit judgments may not adequately predict study behavior. Several experiments have explored subjects' choices about massing and spacing in tasks in which they had to make on-line item-by-item choices about scheduling.

Son (2004) showed that subjects were considerably more likely to space than mass to-be-learned materials when given the option. That result qualifies any claim that subjects do not appreciate the beneficial effects of spacing. Benjamin and Bird (2006) further showed that subjects were more likely to space normatively difficult items and mass the easy ones, indicating that subjects reserved the more effective study procedure for the more difficult materials. This result parallels the finding mentioned in the previous section that subjects typically spend more study time on more difficult materials. However, under conditions in which the study time for each individual item was very short, this preference either disappeared (Benjamin & Bird, 2006) or reversed (Son, 2004). These latter data are consistent with the idea that subjects specifically choose strategies that apply to constraints of the learning situation.

All of these data reveal that learners choose effective scheduling strategies for learning words, at least under some conditions. A related issue is what people understand about the relationship between the *order* of learning events and retention. Dunlosky and Matvey (2001) showed that subjects correctly predict enhanced recall for the first few items (or *primacy* items) in a list of unrelated words. Castel (2006) has shown that subjects predict reasonably accurate primacy and recency (enhanced memory for the last few items in a list) effects when their predictions are solicited prior to the presentation of the to-be-remembered item but not when queried after its presentation, suggesting that subjects have reasonably accurate knowledge of list-order effects but are overwhelmed by idiosyncratic item differences when making predictions in the presence of the items themselves (cf. Koriat, 1997). While learners may be in possession of rudimentary knowledge about these order effects, they do not appear to be aware of the more transient nature of recency than primacy effects (Craik, 1970): during a test of immediate recall, subjects predict enhanced retention for both primacy and recency items on a delayed test (Benjamin, Bjork, & Schwartz, 1998b). Only the advantage for the primacy items remains after a delay; however, so those predictions reveal a lack of appreciation for the more complex relationship between item order and long-term retention.

In addition, subjects who are allowed to select items for study based on their own monitoring of learning perform better on tests of memory than do subjects who are provided randomly ordered items for study (Atkinson, 1972). This result implies that subjects are able to use their self-assessments of learning to generate effective study orderings (although it is worth noting that subjects in the self-generated study group performed more poorly than subjects in a group whose study order was determined by an adaptive algorithm).

C. Learning About Encoding

The fact that learners make utilitarian decisions about what to encode and how to encode it based on their goals and assessments of the difficulty of the material, as well as on their limited knowledge of encoding strategies, begs the question of the origin of such strategic behavior. In this section, I outline several examples of how experience with relevant tasks fosters increasingly strategic behavior, which often leads to superior performance. In that sense, these are examples of "learning how to learn:" performance improvements come about as a function of increased metamnemonic skill.

1. Stimulus Characteristics

An intriguing first clue in the search for improvement in encoding strategies is the fact that the relationship between monitoring accuracy—the degree to which learners can successfully predict which items they will remember and which they will not—and memory performance increases over the course of multiple study-test trials when subjects are allowed to self-select items for additional study (Thiede, 1999). Presumably, the mediating factor here is an increasing ability to discriminate between items that are needy of additional study and those that are not.

Another example concerns the effects of word frequency on recognition. Subjects incorrectly predict superior recognition of common words, but correctly postdict superior recognition of uncommon words (Benjamin, 2003; Guttentag & Carroll, 1998), a point that will be reviewed in more detail in a later section. Benjamin (2003) further showed that, after engaging in such postdictions, subjects correctly *predict* superior recognition of uncommon words when given another opportunity. The act of making explicit judgments during the test appeared to rectify their misconceptions about recognition. It did not, notably, simply act to change their opinions about what types of words are more memorable: Subjects who predicted recall rather than recognition on the second trial correctly predicted an advantage for common words.

2. *Encoding Strategies*

Evidence reviewed earlier suggested that learners have somewhat incomplete knowledge of the relative advantages of effective encoding orientations, such as generating and deep processing. However, it was already noted that the disadvantage of reading relative to generating material can be offset by instructional manipulations (deWinstanley & Bjork, 1997), suggesting that these gaps of knowledge can be remedied. Here the question is: is exposure to relevant conditions and consequent test performance sufficient to underlie such changes? Let us examine the cases of generation and depth of processing that were reviewed earlier, and consider how experience with such encoding strategies affects knowledge of their relative efficaciousness.

deWinstanley and Bjork (2004) conducted an experiment in which subjects read text passages and were tested on specific words from that passage that had been printed in a distinctive color. During study, those words were either read or generated from a fragment cue. On a fill-in-the-blank cued-recall test, previously generated items were remembered more often than previously read words. Subjects then repeated the procedure, but the results were quite different for the second test: Performance on the read items was elevated, leading to the absence of a generation effect. Experience with the different encoding procedures and observation of their respective outcomes led subjects to change how they read items in such a way as to eliminate the traditional disadvantage relative to generation.

With respect to depth of processing and elaborative encoding schemes, several studies have shown how experience can ameliorate metacognitive failures. Matvey, Dunlosky, Shaw, Parks, and Hertzog (2002) showed an improvement in the degree to which mean JOLs approximated actual performance under deep encoding conditions. Subjects with experience showed a decreased (but nonetheless substantial) underappreciation of the value of deep encoding. Dunlosky and Hertzog (2000) similarly showed that exposure to the differential outcomes of repetition and imagery encoding increased the difference between mean JOLs provided to items processed under those conditions. Brigham and Pressley (1988) showed a similar result in vocabulary learning when comparing the use of a keyword mnemonic with the less effective technique of generating a semantic context: although subjects predicted no difference between these procedures ahead of time (Pressley, Levin, & Ghatala, 1984), experience with the mnemonic outcomes of the two encoding types increased understanding of the difference and even influenced later self-selection of strategies for encoding.

All of the results in this section illustrate ways in which experience informs either judgments about the effectiveness of encoding strategies or choices about desirable encoding strategies. However, it is interesting that none of these studies provided evidence that the correlation between predictions and performance increased with experience. It may be that experience with strategies increases the degree to which predictions approximate performance (absolute accuracy) but not the ability to discriminate between items that will and won't be remembered. One possibility is that, although subjects learn to recognize the effectiveness of one strategy over another, they underestimate the effects of that difference and overestimate the degree to which individual characteristics of the words drive performance (Koriat, 1997). This explains why correlations increased across trials when the manipulated variable was a characteristic intrinsic to the word (Benjamin, 2003), but not when it was a characteristic inherent to the processing performed on that word (Brigham & Pressley, 1988; Dunlosky & Hertzog, 2000; Matvey et al., 2002).

3. *Strategies for Association and Categorization*

Another example of learning how to encode effectively comes from Finley and Benjamin (2007). In their experiment, subjects were exposed to paired-associate terms and either given a cued- or a free-recall test in which they were asked only to recall the second member of each pair. Two findings are relevant from that study, and are shown in Fig. 2. First, performance on the free-recall test improved over trials, providing clear evidence of learning how to deal with the demands of the test. Second, a test-expectancy manipulation—in which the final trial was either the same or different from the previous four—revealed a large disadvantage for switching test, regardless of which test it was. Unlike the previous examples from the test-expectancy paradigm, in which it was shown that expecting a recall test increased performance regardless of the criterion test, these results indicate that subjects were effectively catering their encoding to the specific test that they expected, and that violating those expectancies left their memory representations ill-suited to the new test. Specifically, subjects who learned to expect free recall engaged in more target–target association building and learned to ignore the cue words. Subjects who learned to expect cued recall associated each target word with its matched cue word.

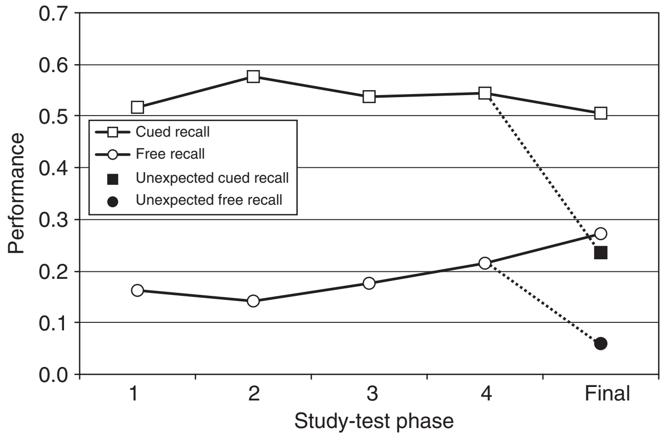

Fig. 2. Performance on cued and free recall as a function of experience and test expectancy (on the final trial).

As described earlier, imposing an organization on material at encoding provides for more successful access and greater recall later when the same organization scheme is used at retrieval. Rabinowitz, Freeman, and Cohen (1992) showed that experience can promote the use of such an organizational strategy. In their experiment, subjects initially studied lists of items that varied in the difficulty with which they could be categorized. They then studied a second list of moderately categorizable stimuli. The amount of clustering is seen in the recall of the second list and the overall performance on that list both increased with the degree to which the *initial* lists were categorizable. This result shows that conditions that promote use of an organizational strategy—in this case, the transparency of the category structure—fostered conditions in which subjects were likely to learn about the effectiveness of that strategy and then apply it in conditions in which they might not have otherwise.

D. Control of Encoding as a Means of Control over Memory

This section has outlined ways in which learners can modulate encoding and encoding strategies in order to control, and effectively reduce, the demands on their memory. Rather than attempting to memorize everything, learners allocate resources commensurate with demands and difficulty. This is one major way in which learners can improve memory performance by improving memory skill. In the next several sections, however, we examine strategies that learners can implement at the time of memory access and how they can be used to improve memory performance.

IV. Strategic Decisions About Memory Access

Once information is in memory, test-takers must make decisions about how to access it. The choices they make should depend on the circumstances (such as the type of test) the urgency of the need for that information or the respective costs and payoffs for errors or successful access, and they should also take into account the type and extent of previous learning or knowledge for the queried material. This section reviews evidence of how learners engage in such strategic processes in order to improve memory performance (see also Barnes et al., 1999). First, I consider the postulated means of memory access and how they differentially contribute to decisions depending on the time available to make those decisions. This is the short section of this chapter that considers processes inside the "memory box" in Fig. 1. The remainder of this section outlines ways in which the outputs from memory processes are flexibly used to guide performance in tasks that vary in their conditions and demands.

Access to memory is particularly troublesome for our friends, the lifeloggers. Although digital memory possesses a clear advantage for retaining information veridically, it does not have any capacity for self-organization. Consequently, access is limited to the user's ability to retrieve from their *actual* memories relevant keywords or details to get a foot in the door and to the quality of the engineering underlying the organization of digital memory. As journalist Clive Thompson noted about the life logger Gordon Bell's memory:

> And it's true—the information is all there—but he hasn't quite figured out how to organize it and sort it perfectly. . .So sometimes it was amazing, but a lot of times he would start to try to find something and then spend 20 minutes trying to find it!
>
> (Gladstone, January 5, 2007)

This example underscores again how important good control of memory is, even in a system with near flawless memory stores. Good organization at encoding and efficient retrieval plans ensure timely access to relevant information. Comprehensive encoding of a day's events increases the need for efficient organization, and lifeloggers at already at an organizational disadvantage: with external memory, organization is a problem of engineering, rather than knowledge. The human memory system is remarkable in its capacity to self-organize and reorganize—this is why knowledge and expertise arise spontaneously out of the acquisition of facts and routines in humans but not in computers.

A. Means of Accessing Memory Traces

This short section serves as a prelude to the larger discussion of how learners strategically regulate memory access and flexibly use the outputs of memory processes to serve their needs. Given the stated goal of this intellectual enterprise as reducing memory and its processes to be as simple and few as possible, why does a memory system need the two routes of access (matching and retrieval) shown in Fig. 1?

The brief answer to this question is that they serve the goal of accounting for two very general and opposing characteristics of human memory, characteristics that are revealed by almost every memory act we engage in (see also Malmberg, this volume). The first characteristic is that of *generalization gradients* and consequent confusability: Errors in memory tasks are more likely than not to reveal phonological (Watson, Balota, & Sergent-Marshall, 2001), orthographic (Underwood & Zimmerman, 1973), or semantic similarity (Roediger & McDermott, 1995) to sought-after information (see also Matzen & Benjamin, 2007). This aspect of memory—which reveals something about the nature of its flexibility and not just its fallibility—is well accounted for by models that postulate distributed representations and memory access to a large set of memory traces in parallel (Eich, 1982; Hintzman, 1986; Murdock, 1993; Shiffrin & Steyvers, 1997), a process often termed *matching*.

Such a mechanism cannot be the sole means of accessing memory, however. Many tests of memory and most uses of memory require more complex output than a degree of match between a probe stimulus and the contents of memory; they necessitate qualitative output, such as the pronunciation of a word, the name of an acquaintance, or the combination to a locker. The matching process provides no means of producing such output from memory. The second major reason that memory must be more than matching is that items that match memory well do not always elicit a higher rate of false alarms on a test of recognition. That is, there are conditions under which subjects accurately reject highly plausible items, their high match notwithstanding. This result suggests an additional *retrieval* mechanism that counteracts the matching mechanism, a claim that is supported by qualitative dissociations in the effects of manipulations of learning on false-alarm rates (FARs). Here, I review a few examples that illustrate how the imposition of time pressure on responses can influence the relative contributions of matching and retrieval. The first two examples are from recognition tasks, and the third is from a metamemory task. This variety of tasks has been chosen deliberately in order to demonstrate the range of phenomena to which that the current framework is intended to apply.

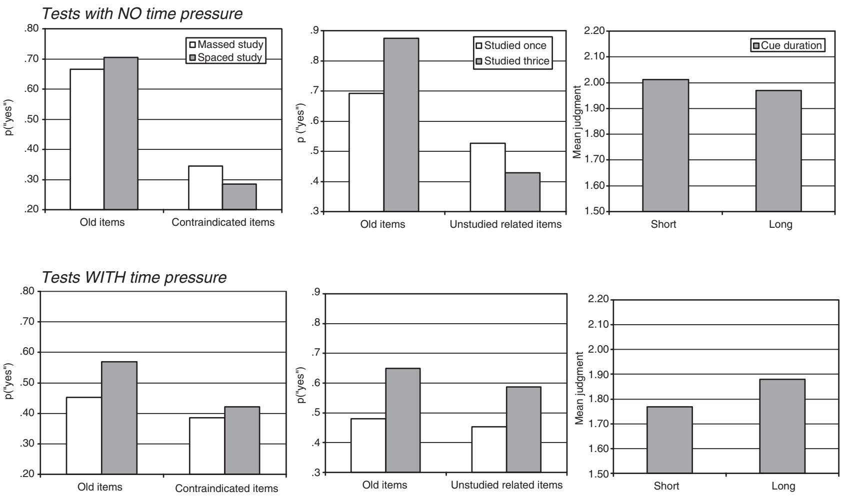

Fig. 3. Three examples of how time pressure changes the contributions of matching and retrieval to memory decisions.

Figure 3 shows the relevant data from the three experiments reviewed briefly here. The far left panel shows FARs (right bars) to words studied in a list that subjects were instructed to exclude (cf. Jacoby, 1991) at test (Benjamin & Craik, 2001). The abscissa represents a manipulation of learning in that experiment (spacing) and the two conditions represented vertically correspond to no time pressure (top panel) and time pressure (bottom panel). Note the critical pattern: The rate of errors decreased with additional learning (i.e., greater spacing) when the test imposed no time pressure, but increased with additional learning when the test was speeded.

The middle panel shows a similar result in a very different paradigm (Benjamin, 2001). In this case, FARs are shown to words that were associatively related to lists of words that were studied either once or three times. In the top panel, in which no time pressure was imposed on the recognition judgments, errors decreased with additional list learning; in the bottom panel, in which there was time pressure, errors increased with additional learning.

The final example is from a task in which subjects were required to make judgments about their ability to recall the second member of a cue-associate pair when presented with the first term. Subjects were provided with the cue (first) term and asked to make their judgments under time pressure or under no time pressure. The data show how judgments varied as a function of how well the cue was previously learned (it had been previously presented for either 1 or 5 s). Under unspeeded conditions, that manipulation—which has no effect on performance in the task of recalling the other word—also has no effect on judgments. However, under speeded conditions, subjects provided higher estimates of being able to recall the target term when the cue term was previously more well learned (Benjamin, 2005b).

Each of these examples demonstrates how matching and retrieval differentially contribute to decisions made under time pressure or under no time pressure. Conditions of time pressure allow the matching process to proceed unimpeded but uncountered by the retrieval process; consequently, what is seen is the pure matching generalization gradient mentioned earlier: Subjects false alarm more to stimuli that were more well learned (Benjamin & Craik, 2001) or related to more well-learned material (Benjamin, 2001), and incorrectly incorporate the match of a cue to memory in predicting memory for a related target (Benjamin, 2005b; see also Reder, 1987). These examples are intended to illustrate two important facts. First is the necessity of (at least) two processes in contributing to memory behavior generally, and the apparent partial independence of these processes. The second fact leads us into the next section: Learners can strategically use these two processes, differentially or in concert, to elicit information that can contribute to memory decisions, depending on the time pressure to make those decisions. However, I provided no evidence here that this effect is purely strategic; it could be the case that subjects under both conditions do the same thing, but that test conditions limit the type of information that is available when the decision is required to be made. The remainder of this section outlines more specific evidence for strategic processing during and after memory access.

B. Decisions About How to Access Memory

The previous section outlined ways in which memory can be accessed—either by matching a probe, which is fast, or by retrieving associated information, which is slow. In this section, I consider ways in which those processes are used selectively or strategically in order to fulfill the demands of a variety of memory tasks.

A reasonable first place to start looking for evidence of strategic control of memory retrieval is the effect of incentives. Although incentives have clear effects when they are provided at the time of encoding, the effects at retrieval are less clear. Several reports have concluded that incentives at retrieval do not affect performance and are thus not under strategic control (Weiner, 1966; Wickens & Simpson, 1968). However, as we shall see later, tasks that afford the rememberer an opportunity to remember more if they work harder (by searching memory for a longer time, for example) do show effects of incentives at retrieval.

1. *To Retrieve or Not to Retrieve?*

The first decision that must be made by someone preparing to answer a question or evaluate how they know someone or something is whether to go to the trouble of querying memory. Subjects can accurately report their absence of knowledge very quickly for questions with unfamiliar terms (Glucksberg & McCloskey, 1981). Similarly, unfamiliar, distant locations elicit rapid judgments of never having been visited (Kolers & Palef, 1976). These data and others like them are well accounted for by a model that presumes that the queried terms in a memory probe like a question are matched to memory rapidly to determine whether any information is present in memory that would allow possible retrieval of the answer (Atkinson & Juola, 1973); when that match is low, a rapid response indicating the absence of information—either "don't know" to a question or "no" to a recognition query—is made.

Similar evidence is apparent in tasks in which people make explicit judgments about their ability to recognize currently unrecallable information (Hart, 1965; see also Koriat & Lieblich, 1974). Such *feeling-of-knowing* judgments increase spuriously when the terms in the memory query are made familiar (Metcalfe, Schwartz, & Joaquim, 1993; Schwartz & Metcalfe, 1992). The same pattern emerges, as noted earlier, when subjects are forced to make very rapid decisions about their ability to retrieve information (Benjamin, 2006; Reder, 1987; Reder & Ritter, 1992). These data indicate that the fast matching process is used as a mechanism to determine the usefulness of more fruitful, but more costly, retrieval access.

2. *Retrieval Versus Plausible Inference*

Choosing not to access memory does not necessarily mean that someone is willing to profess ignorance. I choose not to search my memory when evaluating whether a Ford Model T automobile had an on-board navigation system, but nonetheless might respond confidently that it did not if I have some knowledge of the development of automobile technology. Under many circumstances, the truth of information can either be directly retrieved from memory, with some probability of success and some associated cost, or more simply evaluated for its plausibility, an inferential strategy that presumably has somewhat lower cost and perhaps also a lower probability of success (Reder, 1982). Such inferences are faster than retrieval, and, unlike memory-based recognition judgments, become quicker rather than slower with an increase in the number of relevant facts stored in memory (Reder & Ross, 1983; cf. Anderson, 1974).

Conditions in which memory for the relevant material is not particularly strong, such as after a substantial delay, tend to elicit plausibility judgment strategy use instead of memory retrieval (Reder & Wible, 1984), a policy that would appear to reflect a correct assessment of the decreasing probabilities of success of a retrieval attempt with time. Similarly, Reder (1987) showed that the rate with which people choose to make inferences could be increased by decreasing the proportion of questions that matched previous presented statements or by explicitly instructing subjects to evaluate plausibility (see also Gauld & Stephenson, 1967). It has been argued that choice of strategy is informed in part by a rapid assessment of the degree to which the query is familiar (Reder & Ritter, 1992); this claim is the same as the one described earlier, in which decisions about the value of a retrieval attempt are based in part on the outcome of a rapid match of the memory query to the relevant contents of memory.

3. Retrieval Plans, Search Order, and Output Order

Some memory tasks are difficult not because the material is poorly learned, but because accessing it in an effective way is difficult. Many of us know all 50 of the United States, but attempting to list them typically proves more difficult than one might expect. Rememberers that are successful have an effective retrieval plan, either by taking advantage of structure within the material (Bower, 1970), by taking encoding context into consideration (Thomson & Tulving, 1970; Tulving & Thomson, 1973), or by having a more general strategy (Anderson, 1972; Kintsch, 1974; Shiffrin, 1970). Evidence for the implementation of such a retrieval plan is provided by the fact that recall protocols become more homogeneous—that is, they display more consistent patterns—over multiple trials of free recall (Bousfield & Puff, 1964).

Rememberers may be in a position in which the order with which they recall material is almost as important as remembering it at all. Remembering the steps of a mathematical proof, but not their correct order, might be useless if the student doesn't have the knowledge needed to order those steps appropriately. In addition, some orders with which we query our memory lead to more effective recall than others. Whitten and Leonard (1981) showed, for example, that retrieving names of teachers from early schooling years was more accurate when starting with later years and moving to earlier ones, rather than vice versa. The advantage of that order may lie in the fact that successful retrieval—which is more likely at the later, more recent years—provides more additional prompts for retrieval of more difficult information.

Subjects also clearly provide some subjective organizations to study materials that guide their own later recall. Analyses of output order have shown that preexisting semantic relationships guide the order with which items are recalled (Howard & Kahana, 2002; Rundus, 1971; Tulving, 1972).

Blocking of categorized words at study increases recall (D'Agostino, 1969; Cofer, Bruce, & Reicher, 1966), presumably by increasing the probability of detecting relationships or by helping to formulate a retrieval plan (Slamecka, 1968). Related items are more likely to occur near one another in the output protocol (Bousfield, 1953), and display shorter interresponse times than unrelated items (Patterson, Meltzer, & Mandler, 1971). Consecutively recalled items are also more likely to have occurred near one another in the study list, and also display shorter interresponse times (Kahana, 1996). It thus appears clear that subjects use both semantics and input order as a means of guiding their search through memory, both of which influence recall output order.

Subjects also appear to have a strategy for search and output with respect to serial position. Although JOLs do not reveal an understanding of the superiority of longer-term retention for primacy than recency items (Benjamin et al., 1998b), subjects are likely to recall recency items early in their output protocols, especially with experience (Beaman & Morton, 2000; Deese & Kaufman, 1957). They also tend to output primacy items fairly early, but not as early as recency items. Subjects may even selectively recall first those items that they have had trouble recalling previously (Battig, Allen, & Jensen, 1965), indicating an appreciation for the transience of accessibility to some memory traces.

The advantage for this strategy is made apparent by experiments that manipulate whether recall is forced in a forward or backward order (Cowan et al., 1992), experiments that elicit only a partial report of the set of items (Brown, 1954; Healy, Fendrich, Cunningham, & Till, 1987), and experiments in which the starting position within the input set is forced (Cowan, Saults, Elliot, & Moreno, 2002). In each of these research domains, it is evident that the magnitude of primacy and recency effects in list recall is strongly affected by output order, and that early output of items confers on them a considerable advantage. Thus, by recalling currently accessible but poorly learned items first, subjects put themselves in a position of having greater total recall output.

4. *Constructing Probes for Memory Access*

Whether memory is to be accessed via matching or retrieval, the rememberer must make an important decision about how to query memory. The problem was noted in early work by Tulving and Pearlstone (1966; see also Dong & Kintsch, 1968), who demonstrated that category cues increased recall of members from categorized word lists when compared with pure free recall. This result reveals that success in memory access is driven in part by the successful generation of memory probes, and the general problem is similar to one faced in information retrieval systems in general: How can I successfully limit the response to my query to the most relevant and useful information, but no more? If I intend to search the Internet for information about my friend Adam Jones, do I use the same strategy as when searching for his wife Ophelia Dionysios Cottonwood? Most likely, I recognize the fact that the former search will provide much irrelevant information that I will have to sift through, postaccess, in order to find what I need. I might thus further restrict my search by entering other information that should increase the relevance of the set of returned items, perhaps by using his home town, or employer. Cues must thus be sufficient for access while still maintaining a reasonably high signal-to-noise ratio in the elicited information.

We do something similar with accessing our memory. This phenomenon can be seen in data from an experiment by Diaz and Benjamin (2007), in which the exclusion paradigm mentioned earlier—where subjects are instructed to endorse only a subset of the previously studied items—was applied to the traditional short-term memory scanning task of Sternberg (1966). Subjects studied multiple short lists of words, some of which were printed in red and some in blue. After each list and a short distraction interval, subjects were presented with one of the two colors and then an item. The task for the subject was to endorse the item if and only if it had been presented in the queried color. Figure 4 shows the relevant data, and reveals an important effect: Although response times (RTs) increased with the number of items studied in the queried color, it did not vary with the number of items studied in the unqueried color. This datum indicates that subjects were effectively restricting the subset of items that were probed in memory to include only relevant ones. Similar results have been found in tasks in which people are queried about facts about numerous fictitious people: RTs vary with the number of facts studied about a particular person, but not with the number of facts studied in the very same session about other people (McCloskey & Bigler, 1980).

Given the evidence that we can construct probes that increase the relevance of the output from memory, we turn now to the question of whether probes can be catered to the previous conditions of encoding. It is a well-known principle that retrieval is maximally effective when the processes instantiated at encoding and retrieval are similar (Tulving & Thomson, 1973). Do people intentionally reinstate processes at test to maximize memory performance? Recent evidence bearing on this question comes from experiments in which subjects are tested on their memory for the distractors that were presented during a previous recognition test. Memory for those distractors reflects the type of qualitative processing that was performed on them during the previous test—for example, if subjects made recognition judgments by evaluating the phonology of test items, then their memory for distractors from that test will be poorer than if they had evaluated the semantic aspects of the test items. This result was found by

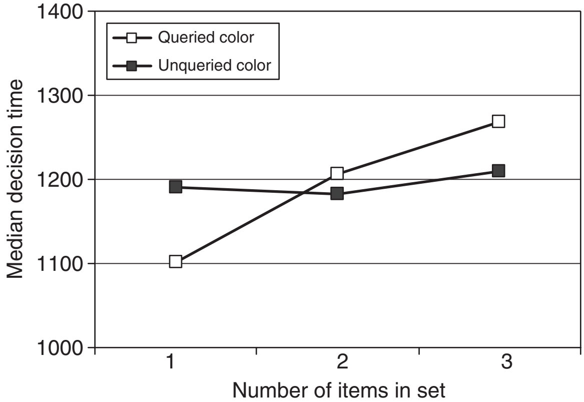

Fig. 4. Mean RTs for exclusion decisions as a function of the set size of items in the unqueried and queried colors.

Jacoby, Shimizu, Daniels, and Rhodes (2005) in a task in which depth of processing was manipulated during the original encoding phase. Subjects who engaged in deep processing during encoding showed superior memory on a second, later test of distractors that were present and evaluated on the earlier recognition test that immediately followed the encoding phase. This result indicates that subjects shaped the memory query to match the type of information they expected to have gleaned from the processing induction during encoding, although older subjects appear to not be able to do so successfully (Jacoby, Shimizu, Velanova, & Rhodes, 2005).

5. *Continuing or Discontinuing Search of Memory*

Once a query has been submitted to memory and information is being extracted, the rememberer must decide if and when to cease search. Search may continue by changing the query slightly, or by using retrieved information to bootstrap oneself to more relevant or a greater number of relevant results. Or it may cease if the rememberer feels that they either have sufficient information to proceed with whatever larger task they are engaged in or that they have little hope of successfully mining any more useful information from memory.

We have already discussed one way in which this can take place: If a match to memory reveals that the terms in the probe match memory poorly, a decision may be made not to search memory at all. But what about cases in which active search has begun and changes to the memory probe must be implemented in order to further that progress? To return to the example of recalling the states of the United States, you might try an alphabetic strategy, a geographic strategy, or even a political strategy. Chances are that you will use one until it becomes unproductive, and then switch to another. These spontaneous and idiosyncratic changes in memory queries have been revealed in a number of tasks. For example, Walker and Kintsch (1985) noted that recall of members of real-world categories (e.g., kitchen utensils) showed evidence for subjects querying their memory with personal and distinctive cues (e.g., breakfast this morning), particularly after the first few obvious members were generated and reported. Others have reported a variety of search strategies in similar tasks (Whitten & Leonard, 1981; Williams & Santos-Williams, 1980). The SAM model of free recall (Raaijmakers & Shiffrin, 1981; see also Gronlund & Shiffrin, 1986) dynamically implements changes to memory queries by including in the probe the most recently recalled relevant item. Each of these results shows that subjects (or SAM) dynamically modifies a memory query in order to bootstrap their way to maximal recall. Earlier models by Restle (1964) and Polson (1972) similarly suggested that subjects modify their retrieval strategy when there is a failure of recall.

Evidence that recall success is largely determined by the quality of the memory probe and not by forgetting comes from the list–length paradigm, in which longer lists of words lead to less accurate recall of individual members of those lists than shorter lists. Shiffrin (1970) showed that overall recall performance depended entirely on the length of the to-be-recalled list and not at all on the length of a list of words interpolated between the critical list and the recall test. This result speaks strongly to the claim that creating an effective memory probe is more important in promoting performance than is minimizing forgetting.

So far, I have reviewed data that support the claim that subjects dynamically modify their retrieval probes during recall, and that the success of the venture depends largely on the quality of that probe. A rememberer may also have to make decisions about when to terminate search of memory. An experiment by Young (2004) investigated how people make decisions about when to cease memory search in a task in which subjects were asked to recall as many exemplars as possible from two different categories in a limited time period. She found that subjects spent more time searching a category if it was of normatively higher potency (i.e., from which more items were typically retrieved) and also that subjects ceased search and switched to a second category sooner when that second category was of relatively higher potency. In addition, higher feeling-of-knowing judgments predict longer search times in memory (Costermans, Lories, & Ansay, 1992; Nelson, Gerler, & Narens, 1984), revealing that rememberers wisely search for a longer time when they believe that that search has a higher probability of success. A failure of this particular control process has even been evaluated as a basis for poorer memory performance in the elderly (Lachman, Lachman, & Thronesbery, 1979). When subjects can not access information that they desire to retrieve, high FOKs may even drive people to continue search outside of their memory stores—by querying other people or by searching through their lifelogs—when they have confidence in their ability to recognize that information on contact.

Rememberers also search for a longer time when the incentives for success are higher. Loftus and Wickens (1970) showed superior memory for paired-associates associated with higher incentives, even when those incentives were only provided at test. Latencies to provide either correct responses or errors were longer when the incentives were higher, revealing that subjects were willing to search their memories longer, and that they gained something by doing so. Barnes et al. (1999) extended this result to semantic knowledge by asking subjects general knowledge questions and separately varying the incentives for correct retrieval and for the costs of search (by penalizing subjects for the time taken to provide a response). Their results clearly confirmed that subjects are willing to search longer when the rewards are greater, and that they cut their search time short when the costs are greater.

These behaviors—in which subjects appear to make smart decisions about which category is more likely to support higher levels of overall success or appear to incorporate knowledge about the respective costs and benefits of retrieval into their decisions to retrieve—map neatly onto the basic assumptions of the *rational analysis of memory* (Anderson & Milson, 1989; Anderson & Schooler, 1991). That framework proposes that search of memory continues only if the estimated utility of retrieving additional information exceeds the cost of searching for it. This framework provides a good example for how the strategies that govern retrieval and retrieval success are determined by a complex interplay of goals, motivational factors, and metacognitive assessments.

C. Learning About Memory Access

There are several lessons one could learn about accessing memory that could improve performance. First, subjects may learn effective ways of accessing material; for example, by reducing output interference. They might acquire more efficient retrieval plans with experience. Finally, they might adjust relevant parameters for decision making, such as response criteria, to more accurately match the demands, payoffs, or base rates probabilities that they only assess accurately with experience.

1. Understanding the Value of Self-Testing

A recurring theme in this chapter has been how memory access can be profitably used because of its diagnosticity about levels of learning or states of knowledge. The outcomes of a matching decision can be used to decide, for example, whether to search memory (Reder, 1987) and for how long (Costermans et al., 1992), or to estimate the likelihood of successful recognition (Hart, 1967). The outcome of a retrieval event can be used to predict future memory performance (Benjamin et al., 1998b) or to foster further study or more effective encoding (Battig et al., 1965). Can subjects learn about the value of self-testing and use that knowledge to increase memory performance?

Clearly, subjects do use retrieval to some degree as a means of keeping information active or retarding forgetting (Rundus, 1971). The evidence for this claim comes from tasks in which rehearsal is prohibited by task demands (Glanzer & Meinzer, 1967) and by experiments that elicit overt rehearsals (Ward & Tan, 2004). But how well do they learn to use self-testing or retrieval strategies with experience?

A relevant study was reported by Dunlosky, Kubat-Silman, and Hertzog (2003) with elderly subjects (who are less likely to spontaneously use self-testing strategies than younger, college-aged subjects; Murphy, Schmitt, Caruso, & Sanders, 1987). In their experiment, subjects studied and were tested on their memory for two lists of paired associates. In the approximately two week period between those study-test events, subjects were taught strategies for successful encoding (such as imagery), and some were additionally taught to use self-testing as a means of assessing their own states of knowledge. Compared to a control group that had no instruction between the two tests, subjects who learned encoding strategies showed improved performance across the two study-test events. More importantly, however, the group that learned self-testing in addition to those strategies outperformed both other groups. Thus, subjects can improve memory performance by improving the quality of their monitoring of their own learning via self-testing.

2. Formulating a Better Retrieval Plan

Can subjects improve their performance on tests by developing better retrieval plans? One example of successful strategy adaptation can be seen in the results of Conover and Brown (1977), who had subjects engaged in multiple study-recall trials. They showed that subjects were increasingly likely to output the recency items first with experience. This is a wise strategy, as those items are not typically well learned and will be forgotten if they are not output early. Consequently, the magnitude of the recency effect increased over lists (see also Maskarinec & Brown, 1974).

Our earlier discussion of retrieval plans emphasized the criticality of generating effective retrieval cues in promoting successful retrieval. We reviewed evidence that subjects use personal (Walker & Kintsch, 1985), semantic (Rundus, 1971), encoding-matched (Tulving & Thomson, 1973), and list order (Kahana, 1996) cues in service of fostering retrieval, and briefly described one model that has a retrieval algorithm that updates its cue regularly. Other models propose that the act of learning to retrieve is the process of working through possible cues until effective ones are found (Halff, 1977). Theories propose a "win-stay/lose-shift" strategy, by which cues are only varied when they fail to elicit a sought-after memory (Polson, Restle, & Polson, 1965; Restle, 1962), and that successful retrieval makes certain retrieval cues more accessible and thus more likely to be used (Izawa, 1971). All of these suggestions have in common the constantly developing nature of a retrieval plan that makes retrieval more likely to be successful.

The basic assumptions of this perspective are borne out by several related findings. First, over multiple recall tests from the same study list, increased clustering of categories is evident (Mulligan, 2001). Second, the phenomenon of hypermnesia occurs in part because the increasing efficiency of retrieval strategies over multiple tests limit the degree of forgetting with time, thus allowing reminiscence—remembering items that were not remembered earlier—to outweigh forgetting and produce net gains in recall (Hunt & McDaniel, 1993; McDaniel, Moore, & Whiteman, 1998; Mulligan, 2001).

D. Strategic Memory Access as a Cognitive Skill

The examples outlined in this section have illustrated ways in which decisions about how to access memory can influence the success of remembering. These strategies are ones that are suited to the peculiarities of the human memory system and to the variety of demands faced by rememberers. Balancing those demands and executing control processes that are appropriate to those demands are a type of memory skill.

How do lifeloggers cope with the demands of accessing the huge database of memory that they store on a daily basis? There appear to be both advantages and disadvantages of such copious capacity when it comes to retrieval. The advantages include the ready availability of useful retrieval probes: Pictures taken over the course of a day or copies of e-mails, documents, and other files can serve as cues to remember intentions and goals that have been forgotten (see Einstein & McDaniel, 2005; this volume). Alan Smeaton, a professor of Computing at Dublin University, reported that a rapid review of the day's events provides extra useful retrieval cues:

> If, at the end of each workday, they [lifeloggers] spent a minute scrolling through the thousands of pictures the SenseCam had taken—a high-speed replay of their day—it had the effect of stimulating their short-term memory.
>
> "You'd actually remember things you'd already forgotten," Smeaton says. "You'd see somebody you met in a corridor and had a two-minute conversation with that you'd completely forgotten about. And you'd go, 'Oh, I forgot to send an email to that guy!"
>
> (Thompson, 2006, p. 72)

This claim is borne out by evidence with both normal daily use (Sellen et al., 2007) and with amnesic patients (Hodges et al., 2006; Kapur, Glisky, & Wilson, 2002).

By contrast, it is not evident that having a stack of photographs from the day's events is a means to solving problems with memory efficiently. Selective encoding yields a library of memories that are highly relevant for future use and the further refinement of knowledge, whereas a stack of postcards is agnostic as to the differential importance of the day's events. This qualitative difference in encoding is a serious disadvantage at this point in the process: Accessing a favorite book is considerably easier from the 100 or so volumes in my home library than from the millions in the university library, and I may be unable to generate the appropriate retrieval plan or memory probe to search effectively through space that hasn't been organized on the way in.

V. Postaccess Decision Processes

In some ways, the job for the rememberer has only just begun after the relevant information has been secured from the depths of memory. In many uses of memory, the task of remembering is trivially easy, but the decision about how and whether to respond is fraught with additional complexities. I might have a chance encounter with an indisputably familiar person in the library, but my interactions with that person are likely to be different if I know them to be an acquaintance from work than if I remember them from a grainy photograph on the wall of the post office.

A. Suppression of Output

One interesting theoretical problem arises from the general view of memory that I have espoused here. If access is driven primarily by the quality of the memory probe, then repeated applications of that probe should elicit the same mnemonic products. Given the evidence that retrieval is a potentiator of memory strength (Bjork, 1975) and that retrieval of a subset of items decreases accessibility to the others (Anderson, Bjork, & Bjork, 1994), it would seem that recall would elicit a great number of repeated items.

This prediction is echoed in models that employ sampling without replacement as a basis for retrieval in recall (Shiffrin, 1970; Slamecka, 1969), an assumption made in part because interresponse times in free recall decrease with the number of words previously recalled and increase with the number of words left to recall (Murdock & Okada, 1970).

However, this prediction is not correct: Repetitions in recall protocols are quite rare (Murdock & Okada, 1970). The answer seems to be a strategic, volitional suppression of repetitions in recall, as suggested by a model proposed by Rundus (1973). This claim is supported by two data: First, subjects seem to have fairly accurate memory for what they have previously recalled (Gardiner & Klee, 1976; Robinson & Kulp, 1970). Second, instructions to subjects to be ‘‘uninhibited’’ in their recall—that is, to report everything that comes to mind as it comes to mind—leads to a much higher rate of repetitions than do standard recall instructions (Bousfield & Rosner, 1970). Similarly, a suppression of response feedback—by having subjects wear noise-canceling headphones during verbal recall or writing their answers on carbon-copy paper in which they could not view their writing—led the number of repetitions in recall protocol to triple (Gardiner, Passmore, Herriot, & Klee, 1977). In addition, older adults—who appear to be more prone to retelling familiar stories to captive audiences—have more repetitions in their recall output and show poorer memory for what they have previously recalled (Koriat, Ben-Zur, & Sheffer, 1988). These data all support the claim that the relative absence of repetitions in recall protocols is a consequence of a deliberate, strategic suppression of those responses.

There is another occasion on which rememberers may want to suppress output. Using memory in conversation and other ‘‘real-world’’ circumstances places demands on the rememberer both to provide as much information as possible and be accurate (Koriat & Goldsmith, 1996). Responding with irrelevant, redundant, or even misleading details can be worse than not responding at all, so decisions must be made about when to report the results of memory access and when to withhold reporting. This situation is analogous to the problem faced in evaluation of memory in eyewitnesses (Fisher, Geiselman, & Raymond, 1987; Hilgard & Loftus, 1979), for whom errors of commission carry quite different consequences than errors of omission (Fisher, Geiselman, & Amador, 1989).

Indeed, incentives to be accurate or to produce a high quantity of recall output appear to affect recall protocols in a straightforward manner: Accuracy instructions reduce total output but increase the accuracy of output (Koriat & Goldsmith, 1994), even in children (Koriat, Goldsmith, Schneider, & Nakash-Dura, 2001). Incentives to increase the quantity of output do not increase the number of items correctly recalled relative to a control condition (Barnes et al., 1999; Weiner, 1966), nor do encouragements to be lenient in output (Erdelyi, 1970; Roediger & Payne, 1985). This combination of results suggests that this may be yet another domain in which having good control of memory is more important than having good memory: In free-report situations, rememberers exert control over the accuracy of their output by deliberately failing to report retrieved information that they assess as having a low probability of being correct (Koriat & Goldsmith, 1996).

B. Output Grain

Even when someone has made a decision to respond overtly, additional choices must be made about how to respond. Just as someone might withhold information in order to be accurate, they might also choose a level of detail with which to report the contents of their memory search appropriate to an accuracy demand imposed by themselves or the situation. When I'm asked where I live by a neighbor in a local park, I indicate the approximate intersection, allowing them to localize my house to within a couple hundred feet. If a colleague at an international conference asks me the same question, I might respond with the city, the state, or even the country—allowing them to localize my house only within an area of ~9 million km^2. In this case, the pragmatics of the situation dictate the trade-off between the accuracy and the informativeness of my response (Grice, 1975; Yaniv & Foster, 1997). In other cases, explicit demands on estimation accuracy determine the coarseness of output (Einhorn & Hogarth, 1985; Erev, Wallsten, & Neal, 1991; Wallsten, Budescu, Rapoport, Zwick, & Forsyth, 1986).

People exercise control over the precision or coarseness of their output in order to decrease errors of commission (Neisser, 1988), to reduce the effects of forgetting (Goldsmith, Koriat, & Pansky, 2005), and, most generally, to place themselves at an optimal point on the informativeness-accuracy tradeoff function (Goldsmith, Koriat, & Weinberg-Eliezer, 2002). Goldsmith et al. (2002) provided additional support that the choice mechanism underlying grain size choice in their tasks—in which subjects provided multiple answers to questions at different grain sizes and then chose one of them as a more desirable response—was a basic preference for more fine-grained answers that could be vetoed when the assessed probability of that answer being correct was below some threshold. This mechanism is thus essentially the same as the one that is presumed to govern the choice of responding or withholding a response, as discussed in the previous section.

C. Criterion Placement and Adjustment in Recognition

To this point, this section has reviewed how qualitative evidence retrieved from memory is selectively modified and reported in the service of meeting the accuracy demands on a given situation. An analogous situation exists following access to memory by means of the matching mechanism: Continuous evidence—in the form of a mnemonic response to a matching query—must be translated into a binary, or *n*-ary, decision of one sort or another. Usually, that decision is of whether a queried stimulus has been previously studied (Mandler, 1980), but it may also refer to whether it was studied in a particular context (Jacoby, 1991), or how recently (Hintzman, 2003; Peterson, Johnson, & Coatney, 1969) or how frequently (Hintzman, 2001; Rowe & Rose, 1977) it was studied. Similarly, quantitative information from a memory match appears to subserve metamnemonic judgments, such as JOLs (Benjamin, Bjork, & Hirshman, 1998a; Benjamin & Diaz, in press). The mechanism by which such judgments are made is the comparison of a test value to a criterion. That criterion may be in terms of absolute amounts of evidence or in terms of the relative evidence for one decision alternative over another (Green & Swets, 1966), and may be thought to be stationary (Peterson, Birdsall, & Fox, 1954) or labile and variable over conditions (Benjamin & Wee, 2007).

The theory of signal detection (TSD; Green & Swets, 1966) has guided conceptualization of the recognition task as analogous to other tasks involving detection or discrimination (Egan, 1958; Parks, 1966). The theory makes explicit assumptions about the nature of the probability distributions governing the evidence yielded by different types of stimuli, and from those assumptions provides derivations of how criteria can be placed optimally (and thus also provides figures of merit with which to evaluate the quality of criterion placement).

It is quite difficult to evaluate the optimality of criteria in memory tasks, most of which solicit either yes/no or more finely grained judgments. Each of these procedures has known problems. The parameters that are derived from yes/no tasks are known to be inadequate because they fail to explicitly account for greater variance in the probability distribution in the strengths of studied than unstudied items (Macmillan & Creelman, 2005), as are "nonparametric" variants of those values (Benjamin, 2005a). In addition, the ratings task is known to introduce unwanted variability to parameter estimates (Benjamin & Wee, 2007; Markowitz & Swets, 1967). An additional difficulty is purely conceptual: Although Green and Swets (1966) discussed criteria in terms of likelihood ratios (LR)—that is, the relative evidence for one alternative as compared to another alternative—many studies discuss criteria in terms of evidence values—that is, their value on an arbitrary scale (these questions are considered in more depth in the chapters in this volume by Rotello and Macmillan, and Dobbins and Han).

Unfortunately, LR and evidence are not monotonically related when the distributions are of unequal variance. Equivalent LRs often imply quite different evidence values, and equivalent evidence values imply different LRs (Stretch & Wixted, 1998a). LR criteria appear to vary more or less optimally with manipulations of prior odds in perceptual (Swets, Tanner,

& Birdsall, 1961) and numerical judgment tasks (Healy & Kubovy, 1977) but not in recognition (Healy & Jones, 1975; Healy & Kubovy, 1977). However, this result leaves open the possibility that recognition lends itself more naturally to setting and adjusting criteria on evidence, rather than LR, scales.

And, indeed, studies that evaluate criterion placement in terms of their locations on an evidence axes report robust and reasonable responses to experimental manipulations. Hirshman (1995) compared criterion placement for words studied for a short period of time in homogeneous lists and in mixed lists in which half of the items were studied for a longer duration, and showed that subjects set a higher criterion for the recognition of those items from the mixed list, indicating that the overall memorability of the list influences the placement of criteria. Similarly, Benjamin and Bawa (2004) showed that subjects employed more stringent criteria on tests that included distractors that were more difficult to discriminate from the previously studied items. Each of these results indicates a difference in criterion placement that is consistent with the theory of Green and Swets (1966), although it is worth noting that differences are typically smaller and that criteria are often somewhat more conservative than predicted by TSD (Healy & Jones, 1975; Healy & Kubovy, 1977). These data show that subjects can modulate their criterion in response to manipulations at encoding and at test, but there remain questions as to whether subjects can modulate criteria based on stimulus factors on an item-by-item basis.

1. Stimulus Memorability and the Mirror Effect

Of particular relevance is the *mirror effect*, which describes the finding that manipulations that enhance memory often operate both by increasing the hit rate (HR) of items from a particular category, and also by decreasing the FAR to items from that category (Glanzer, Adams, Iverson, & Kim, 1993). The signature case of this effect involves normative word frequency (McCormack & Swenson, 1972), and is thought to reflect the fact that uncommon words elicit superior encoding by virtue of their distinctiveness (Malmberg, Steyvers, Stephens, & Shiffrin, 2002) and that subjects set a higher criterion commensurate with that encoding advantage (Benjamin, 2003).

That explanation makes two serious assumptions about the role of strategic processes in producing the mirror effect: (a) that subjects set higher criteria for material that they deem to be more memorable, and (b) that they recognize low-frequency words as being more memorable. I shall treat these two assumptions in turn.

It has been shown that subjects confidently and accurately reject distractors on a test that are idiosyncratically memorable, like the names of relatives or towns that they have lived in (Brown, Lewis, & Monk, 1977), or stimuli that are episodically distinctive (Strack & Bless, 1994). Ghetti (2003) showed that this effect increases with age in children, suggesting that experience is necessary to support the translation of high memorability into stringent criteria.

The mirror effect also obtains, albeit only in some circumstances, when differences in memorability are rendered experimentally (e.g., by variations in study time or number of study repetitions). Such "strength-based" mirror effects typically obtain when memorability is manipulated between subjects or between lists, but not always when it is manipulated within list (Stretch & Wixted, 1998b). For example, Morrell, Gaitan, and Wixted (2002) presented subjects with lists of professions and locations, one of which was presented in red and one in blue. In addition, one category was repeated multiple times and the other was not. Memory for the studied members of the categories differed as expected, but no difference in FAR to new items from those categories was obtained, suggesting that subjects did not adjust their criteria on an item-by-item basis. However, other within-list manipulations of strength did elicit different FAR for different categories (Benjamin, 2001; Dobbins & Kroll, 2005; Singer & Wixted, 2006). It appears as though subjects are only willing to shift criteria on a within-list basis when the category membership is inherently related to the difference in memorability (like word frequency) or when the relationship is made particularly apparent.

The second major component of the theory relating criterion shifts to the mirror effect is the appreciation of the superior recognizability of uncommon words. Early results showing that subjects mistakenly predict higher recognition ability for uncommon over common words appeared to contradict this claim (Greene & Thapar, 1994; Wixted, 1992). However, when subjects are asked to make judgments *during* the recognition test itself—the point at which mirror effects actually obtain—subjects correctly judge uncommon words to be of greater memorability (Benjamin, 2003; Guttentag & Carroll, 1998).

Although criterion shifts are not the only theoretical means with which mirror effects can obtain (Criss, 2006), it does appear to be a particularly parsimonious means of explaining the ubiquity of mirror effects and understanding the variety of occasions on which they do not obtain.

D. Learning About How to Make Memory Decisions

Although it is possible that task experience can change either the suppression or the grain of output, I know of no data investigating those topics. Within the context of memory judgments, however, there is evidence about how criteria can change with experience on a task.

Criterion shifts. Bear in mind that it is a theoretical possibility is that subjects set their criterion based purely on the range of memory strengths assessed following learning (Hirshman, 1995), and thus that criteria do not vary across the test. We have already reviewed evidence that this perspective is incomplete, as criteria do vary with test characteristics (Benjamin & Bawa, 2004; Brown, Steyvers, & Hemmer, 2007).

To some degree, criteria must be malleable and responsive to test characteristics, simply because they often exhibit probability matching (Parks, 1966), and the probabilities of targets and lures can only be stably estimated over a large number of trials. However, there is evidence that subjects can be remarkably insensitive to such test characteristics: Compared to standard recognition testing conditions, HRs remain the same on a test with no distractors (Wallace, 1980) and FARs remain the same on a test with no targets (Dobbins, this volume).

Experiments that vary characteristics within a list or across multiple lists—for example, by varying the composition of targets and lures—reveal that subjects are quite insensitive, but not wholly so, to characteristics that should influence criteria. Verde and Rotello (in press) showed that FARs did not differ across list halves when one half contained only well-learned items (and distractors) and the other half contained more poorly learned items (and distractors), except when subjects were provided with performance feedback. Such data have caused some authors to conclude that criterion adjustment does not occur under normal recognition testing conditions. Although there are numerous results that are consistent with this claim (Morrell et al., 2002; Stretch & Wixted, 1998b), this conclusion fails to provide a ready explanation of why changes in either prior probabilities (Heit, Brockdorff, & Lamberts, 2003) or payoffs (Van Zandt, 2000) sometimes *do* influence criterion changes across multiple lists.

Benjamin and Bawa (2004) showed that shifts occur when the tests get harder, but not when the tests get easier, suggesting that the mechanism underlying criterion adjustment with experience is not simply one of optimization. Theories of criterion-setting have been proposed in other decision tasks (Treisman & Williams, 1984), but have not been systematically considered in the case of recognition memory (Benjamin & Wee, 2007). The fact that distractor manipulations (Benjamin & Bawa, 2004) but not target manipulations (Verde & Rotello, in press) influence criterion adjustment suggests a useful conceptualization might be as a Neyman–Pearson decision process, by which subjects attempt to maintain a constant rate of false alarms. The chapters by Rotello and Macmillan and by Dobbins and Han in this volume also review this evidence; it is clear that a full theoretical conceptualization about how subjects shift criteria with experience would be premature, but it is also quite clear that there are circumstances in which criteria do shift in response to task demands.

E. Postaccess Decision Processes as a Means of Control Over Memory

This section has outlined three ways in which performance on tests of memory can vary as a function of decision processes that take place after memory is accessed: by deciding when to suppress output of a response, by choosing the appropriate level of detail to provide, and by imposing criteria for memory judgments that are appropriate to the task and the situation at hand.

VI. Conclusions

This chapter has reviewed ways in which subjects strategically use encoding, access, and decision processes to influence performance on tests of memory. As a theoretical exercise, I have taken the perspective that memory itself is unmalleable, and perhaps even nonvariable across subjects, and I have investigated the range of memory behavior that could nonetheless differ across circumstances and across people simply as a function of ‘‘memory skill’’—the degree to which people use their strategies to effectively allow them to achieve their intellectual goals, such as doing well in an examination. Given this strong claim that memory behavior has more to do with extra-mnemonic skill than storage capacity, let us revisit the life of the lifeloggers, the advantages they enjoy from flawless and constant encoding, and the disadvantages they may face from farming out the ‘‘scut work’’ of storage.

As discussed earlier, lifeloggers replace strategic mental encoding with comprehensive external encoding. This strategy has four principal advantages. First, information is less likely to be ‘‘forgotten’’ from a hard drive. Second, time and resources are freed up for other activities. Third, decisions do not need to be made about what and how to encode because storage capacity is effectively unlimited. And fourth, if circumstances and demand for information changes, events and materials that were previously deemed low-priority—and thus perhaps poorly encoded in the memory of nonlifeloggers—will still be accessible to lifeloggers.

The solution to the problem of how to select material for encoding is solved by the lifeloggers by outsourcing it. The rest of us use the strategic and selective allocation of encoding resources in order to efficiently reach our learning goals. This is an effective way of reducing the load on a taxed memory system: keeping nonvital information out. But what about the information we desire to remember? And are we truly less productive and creative because we force our brain to do the yeoman's work of encoding? The theme of this chapter is that productivity and creativity derive from mechanisms of information aggregation that are the *sine qua non* of human memory systems but are as yet unrealized in artificial systems. The knowledge structures that then arise influence the strategic decisions we make about our memories, and it is in this way that we bootstrap ourselves to greater understanding of complex domains and to the new thoughts and ideas that underlie advancement in those domains. It thus seems somewhat disingenuous to conclude that the time and effort we spend making encoding decisions robs us of an opportunity to use our minds productively.

There is, also, at least one advantage of lifelogging with respect to memory *access*—having cues available in the form of photographs or documents decreases the need for rememberer to generate their own cues and modify them as needs dictate. Perhaps these advantages obviate the need for strategic memory use on the access side?

Perhaps not. Consider the case of S., a patient studied by the neuropsychologist Aleksandr Luria in his now-classic case study *The Mind of a Mnemonist* (Luria, 1968/1987). S. exhibited such an extraordinary and durable memory that no means of testing revealed limits to his capacity. In fact, S. exhibited problems related to his inability to *forget*; as noted by Luria on viewing the way S. read and attempted to understand a short story:

> There were numerous details in the text, each of which gave rise to new images that led him far afield; further details produced still more details, until his mind was a virtual chaos." (p. 67)

S.'s inability to discard irrelevant and tangential details kept him from focusing on the central structure of the text and decreased his ability to meet the demands of reading; namely, understanding the gist of a series of events. How did S. eventually learn to forget? He became a proto-lifelogger:

> Why, he reasoned, couldn't he use some external means to help him forget—write down what he no longer wished to remember..."People jot things down so they'll remember them," he said. "This seemed ridiculous to me, so I decided to tackle the problem my own way." As he saw it, once he had written a thing down, he would have no need to remember it; but if he were without means of writing it down, he'd commit it to memory." (pp. 69–70)

S. recognized and used to his advantage the simple fact that external encoding diminishes memory encoding. But, whereas this technique proved advantageous for S., it creates a considerable intellectual cost for a normal memory user. But perhaps memory encoding should be considered superfluous, given the greater reliability of external encoding?

Here we must consider one advantage that S. had that lifeloggers do not—ready access to a reasonably well-organized structure of knowledge. The access advantage for lifeloggers—effectively, the ability to turn recall into cued recall—has a tremendous downside: The cues themselves are agnostic as to their importance or relevance for a particular task. So, a lifelogger might indeed remember to send his colleague an email and the nonlifelogger will forget, but they may both have considerable difficulty generating the content of that email. Their external "memories" are bloated with unimportant and irrelevant details, much like S.'s memory but quite unlike the average memory user, and sorting through that morass is harder because the knowledge structures that guide recall from memory are unavailable or primitive in external memory systems. It is certainly my hope that knowledge of human cognition can inform engineering sufficiently to someday provide search and retrieval algorithms that rival access to human memory, but it is also evident that that day is not today.

To end our discussion of lifeloggers, it is worth reflecting again on the nature of expertise. All of the contributors to this volume are experts in research on human memory. Is that expertise no more than the stack of professional articles and books that comprise what each of these experts has read in their lifetime? Could an outsider with access to those stacks write this book? The ability to synthesize, to use memory traces to generate new knowledge, underlies expertise, creativity, and the ability to generate new knowledge. A SenseCam can not perform that synthesis and, even if it had some mechanism for doing so, its deliberately nonselective encoding mechanisms may render that task impossible. Just as the central premise of this chapter has been that higher-order cognition guides the action and use of memory, memory itself underlies higher-order cognition. It is difficult to imagine how artificial memory devices could supplant the balance of goals, motivations, and abilities that human memory provides, and it is perhaps valuable to consider how such devices can be used to augment human memory capacity, rather than replace it.

We often think explicitly about our memory only when it betrays us, perhaps by failing to provide us with needed information that we know was recently available, or maybe by tricking us into believing things that aren't true. However spectacular these failures might be on occasion, it is a fact that almost every meaningful behavior we engage in relies on placing new information in memory, accessing information from memory, or both; and that every cognitive act we engage in relies on the effective use of memory strategies in both enhancing and limiting storage. Most of the time these processes operate so effectively that we hardly give them a second thought, or give memory its proper due. This chapter has emphasized how interacting with memory is a, if not the, vital component in the effective action of memory.

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