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Information-Processing Conceptualizations of Human Cognition: Past, Present, and Future

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Historically, scholars have used contemporary machines as models of the mind. Today, much of what we know about human cognition is guided by a three-stage computer model. Sensory memory is attributed with the qualities of a computer buffer store in which individual inputs are briefly maintained until a meaningful entry is recognized. Short-term memory is equivalent to the working memory of a computer, being highly flexible yet having only a limited capacity. Finally, long-term memory resembles the auxiliary store of a computer, with a virtually unlimited capacity for a variety of information. Although the computer analogy provides a useful framework for describing much of the present research on human cognition, it is insufficient in several respects. For example, it does not adequately represent the distinction between conscious and non-conscious thought. As an alternative, a corporate metaphor of the mind is suggested as a possible vehicle for guiding future research. Depicting the mind as a corporation accommodates many aspects of cognition including consciousness. In addition, by offering a more familiar framework, a corporate model is easily applied to subjective psychological experience as well as other real world phenomena.

> Currently, the most influential approach in cognitive psychology is based on analogies derived from the digital computer. The information processing approach has been an important source of models and ideas but the fate of its predecessors should serve to keep us humble concerning its eventual success. In 30 years, the computer-based information processing approach that currently reigns may seem as invalid to the human mind as the wax-tablet or telephone switchboard models do today. (Roediger 1980, 248)

For thousands of years scholars have used contemporary technological instruments to model human cognition. Plato, in the third century B. C., described memory, a fundamental aspect of cognition, as a wax tablet that can take on endless impressions. In the seventeenth century, Descartes fashioned many mental processes after the complex clock robots that were popular at the time. During the first half of this century, human cognition was likened to a telephone switchboard, with incoming calls from the environment (stimuli) being connected to the appropriate telephone (response). By mid-century, human thought was suggested to resemble a symbol manipulation machine, similar to a mechanical calculator but considerably more powerful (Craik 1943). Other technological innovations that have been used to model the mind have included cameras, tape recorders, and even written text (Neisser 1982b; see also Roediger 1980).

Given the reliance on the technological advancements of a time by creators of contemporary models of cognition, it is not surprising that for the last several decades the popular model for understanding human thought has been the computer. One purpose of this article is to illustrate how many of the basic findings of cognitive psychology have been described within the computer model analogy. We then describe some current research that is less easily accommodated by the computer analogy. Finally, we suggest a new framework for discussing human cognition that may minimize some of the problems associated with machine models.

Generally, models that use computers as an analogy to human thinking are said to use an information processing approach to underscore the similarities between the functions of mental processes and those of a computer. Besides simply noting analogous functions of human thought and the computer, information processing models invariably suggest similar processes as well. For example, mental systems, like computers, have been argued to be divisible into two basic types of component processes: processes similar to computer software in the sense that they are learned (or programmed), and processes that are similar to computer hardware in the sense that they are wired into the system and cannot be changed by the environment.

Many other parallels between human thinking and computer processing have been suggested at one time or another (see Hintzman 1978; Loftus and Loftus 1976), however, there is one similarity that is central to almost all information processing models. Specifically, practically all computer models of mental processes include three basic stages of mental processing equivalent to the buffer, working memory, and auxiliary memory of computers (Hintzman 1978). In a computer, a buffer store, or register, holds each symbol of a given input string in memory while the remaining items are read. This stage allows the computer to read all of the symbols in a string together as a single entry. After an entry has been formed, it is combined and temporarily stored with other entries so that symbol manipulation can be performed. This process is often referred to as working memory. Working memory, though highly flexible, has only a limited capacity, hence most computers have an additional system often referred to as auxiliary memories that allow for the storage of information that is not currently in use. These three aspects of computers have almost identical analogies in the information processing framework and form the skeleton on to which much of cognitive research has been fit. In the next three sections we briefly review some of this research.

Sensory Memory

The first stage in the information processing framework is equivalent to the buffer of a computer and is often referred to as sensory memory. Like the buffer of a computer, sensory memory briefly stores information, providing sufficient time for meaning to be extracted. Actually, there are several sensory memories, each corresponding to a different sensory modality. With visual information, entrance is through the eyes and the information enters a visual sensory memory, often called iconic memory (Neisser 1967). With auditory information, entrance is through the ears, and the information enters into an auditory sensory memory, often called echoic memory. We can think of a sensory memory corresponding to each of the other modalities as well.

After a brief visual stimulus has been presented, a visual image or icon is held in the sensory memory while its features are being extracted. In a now classic series of experiments, Sperling (1960) demonstrated that the icon contains a substantial amount of information, but due to its brief life, most of the information is lost before it can be reported. Sperling's procedure involved briefly flashing rows of unrelated letters and then asking subjects to recall as many of the letters as possible. Generally, subjects could only recall a small percentage of the letters viewed. In a second condition, the partial report condition, subjects only had to recall a few letters. A signal indicated to subjects which portion of the letter array they should try to report. Since the signal varied from trial to trial, subjects had no way of knowing which letters they were going to have to recall until after the letter presentation had physically disappeared. Accuracy was very high. To perform so accurately subjects needed to retain at least briefly what letter occupied every position. One implication of this finding is that subjects can recall all of the briefly presented information, but only for a very limited duration; when subjects have to name everything they see, they simply forget much of it before they have a chance to say it. Apparently, the icon contains considerable information most of which is forgotten or becomes inaccessible if it is not immediately attended to.

While the discussion thus far has focused on the viewing of a single brief stimulus, natural viewing conditions are often much different. We generally look at enduring complex scenes, not individual tachistoscopic flashes. When we acquire information from our environment, the available evidence adds up to a picture of the eye sweeping over the scene to which it is directed with a series of eye fixations. The early portion of each fixation is spent extracting information from the stimulus while later portions appear to be spent making a decision about where to fixate next (Gould 1969; Loftus 1972). With each single fixation, the iconic image replaces the image from the previous fixation. Somehow, quite miraculously, each of the individual "looks" is then integrated into a smooth and complete representation.

Most of our conclusions rest, in large part, on experiments involving tachistoscopic stimuli (i.e., stimuli flashed for very brief durations). Recently, Haber (1983) has questioned the value of tachistoscopic experiments because the conditions they present are so dramatically different from any phenomenon observed in the real world. Specifically, a number of studies have demonstrated that the icon can be eradicated if a briefly flashed stimulus is followed by a flash of light or other type of visual stimulus (see Turvey 1973 for a review). Haber argues that with the exception of reading in a thunderstorm, there is no opportunity in real life situations to experience the icon, since under normal circumstances it will be constantly masked by subsequent visual stimuli. Although there is certainly some truth to Haber's observation that tachistiscopic conditions are rare, that does not necessarily prove his conclusion that it is worthless to study the icon. It is clear that some process is necessary in order to hold information long enough for it to be adequately sorted, evaluated, and acted upon. The icon appears to have all of the qualities of such a needed mechanism. It therefore seems likely that the icon, or some icon-like process, fulfills this buffer role.

It may be that in normal situations iconic images continue to exist after masking but are simply not consciously visible. In other words, the icon's function may be to provide information to mental systems that are operating at a less than fully conscious level. Indeed, there is now emerging evidence that complex processing occurs for stimuli that are never consciously perceived (e.g., Marcel 1983), a subject that we discuss later in this article.

With regard to other sensory modalities, memory for smell (Engen and Ross 1973), tactile information (Gilson and Baddeley 1969), and auditory information (Crowder and Morton 1969) have all been studied with the

bulk of the research attention being devoted to audition. Auditory information, for example, is thought to enter an auditory sensory store called echoic memory, analogous to the one posited for visual information. Information from this store decays quite rapidly, although somewhat more slowly than the decay from the iconic store. Most estimates hover around two to four seconds (Crowder and Morton 1969; Darwin, Turvey, and Crowder 1972). It is typically the case that the last few items in a list are recalled at a higher level if they have been presented auditorily rather than visually, a finding that is usually attributed to the relatively long-lasting echoic memory traces.

As in a computer buffer that stores a series of individual entries together until they can be read as a control word, sensory memory requires a process whereby sensory information is converted into more meaningful information. This process is commonly known as pattern recognition and basically involves identifying sensory stimuli. Exactly how this process is accomplished is still not completely understood, but a common proposition is that it involves a matching of the current stimulus against a likely set of prototypes in long-term memory. The stimulus is then classified according to the name of the best matching prototype (Reed 1972).

In sum, sensory memory, as it has been studied within the information processing approach, closely resembles the buffer of a computer. It stores information briefly, with the precise duration depending on the modality. During this brief storage period information is sorted and some portion is interpreted and given meaning. According to the model, it is only this processed information that proceeds to the next stage in the system, generally known as short-term memory.

Short-Term Memory

Short-term memory, like the working memory of a computer, is viewed as the place or state where cognitive operations take place. Short-term memory has a number of general characteristics, many of which resemble the working memory of a computer. First, it has a limited capacity; that is, it cannot hold very much information. About four to six chunks of information is typical. Second, like a computer, access to information in short-term memory is generally believed to occur serially; that is, we can only access one item at a time. Third, information from this memory decays very rapidly—common estimates are between fifteen to twenty seconds—unless we engage in some activity, such as rehearsal, to prevent this decay.

Short-term memory is thought to have a limited capacity. Miller (1956) first argued that it holds seven + or − items or "chunks" of information, regardless of their size. The exact definition of a chunk is somewhat elusive, but it might be characterized as a stimulus that has some unitary representation in long-term memory. Thus, the letters "K C U D" constitute four chunks but in reverse order, the letter string "D U C K" is a single chunk.

Miller claimed that short-term memory could hold about seven chunks since this was about the number of items we could repeat back after a single hearing (the memory span). However, the memory span is in part aided by long-term memory and thus may not be a good estimate of the capacity of short-term memory. Waugh and Norman made this point in their 1965 article entitled "Primary Memory." The suggestion was that information could be copied into long-term memory quite quickly, while it was also maintained in short-term memory, a suggestion that implied that information about an item could reside in both systems simultaneously. This means that even a short time after presentation, the recall of some particular information will depend on the operation of both short- and long-term memory. This sort of thinking has led some investigators, including Mandler (1967), to argue that seven chunks is too large an estimate and the capacity of short-term memory is probably closer to four or five.

Access to information in short-term memory has been extensively investigated by Sternberg (1966). In his experiments, a subject is first read or shown a string of items called the memory set which the subject places in short-term memory. Next a test item is presented and the subject's task is to report whether the test item was or was not a member of the memory set. Thus, if the memory set consisted of the letters X P T V and the test item is T, the correct response would be "yes." The variable of interest is how fast the subject responds, and the typical finding is that the times increase with the numbers of symbols in the memory set. This finding indicated to Sternberg that access to items in short-term memory is serial, that is item by item. Although there is some dispute over this interpretation of Sternberg's results (see for example, Theios et al. 1973; Townsend 1972), the notion of serial processing has been one of the characteristics of short-term memory that has been commonly associated with the computer analogy to mental processing.

Estimates of the decay of short-term memory come from experiments using the Brown-Peterson paradigm (Brown 1958; Peterson and Peterson 1959). On each trial a subject is presented with a string of three consonants such as "BKG." Following the consonant trigram, a retention interval passes ranging from 0 to 18 seconds. To prevent rehearsal of the trigram, the subject is required to perform a fairly demanding mental arithmetic task during the interval, namely counting backwards by threes from a three-digit number. At the end of the interval, the subject recalls the trigram. The typical result is that when the trigram is tested immediately—after a retention interval of 0—recall is nearly perfect. At longer intervals, however, memory performance drops steadily, reaching asymptote after an interval of about 15-20 seconds, at which point the trigram is recalled about 10 percent of the time. These results suggest that loss of information from short-term memory is complete by about 15-20 seconds.

In sum, short-term memory represents the processing stage in the computer model of memory. Like the working memory of a computer, short-term memory has a limited capacity and appears to process information in a serial manner. Information that is not processed or rehearsed decays rapidly and is not transferred to the next stage of the system, long-term memory.

Long-Term Memory

Long-term memory, like the auxiliary memory of a computer, is viewed as being an unlimited storehouse of information from which short-term memory can draw. Long-term memory includes information that we learned a few minutes ago as well as information learned years earlier.

Because of the proposed similarities between long-term memory and computers, many researchers have attempted to develop complex computer models to simulate these memory processes. These studies (e.g., Anderson 1976, 1983; Norman and Rumelhart 1975) have generated striking simulations of human performance. Nevertheless, in evaluating these simulations, it must be kept in mind that totally different processes can ultimately produce very similar final responses. Therefore, as effective as computer simulations may be, they may not necessarily describe what occurs during actual human information processing.

Propositional and Procedural Information

The information contained in long-term memory can be roughly broken down into two basic classes: propositional information and procedural information. Propositional information pertains to factual knowledge that can be explained. Procedural information pertains to skills that can be implemented. This distinction can be summarized as differentiating between "knowing that" and "knowing how." Possibly because of the computer analogy's emphasis on information processing, most studies of procedural information have focused on the procedures involved in processing propositional information. Thus, a discussion of long-term memory for propositional information incorporates much of what is known about procedural knowledge.

Tulving (1972, 1983) makes an important distinction between two basic types of long-term memory which he terms *semantic* and *episodic*. These memories contain qualitatively different types of propositional information. Semantic memory contains general facts including words, historical facts, rules, etc. For example, the statement "An apple is a fruit" is a semantic fact. Episodic memory pertains to personal facts that can be described in terms of the time and place of their occurrence. For example, the statement "Yesterday I ate an apple" is an episodic fact. This distinction between semantic and episodic memory has been important both in terms of elucidating the possible types of long-term memory stores as well as providing a convenient way of dividing this memory into different areas of study.

Some researchers maintain that semantic and episodic information are actually stored separately. In his recent book, Tulving (1983) cites two basic sources of evidence for the functional separation of these two types of memory. First he notes the many studies that have demonstrated that certain variables can affect subjects' performance on semantic memory tasks without affecting their performance on episodic memory tasks and vice versa. A second class of evidence to support this distinction is physiological. For example, one study observed differences in blood flow in the brain depending on whether a task required semantic or episodic information (Wood et al. 1980). In addition many clinical reports describe patients who experience deficiencies in one type of memory while the other type of memory remains relatively intact (see Schacter and Tulving 1982). Although Tulving's gathering of evidence and his arguments are relatively compelling, the distinction, at least at the functional level, has been rejected by some researchers (e.g., Anderson and Ross 1980). These critics point to studies showing substantial interdependence between the two allegedly separate memory systems.

Although researchers disagree on whether this distinction represents two functionally distinct systems, there is common agreement on the value of the distinction as a heuristic device for classifying different types of long-term memory information. Specifically, with the exception of a few global lines of study (e.g., Anderson 1983) most investigations of long-term memory primarily apply to either semantic or episodic memory. It is therefore convenient to discuss separately the basic principles that have been attributed to the processing of semantic and episodic memory.

Episodic Memory

In terms of episodic memory, two principles are particularly important (Tulving 1983). The first principle involves the constructive nature of long-term memory for episodes; that is, episodic memories are not only retrieved from the past, but they are also abstracted and distorted. What this means is that in recalling episodic information from memory we often take

in an incomplete account and then use our general knowledge to construct a more complete description of what we experienced. For example, if we hear the sentence "The lawyer stirred her coffee," or actually see this happening, we might infer that she stirred it with a spoon, and we might add this inference to our memory of the incident. Our long-term memory for the episode will then contain not only the original information that we encoded from the initial event but bits of knowledge that we constructed and added to our memory.

This constructive process can help us accurately fill in forgotten details, but it can also produce errors. For example, when told "The floor was dirty because Sally used the mop," many people will infer that the mop must have been dirty and will later think that they had been presented with the statement "The floor was dirty because Sally used the dirty mop" (Bransford, Barclay, and Franks 1972). This occurs because the original information and the inferences are integrated into a single memory for the episode. One consequence is an inability, or at least a severe difficulty, in distinguishing between what was actually presented and what was only inferred afterward.

Similar effects are observed when people who have experienced complex events are exposed to subsequent misinformation about that event. It is common to find that the new information becomes incorporated into memory, supplementing or altering the original memory. For example, in one experiment college students were presented with a film of an automobile accident and then half of the subjects were asked "How fast was the white sports car going when it passed the barn while traveling along the country road?" whereas no barn existed. Later the subjects were asked whether they had seen the barn. The subjects who heard the statement suggesting the barn were considerably more likely than the control subjects to recall having witnessed the nonexistent barn (Loftus 1975). In this case the false information was integrated into the person's recollection of the event, thereby supplementing that memory.

In other studies, it has been shown that new information can do more than simply supplement a recollection; it can occasionally alter or transform a recollection. Subjects saw a series of slides depicting an auto-pedestrian accident; some saw the car come to an intersection with a stop sign and others saw a yield sign. Later subjects were exposed to misleading information about the sign, and finally they were asked to recognize which sign they had actually seen. In numerous studies using these materials, many subjects chose the sign that corresponded to the subsequent information, rejecting the sign that they had actually seen (Loftus, Miller, and Burns 1978). These results suggest that people will not only generate inferences, but they will use other information available to them to fill in the gaps in their memories. This process of rounding out fairly incomplete knowledge has been called refabrication.

Refabrications have been extensively investigated, yet, there remains considerable dispute over whether these new memories have replaced the original memories, or whether they are simply more accessible at the time of retrieval. A recent study by Bekerian and Bowers (1983) addresses the issue of whether suggested memories replace or coexist with original memories. They added an innovative condition to the stop sign/yield sign experiment conducted by Loftus, Miller, and Burns described above. Bekerian and Bowers presented the final recognition test slides in a sequential order that more closely approximated the order in which the slides were originally presented. In this condition, subjects were able to disregard the misinformation and recognize the sign that they had originally seen. Thus, the original information must have still existed. Bekerian and Bowers concluded that the sequential order of the test slides reinstated the context of the original presentation thereby allowing the original information to be retrieved. Unfortunately context reinstatement does not always induce the recall of original information (McSpadden and Loftus 1983). Thus, the issue of whether destructive updating ever occurs is still open.

The issue of context reinstatement leads naturally to a second important principle of episodic memory: encoding specificity (Tulving and Thomson 1973). According to this principle, the likelihood that an episodic bit of information is retrieved is a function of the similarity between the conditions under which it is encoded and the conditions under which it is retrieved. The encoding specificity principle is reminiscent of advice that is commonly offered when one can't find something: "If you can't find it, retrace your steps." By retracing your steps you effectively reinstate the context in which you originally encoded the placing of the object, thereby making the retrieval conditions similar to the encoding conditions.

The presentation of test slides in a sequence similar to that in which the slides were first viewed is another way of equating the conditions of encoding with the conditions of retrieval. This same basic principle has been used to explain why memorized words are often not recognized when they are presented in a context that suggests a meaning different from the meaning in which they were initially encoded (Tulving and Thomson 1971). It also accounts for why scuba divers who memorize words under water recognize more of the words when they are tested under water than when they are tested on dry land (Baddeley et al. 1975). Moreover, it explains why subjects' recognition of memorized words is facilitated by recreating the mood that they were in when they memorized the words (Bower 1981).

Thus, it appears that the recall of episodic information involves a combination of 1) the refabrication of new information, and 2) the retrieval of original information via successful recreation of the circumstances associated with the formation of a memory. Together the principles of constructive refabrication and encoding specificity powerfully determine what is recalled from episodic memory.

Semantic Memory

In some ways the processes involved in the retrieval of episodic and semantic long-term memories are different. Specifically, semantic information by definition does not include the context in which it was encoded, therefore the notion of equating context of encoding with context of retrieval is not really applicable. Moreover, for much of semantic memory—knowledge of words—the notion of refabrication does not apply. Thus, regardless of whether semantic and episodic memories are stored separately, they must certainly differ at least with regard to some of their respective retrieval processes.

In the case of the retrieval of semantic memory, considerable research has focused on the relationship between the semantic similarity of items and the speed of their retrieval. Generally, it has been observed that the time necessary to access memory is in part a function of the type of information that was previously accessed. For example, it has been shown (Meyer and Schvaneveldt 1971; Schvaneveldt and Meyer 1973) that the time to retrieve semantic information from memory is shorter if related information has been accessed a short time previously. In this research, subjects were required to classify letter strings as words or nonwords. In general the response time to classify a letter string as a word is shorter if the subject has just classified a semantically similar word, as opposed to a semantically dissimilar word. For example, subjects take less time to classify *butter* as a word if *butter* is preceded by *bread* than if it is preceeded by *nurse*. This result, along with others involving widely different paradigms (e.g., Loftus 1973), suggests that the retrieval of semantic information initiates a "spreading activation" of related semantic facts.

The spreading-activation theory (summarized by Collins and Loftus 1975) provides a vehicle for discussing these facilitation effects. The theory states that when an item in semantic memory is processed, other items are activated to the extent that they are closely related to the first item. Put another way, activation spreads through long-term memory from active portions, and along its pathway new portions of memory are temporarily more accessible. This basic notion of spreading activation has served as the springboard for many models that conceive of semantic memory as a network of propositions (Collins and Quillian 1972; Collins and Loftus 1975); accordingly, the position of semantic propositions within such networks can be examined by observing the spread of activation from one semantic fact to the next.

Recently, the simple notion of spreading activation of semantic memory has been complicated by the appearance of some experiments in which the retrieval of information was inhibited by the prior retrieval of related information (Brown 1979). This finding posed some difficulties for spreading-activation models that are based on the notion that the activation of semantic facts facilitates rather than inhibits the access of closely related facts. A recent study by Roediger, Neely, and Blaxton (1983), however, suggests that Brown's findings are due to particular response strategies associated with the type of material that he used in his research. Thus, the concept of spreading activation is alive and well (see also Anderson 1983).

Although the retrieval processes attributed to episodic memory, such as refabrication and encoding specificity, are not easily applied to semantic information, a number of spreading-activation models have attempted to include episodic information within their propositional network (e.g., Anderson 1976, 1983). In these cases the spread of episodic information is a function of 1) how closely associated the items were at the time of encoding, and 2) the number of different items that were associated with the activated information.

In sum, long-term memory represents the final stage in the computer analogy. It has a tremendous capacity and contains a great variety of information. Much of the information contained can be broadly classified as either episodic (personal) or semantic (general). The study of memory for episodic information has illuminated two important retrieval principles: refabrication, which involves the construction of new memories that fill in gaps, and encoding specificity, which suggests that the likelihood of recalling a memory is a function of the similarity between the conditions of its encoding and its retrieval. Considerable research in semantic memory has focused on the concept of spreading activation which helps delineate the structure of semantic networks.

Evidence for the Stage Model of Information Processing

In addition to providing a heuristically useful parallel between computers and the mind, the three-stage model of information processing i supported by both experimental work and clinical observation. Evidence for the sensory stage is primarily limited to research, described earlier, demonstrating the rapid decay of very detailed information that is apprehended in the same mode (e.g., acoustic, visual) in which it is experienced. The evidence for a short-term, as distinct from a long-term, memory is considerably more complicated and can be grouped into three

relatively independent lines of research including: 1) free recall data, 2) observations in a clinical setting, and 3) memory consolidation studies.

Free Recall Studies

In numerous experiments, subjects have been presented with a list of words and then asked to recall them in any order. When the probability that a word is recalled is plotted against its location in the list (its serial input position), the typical serial-position curve results. The curve indicates that words at the beginning of the list (the primacy effect) and words at the end of the list (the recency effect) are recalled better than words in the middle. Why does the recency effect occur? Is it because the words at the end of the list were encountered most recently and so are less likely to be forgotten during the recall test? Those who believe in the short-term memory/long-term memory dichotomy have a different explanation. They argue that the words at the end of the list are very likely to be in short-term memory when the recall test begins, since no words followed that could displace them. Thus, they can be readily recalled.

A simple variation on the free-recall experiment provides support for this explanation and for the distinction between short-term and long-term memory (Postman and Phillips 1965; Glanzer and Cunitz 1966). In these experiments, subjects were presented with a list of words, followed by a distracting arithmetic task, followed by recall. Their recall was compared with that of control subjects who recalled the words immediately after they were presented. Control subjects showed the usual recency effect, whereas experimental subjects who had performed the distracting arithmetic task recalled the last few words poorly. In other words they showed no recency effect. Proponents of a dichotomous memory system explain this result by proposing that the last words on the list are still in short-term memory and can be readily recalled by control subjects. For experimental subjects, information from the arithmetic task enters short-term memory and interferes with recall of the words.

Clinical Evidence

The dichotomy between short-term and long-term memory has received further support by reports of clinical cases in which one memory system is apparently normal while the other is deficient or nonoperative (Milner 1970; Warrington and Shallice 1972.) One example is the patient H.M. who had temporal lobe surgery to treat a severe epileptic condition. Although his epilepsy was helped by the treatment, he developed a profound memory defect. His intelligence, as measured by standard tests, was even a bit higher than it had been before. His short-term memory was adequate, as was his ability to retrieve information from long-term memory that was acquired before the operation. However, he could not transfer information from short-term memory to long-term memory, a highly debilitating deficit. For example, ten months after H.M.'s operation his family moved to a new house situated only a few blocks away from the old one. A year after the move, H.M. had not yet learned the new address, nor could he be trusted to find his way home alone. The finding that one portion of the memory system can be grossly deficient while the other remains intact argues in favor of distinct systems.

Memory Consolidation Studies

Consolidation studies also provide evidence for the short-term/long-term distinction. In these studies electroconvulsive shock (ECS) is delivered to the brain soon after learning. This shock can prevent the new information from consolidating into long-term memory. The literature on memory consolidation is large and complex, but there is little doubt that when shock is given immediately after a learning experience it interferes with the normal link between short-term and long-term memory (McGaugh and Herz 1971).

Arguments against the Stage Model of Information Processing

Although the stage model is one of the most widely accepted concepts within the information processing field, it has not been without its critics. One of the most important criticisms of the stage model is that the stages are not always clearly defined. The duration of sensory memory can span from a fraction of a second to many seconds depending on the task (e.g., Phillips and Baddeley 1971). Differences between short-term and long-term memories are also often task dependent (Shulman 1971).

Levels of Processing Framework

Because of the fuzziness in distinguishing the stages, a number of researchers (e.g., Cermak 1972; Craik and Lockhart 1972) have suggested that information processing be viewed as a continuum rather than as discrete stages. This approach, often described as a "levels of processing framework" (Craik and Lockhart 1972) postulates that the strength of a memory trace is not a discrete matter of whether or not it is transferred to long-term memory, but is instead a continuous function of the "depth of processing" that that given piece of information receives. Thus, if rehearsal is of a shallow variety—like the type we perform to keep a new telephone number in mind long enough to dial it—little will be subsequently retrievable. If the rehearsal is of a deep, elaborative type, as when we try to set up meaningful connections among the items we are trying to remember,

much more of the information will be available for later retrieval. Experiments by Craik and Watkins (1973) and Jacoby (1973) observed that when subjects viewed words in the context of tasks requiring meaningful processing, such as whether words would make sense in a particular sentence, they recalled considerably more words than subjects who encountered the same words in the context of a more superficial task, such as deciding whether a word was in upper or lower case. In "depth of processing" language these observations suggest that deeper processing results in stronger memory traces.

The depth of processing framework, while appealing in many ways, is not without its faults. Specifically, one corollary to the notion that depth of processing is responsible for the strength of a memory trace is the prediction that repeated rehearsal of an item at the same depth of processing should not result in any difference in the memory trace. At least one study, however, demonstrated that simply encountering the same word twice in a single superficial task increases the likelihood that that word will be subsequently recalled (Nelson 1978). The observation that increased rehearsal, even in the absence of deeper processing, can strengthen a memory trace, indicates that the concept of "depth" cannot exclusively account for the strength of a memory trace.

A second problem with the depth of processing approach is that it is not clear how depth is defined; for example, why is semantic processing inherently "deeper" than visual processing? Perhaps semantic processing is not deeper than other kinds, but is just different. Accordingly, differences between the retrieval of words processed visually, acoustically, or semantically is not a function of the depth of processing, but rather of the similarities between the context of encoding and the context of recall. Since free recall is in many ways a semantic task, it is not surprising that words learned in a semantic context would be better retrieved during semantic free-recall. If the retrieval situation asks subjects to recall words in an acoustic context such as by deciding what words rhymed with *train*, acoustically encoded words are better recalled (Morris, Bransford, and Franks 1977). The observation that retrieval is often a function of the type rather than the depth of encoding has led Baddeley (1982) to suggest that memory should be viewed as containing domains of processing rather than levels of processing.

Ultimately it seems likely that a compromise among the various approaches will become popular. Specifically, there is little doubt that items that are given greater attention—processed more deeply—are more readily retrieved (Anderson 1983). At the same time, it seems inappropriate to term one type of attention (e.g. visual, acoustic, semantic) as inherently more important than another. Moreover, neither the concept of levels of processing nor that of depth of processing necessarily excludes the existence of a central processor with a limited and temporary memory similar to that posited for short-term memory.

Thus, one compromise is the postulation of a central processor with limited capacity and temporary information retention that moves freely between different domains of memory. The strength of a memory trace would simply be a function of the amount of attention that the processor gives to a piece of information within a domain. The probability of retrieval would thus be a joint function of (1) the strength of the original trace and (2) whether the information is accessed in the same domain in which it was encoded. The above compromise is in many ways a simplified synthesis of some of the aspects of a number of recent memory models (e.g., Anderson 1983; Broadbent 1983; Tulving 1983). Its emphasis on a central processor that travels freely between domains is especially valuable because it addresses the common criticism of the computer-based stage model; namely that it does not adequately reflect the variety of processing strategies involved in human thinking.

The "Maltese Cross" Framework

Broadbent (1983), previously a major proponent of the stage model, recently outlined a series of criticisms of what he terms the "pipeline approach." He is troubled by the present model's inability to adequately identify the role of individual control processes. He argues that the tendency to reduce human processing to a strict flow chart serves to overly downplay the ways in which the individual can act on his or her environment.

He argues, for example, that present models portray the person as inappropriately passive, always the recipient of stimuli, and rarely initiating internal processes. Moreover, he argues that interpretation of stimuli is not just a matter of what stimuli are presented, but also reflects the personal cognitive operations of the individual. Finally, he notes that most models fail to adequately consider the multitude of different strategies that the individual may employ while engaging in mental tasks.

As an alternative, Broadbent proposes the "Maltese Cross," a theory which includes a central processor that is responsible for all of the flexible processing that is normally assumed to be under an individual's control. Broadbent suggests that the information processing system involves the interaction of a central processing system with four basic memory processes that he terms the sensory store, the motor store, abstract working memory, and the long-term store.

Broadbent uses the analogy of a man at his desk. On the desk are two baskets. One basket, equivalent to the sensory store, contains the incoming mail. A second basket contains all outgoing mail and is equivalent to the

motor store which represents the executive's intended responses. The desk top on which he is working is analogous to working memory and includes all of the ideas that he is currently manipulating. Finally, the file behind him is equivalent to the long-term store and represents all of the information that is accessible to the man when he needs it. Using a set of flexible but preprogrammed rules, the man at his desk interacts with these four areas, processing new information as well as calling up old information that can be rearranged on his desk to produce seemingly spontaneous ideas.

Although Broadbent's model does not really posit any new components—ideas such as a motor memory (Sperling 1967), a central processor (Craik and Lockhart 1972), or flexible control processes (Atkinson and Shiffrin 1968)—it does help to highlight some of the difficulties with previous computer models. Specifically, by using a model that contains a conscious entity within it, it indirectly identifies a weakness of the computer model: its inability to naturally reflect the existence of conscious thought.

Conscious versus Nonconscious Processes

Previous attempts to include conscious and nonconscious processes in the computer model of human information processing have emphasized the distinction in computers between flexible and nonflexible processing strategies. For example, Atkinson and Shiffrin (1968) suggested an elaborate series of flexible control processes similar to computer software, which determined what stimuli were transferred to long-term memory. These variable control processes were contrasted with the invariable—(hardware)—structural processes. The difficulty with the hardware/software distinction is that it ignores the important distinction between what one is aware of and what one is in control of. For example, if control is defined as those responses whose outcome is dependent on a flexible set of prior experiences and resulting expectations, then it is possible that one could be "in control" of a perception, and at the same time be unaware of those control processes. For example, judging an ambiguous figure often involves the expectations of the perceiver, and yet a person may be unaware that he or she had control over what was perceived.

It could be argued that what an individual is aware of is ultimately inconsequential. All that is necessary to understand the mind is an appreciation of the internal processes that occur within an individual. Whether or not the individual is aware of those processes does not matter, since it is the processes themselves that are of interest. Indeed it is probably thinking of this sort that has enabled psychologists to so closely align the act of thinking with the processes of a nonconscious computer. Recent researcl conducted by Marcel (1980, 1983), however, indicates that whether or not individuals are aware of their thought processes has considerable bearing on the nature of those processes.

Marcel describes a series of subliminal perception experiments in which words are presented very briefly, followed by a flash of light that masks not only the meaning of the word but even the fact that it was presented. These unperceived words exert an effect on thought processes. In one paradigm, Marcel demonstrates that the presentation of a word, even subliminally, can affect subjects' reactions to later words. He observed, for example, that the letter string "Doctor" was recognized faster if its presentation was preceded by the subliminal presentation of the related letter string "Nurse." Apparently, the subliminal presentation of a word can activate related words. This finding indicates that complex semantic processing can occur without conscious awareness.

Marcel (1980) also demonstrated that nonconscious processing, though highly complex, differs in a fundamental way from conscious processing. He examined the priming effects of polysemous words (words that have more than one meaning, such as *palm*. When a polysemous word is presented long enough to be consciously perceived, only one of its meanings apparently exerts a priming effect. For example *palm* might prime *hand* or *tree,* but not both. When polysemous words are presented subliminally, however, both associated meanings can serve as primes. Marcel (1983) concludes: "Apparently more than one interpretation of an event in any one domain can be represented simultaneously nonconsciously but only one interpretation at a time can be represented consciously" (p. 252). Thus, it appears that nonconscious processing differs in a fundamental way from conscious processing in that at the nonconscious level various interpreting processes may occur simultaneously.

Marcel's research suggests that conscious attention itself is an important aspect of cognitive processing, an observation that is not naturally accommodated by the computer model. Specifically, computers cannot in any real sense be thought to be aware of some processes more than other processes. Thus, the distinction between conscious and nonconscious thought, unlike the hardware/software distinction, is not a natural one in the computer model.

Undoubtedly it is possible to design computer models that are able to simulate many of the properties of conscious and nonconscious thought, including the existence of parallel processing at the nonconscious level. Such pursuits make sense since the human mind, which operates in this way, is such an effective processor of information. Exclusive reliance on computers as a model of human thinking, on the other hand, makes little sense. By studying human thought in the context of the capabilities of

present computers, we limit ourselves to considering only those aspects of human thought that are shared with the computer. The fact that, unlike computers, humans have both consciousness and an awareness of their own cognitive functioning, cries out for the development of new models that can more readily accommodate these neglected aspects of human thought.

An Alternative Model of Human Cognition

Broadbent's executive metaphor nicely accommodates conscious awareness and, therefore, represents a step in the right direction. Unfortunately, it fails to adequately represent parallel nonconscious processes. In Broadbent's view, if the executive does not process something, it simply does not get processed. Unless we are talking about a very busy person who is able to do many different things simultaneously, Broadbent's executive cannot readily handle parallel cognitive processes.

What executives need in order to process all of the information that is handled by the human mind is, quite literally, help. They need a secretary to handle files, various assistants to help sort the input and output piles, and, most importantly, helpers to do various different tasks simultaneously while the executives spend their time handling the important issues. In other words, the executive metaphor may have some applicability for the mind, if augmented by the rest of the corporation.

A model of the human mind as a well-run corporation accommodates many of the issues that are not well represented by the mechanistic computer model. It naturally provides a place for consciousness as the president of the organization. It captures the distinction between the serial processing at the conscious level—a leader can only think about one thing at a time—and the parallel processing at the nonconscious level: all of the subordinate members of the corporation can work simultaneously.

In addition, it offers a more natural way to envision the stages and levels of information processing; that is, by the status and departments of the various sensory and storage bureaucrats within the corporation. A bureaucracy contains members of differing status who receive differing amounts of the president's attention. Assume that what the president knows about any given member of the corporation is a function of the amount of attention that that member receives. In this sense, the corporate metaphor nicely exemplifies the relationship between the amount of attention that a stimulus receives and its subsequent retrievability. A bureaucracy may also contain various departments that are roughly equivalent in status. The president's ability to retrieve information would also be a function of whether or not he or she consulted the appropriate department, thereby capturing the notion that successful recall requires a correspondence between the memory domain involved in encoding and that involved in retrieval. Finally, different departments of a bureaucracy can work on similar issues—denoting the sometimes ambiguous distinctions between various aspects of memory.

By including a conscious entity, the corporate model is naturally susceptible to the "homunculus" criticism that including a conscious entity within a psychological model makes it circular. Yet, the president in the mental corporation is very different from a complete individual. Like all of the members of a corporation, this role is limited to specific functions; for example, the president does not have direct access to all of the information in the system but instead must rely on various sensory and storage assistants. Because the corporate president is not like a complete individual, the corporate metaphor is not a simple reintroduction of the concept being explained.

Although the corporate president does not have all of the qualities of a complete individual, he does have consciousness, so the corporate model can be viewed as circular to the degree that it attempts to define consciousness. However, the experience of consciousness is perhaps the one thing that we can take for granted. As Descartes understood long ago: "I think therefore I am." Thus, instead of ignoring consciousness, perhaps researchers should ask, "Given a consciousness, what does it experience?" Which processes are under its control, and which are not? How can it (I) have more control? Once the question becomes not what is consciousness but what is consciousness aware of, then the present model offers a way to conceptualize the conscious experience. For example, it hints at the many sides of our personalities, and suggests ways of understanding how individuals can think and feel dramatically different depending on the circumstances (or in the terminology of the present model, depending on whom in their mental corporation they are currently consulting).

Although the corporate model appears at first glance rather unusual, in many ways it resembles the once popular pandemonium model of pattern recognition (Selfridge 1959). In this model, perception is depicted as a series of demons who each shout when they see features that correspond to their particular bias. The closer the correspondence, the louder they shout. These lower demons are then heard by demons of a higher status, who begin shouting about feature combinations. This hierarchy of demons continues, as the message of the loudest shouting demons is passed from stage to stage, until finally the appropriate response is made by the individual at the top. Our corporate model resembles pandemonium in that it depicts the mind as a hierarchy of independent function-specific entities each simultaneously doing their own thing, but ultimately presenting a cohesive message to the consciousness at the top.

Besides accommodating a number of empirical findings that are not easily incorporated in the computer model, the corporate model of the mind also lends itself to more adequately responding to a number of other practical and philosophical issues that have been leveled against the mechanistic computer models. Cognitive psychology has often been criticized for failing to study what is meaningful or relevant to anyone outside of the field (Neisser 1982a). Indeed computer models are inherently alien to people outside psychology—it's just plain tough to honestly think about oneself as a computer. On the other hand, it is not difficult to imagine an organization, with a conscious leader who consults with various departments and individually handles those issues that require special attention. Moreover, the corporate model raises questions of a more socially relevant nature. Beyond asking how does information get from one stage to another, it would naturally emphasize the effective strategies for successful memory management. Research aimed at discovering strategies that individuals use to manage their "mental corporations" would not only facilitate our understanding of human cognition but might also indicate how information management might be improved.

Current machine models are also said to incorrectly depict human thought as a static, unchanging process (Samson 1981). By viewing the human condition as a static mechanism, cognitive psychology is making an ideological statement about the nature of people that may hinder our ability to observe how thinking can and does change. Comparing the individual to social organizations, on the other hand, focuses on the dynamic quality of human thought.

Depicting the mind as a social organization helps us to think about how society shapes the processes of human thought. Indeed, considerable evidence reveals that our cognitive operations reflect our social environment. For example, Vygotsky (1978) convincingly argues that thoughts are simply the internalization of conversations with others. Even in adulthood, the characteristics of one's internal thinking reflect the nature of the social organizations with which one is associated. For example, Kohn and Schooler (1983) observed a causal relationship between the characteristics of an individual's occupation and the characteristics of his or her internal thought, such that the more personal independence offered by one's occupation, the more apt one is to think independently.

Thinking about the relationship between the social environment and cognitive processes suggests the ways in which different types of mental corporations may be formed. For example, the amount of responsibility that individuals have within a social organization may affect the degree to which they actively supervise the processes occurring within their own mental corporations. Thus, social organizations that have decentralized control, may induce people within those organizations to develop more centralized mental corporations, and vice versa. Other models of cognition never made one think at all about the nature of society and its relationship to the individual.

As Neisser (1982b) aptly notes: "Models of the mind always follow the latest advances in gadgetry" (p.7). The computer model is no exception. As long as we are limited to mechanistic models, undoubtedly we will continue to change and update our models to keep up with modern technology, and undoubtedly people will continue to have difficulty applying these models to their own experience. Anderson (1977) has suggested that cognitive models are equally viable to the degree that they make similar predictions. Indeed, computer models have proven remarkably effective in providing accurate predictions of human performance. However, computer models, as predictively useful as they may be, do not provide a comfortable framework for describing human experience. There may be an important place for computer models in psychology, if only because of the level of precision that they permit. But the future demands that we also develop models that can describe the results of psychology in a framework that can be applied to our own experiences.

By including consciousness in its metaphors, cognitive psychology will be able to describe its findings in a more familiar context thereby allowing for increased communication between psychology and the rest of the world. Scholars previously estranged by psychological models may begin to see how psychological research fits into their own area of expertise, and additionally see how their own findings might apply to psychology. Moreover, nonscientists may finally be able to relate the findings of psychology to themselves. Since one of the goals of psychology is to illuminate the human experience, it seems only fitting that we describe thought processes in terms of humans. In the words of Neisser (1982b): "The dependence of popular conceptions of memory on current technology is obvious enough. Understanding that dependence may help us become free of it." (p.9)

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