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Memory metaphors in cognitive psychology

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In describing memory phenomena in natural language, a spatial metaphor is typically employed. Memories are considered to be objects that are stored in a mind space, and the process of retrieval is conceived as a search for these objects. It is argued that this metaphor has been carried over into many of the popular theories of memory in cognitive psychology and that seemingly diverse theories employ the same underlying set of assumptions. A survey of the analogies that have been used to explain memory is presented and alternatives to the dominant spatial storage and search assumptions are discussed. The spatial metaphor is evaluated, and the role of analogical explanation in psychology is briefly considered. One result of the increasing number of analogical models is the proliferation of hypothetical mental constructs that are only loosely connected to behavioral measures.

It is a natural impulse, when confronted with a phenomenon that we do not understand, to try to relate it to things that we do understand or at least are more familiar with. When our past knowledge can be brought to bear on the new phenomenon, it seems to fall into place, to be readily understood and comprehended. This attempt to gain understanding by relating new information to that which we already know is as apparent in scientific matters as in everyday affairs. Scientists often attempt to explain phenomena that are poorly understood by relating them to more familiar or better understood entities. In short, scientists frequently use analogies, metaphors, and similes when deriving an explanatory account of some phenomenon.

A familiar example is wave theory in physics (e.g., Oppenheimer, 1956). Waves on water exhibit regular, rhythmic changes and several other easily observed characteristics. For example, when waves collide, they may interfere with each other or cancel each other out, or they may add together. That is, waves superpose in a manner that depends on their phase. Another abstract characteristic exhibited by waves is diffraction: When waves pass around an object (or through a hole) that is small with respect to the length of the wave, there are regular blurring effects. In attempting to explain various disparate phenomena, physicists have successfully likened the phenomena to wave motions. Most directly analogous is motion of sound waves, since again there is wave motion in a physical medium and diffraction, interference, and other similar properties (e.g., reflection from a surface also occurs). The extrapolation of the analogy to light is somewhat less direct, since there is no substrate of matter in motion. Nonetheless, the analogy is still profitable, since the abstract properties of diffraction, interference, superposition, and reflection are still exhibited. A theory based on this analogy is able to predict the behavior of light accurately. The waves of atomic mechanics, of wave mechanics, are even more abstract examples of the analogy to waves in physical matter. They are supposed to occur in multidimensional space, they are not directly observable, and they are represented by complex numbers that are not directly measurable. Yet the same structure and relations are used as with the actual physical waves, and the same abstract properties of diffraction and so on are exhibited.

This article is devoted to a discussion of analogies employed in models in cognitive psychology, in particular those employed in an attempt to understand the phenomena of human memory. The paper begins with consideration of how memory phenomena are accounted for, to the extent that they are, in common language. It is concluded that one type of metaphor is primarily employed to explain memory phenomena in everyday discussion. The major part of the paper presents a listing and discussion of most of the analogies that have been employed by psychologists and philosophers attempting a more formal characterization of memory. The majority of these analogies are of the same type employed in everyday language; the ideas of the psychologists about memory are guided by the same metaphor that has dominated common thinking about the topic. Other approaches to the study of human memory are also discussed, and a few remarks are offered about the effects of the increasing number of analogical models in cognitive psychology.

COMMON CONCEPTIONS OF MIND

Jaynes (1976) puts forth the remarkable thesis that subjective consciousness has evolved only in the last

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2,000-3,000 years. Prior to this, he argues, human behavior was controlled by voices emanating from the right cerebral hemisphere that were perceived as commands from the gods. Regardless of the validity of Jaynes' views on the origins of consciousness, he makes several interesting observations regarding the way people in Western civilization commonly conceptualize consciousness (see especially pp. 48-66). In thinking of consciousness, or more broadly, of mind, we usually resort to a metaphor of an actual physical space, with memories and ideas as objects in the space. We think of our minds as *places* that hold *things*. We speak of *holding* ideas *in mind*, of ideas *being* in the *front* or *back* or *top* of our minds. Ideas may be in the *dark corners* or *dim recesses* of our minds; ideas are difficult to *grasp* or have difficulty in *penetrating* our minds. Some people are said to have *broad* or *deep* or *open* minds, while others' minds are *narrow, shallow,* or *closed*. We should *allow room* for new ideas that must *sink in*. In the second sentence of this article, it was argued that a schema allowing new facts to be interpreted in terms of previous knowledge allows these new facts to *fall into place*. We *keep* or *have* or *hold* ideas and memories *in* mind, or they may be *out* of mind or *beyond* our minds, and so forth.

The language we use to describe our conscious thought processes is often similarly based on the perception of objects as they are seen in physical space. Our ideas may seem *bright, dim, hazy,* or *fuzzy*. We may *approach* a problem from a particular *viewpoint* or *perspective* and then *see* its solution, unless it happens to be *obscure*. A particularly good solution is *brilliant*, while the person who *found* it is described as *brighter* than other *dull* persons who were not *clear-headed* enough to *perceive* the solution, and so on.

Mental processes are often described in terms that apply to actual behavior in a physical space. We speak of *storing* memories, of *searching* for and *locating* them. We *organize* our thoughts; we *look for* memories that have been *lost*, and if we are fortunate we *find* them. The term *recollection* implies that memories are objects left at some earlier time that are now collected again. The adjectives we use to describe mental behavior are similarly borrowed from those used to describe physical behavior, such as *active, nimble,* or *quick* minds on the one hand, and *slow* or *sluggish* minds on the other.

Jaynes (1976) argues that when consciousness was invented, we developed these metaphors likening the mind to a physical space to describe it. The basic function of the metaphor was to provide understanding of something whose qualities were not known (mind and consciousness) by substituting something better understood or more familiar in its place (objects and activity in physical space). Thus the dominant metaphor in common language for mind and consciousness is an actual physical space, perhaps like a large room. When applied to memory phenomena, the analogy between mind and a physical space has two important implications. First, memories or memory traces are considered to be discrete objects stored in particular locations in the mind space. Second, in order to recall information, it is necessary to search for and find these memories. These two assumptions will be referred to as the spatial storage and search metaphors for memory. They are implicit in the way people describe memory in everyday terms, and in the next section it is argued that this view of memory has been carried over by philosophers and cognitive psychologists and made central to our current theories of learning and memory.

MEMORY METAPHORS

Philosophers and psychologists have employed many analogies in attempting to understand the workings of memory. Some of these analogies have been quite casual comparisons, some have been lighthearted and playful, but most have been serious attempts to develop a model or theory of human memory. These models or theories have often been based on an analogy between memory and some object. Presented in Table 1 is a fairly complete, but certainly not exhaustive, list of memory analogies produced by psychologists and philosophers. The list is divided into three subgroups. The largest subgroup is labeled "Spatial Analogies," since each of the analogies in this column assumes that memories are deployed in some kind of space when stored. In each case, there is a comparison between memory and some object or objects. Since the memories are stored by distribution in the mind space, it is common to consider the retrieval process as a search for memories stored in this space, just as we can search for lost objects. The same assumptions are embodied in the group labeled "Spatial Theories." Each of these theories seems to agree that memories can be characterized as distributed across some conceptual space, even though no particular object in the external world is employed to characterize this representation. The other group of analogies is not characterized by the idea that memories are deployed in space. This group is quite small relative to that of the spatial analogies. Each group of analogies will be considered in turn.

Spatial Analogies With Search

Perhaps the earliest formal analogy used to help understand learning and memory phenomena was the wax tablet, or more strictly, the application of a seal to wax. Both Aristotle and Plato used this analogy. In a famous passage in the *Theaetetus* concerning the nature of knowledge and the possibility of false judgment, Plato ascribes to Socrates the following statements (translated by Hamilton, 1961, p. 897): "Imagine, then, for the sake of argument, that our minds contain a block of wax, which in this or that individual may be larger or smaller, and composed of wax that is comparatively pure or muddy, and harder in some, softer in others, and sometimes of just the right consistency . . . . Let us

Table 1

A. Spatial Analogies With Search
wax tablet (Plato, Aristotle)
gramophone (Pear, 1922)
aviary (Plato)
house (James, 1890)
rooms in a house (Freud, 1924/1952)
switchboard (see John, 1972)
purse (G. A. Miller, 1956)
leaky bucket or sieve (G. A. Miller, 1956)
junk box (G. A. Miller, 1963)
bottle (G. A. Miller, Galanter, & Pribram, 1960)
computer program (Simon & Feigenbaum, 1964)
stores (Atkinson & Shiffrin, 1968)
mystic writing pad (Freud, 1940/1950)
workbench (Klatzky, 1975)
cow's stomach (Hintzman, 1974)
pushdown stack (Bernbach, 1969)
acid bath (Posner & Konick, 1966)
library (Broadbent, 1971)
dictionary (Loftus, 1977)
keysort cards (Brown & McNeill, 1966)
conveyer belt (Murdock, 1974)
tape recorder (see Posner & Warren, 1972)
subway map (Collins & Quillian, 1970)
garbage can (Landauer, 1975)
B. Other Spatial Theories
organization theory (Tulving, 1962)
hierarchical networks (G. Mandler, 1967)
associative networks (Anderson & Bower, 1973)
C. Other Analogies
muscle ("strength") (Woodworth, 1929)
construction (Bartlett, 1932)
reconstruction of a dinosaur (Neisser, 1967)
levels of processing (Craik & Lockhart, 1972)
signal detection (Bernbach, 1967)
melodies on a piano (Wechsler, 1963)
tuning fork (Lockhart, Craik, & Jacoby, 1976)
hologram (Pribram, 1971)
lock and key (Kolers & Palef, 1976)

Note–Lists of entities to which memory has been compared are in the A and C sections. Section A contains analogies in which memory is generally considered to be a receptacle containing objects. In Section B are other theories that have a spatial character, but without an explicit object of comparison. In Section C are listed other analogies that have been used in explaining memory.

call it the gift of the Muses' mother, Memory, and say that whenever we wish to remember something we hear or conceive in our own minds, we hold this wax under the perceptions or ideas and imprint them on it as we might stamp the impression of a seal ring. Whatever is so imprinted we remember and know so long as the image remains; whatever is rubbed out or has not succeeded in leaving an impression we have forgotten and do not know."

Aristotle developed the analogy further to account for differences in learning and retention. With some people, "the design makes no impression because they are worn down like old walls in buildings, or because of the hardness of that which is to receive the impression . . . . For a similar reason neither the very quick nor the very slow appear to have good memories; the former are moister than they should be, and the latter harder; with the former the picture has no permanence, with the latter it makes no impression" (quoted in Yates, 1966, p. 33).

The wax-tablet analogy has led scholars to argue that the classical Greek view of mind was a passive one, in which experience is simply imprinted on humans in an automatic fashion. However, Plato's fanciful aviary or "birdbrain" analogy is much more in tune with the active, constructive view of the human mind currently in vogue in cognitive psychology. This metaphor is presented in an interchange between Socrates and Theaetetus shortly after the seal-and-wax analogy. Interestingly, the topic under discussion was the nature of knowing and the distinction between possessing and having knowledge. Socrates asks Theaetetus to consider if possessing knowledge is not "like a man who has caught some wild birds–pigeons or what not–and keeps them in an aviary he has made for them at home . . . . Once more then, just as a while ago we imagined a sort of waxen block in our minds, so now let us suppose that every mind contains an aviary stocked with birds of every sort, some in flocks apart from the rest, some in small groups, and some solitary and flying in any direction among them all . . . . When we are babies we must suppose this receptacle empty, and take the birds to stand for pieces of knowledge. Whenever a person acquires a piece of knowledge and shuts it up in his enclosure, we may say he has learned or discovered the thing of which this is knowledge and this is what 'knowing' means" (from Hamilton, 1961, p. 904).

The aviary view employs an explicit search process for retrieval. Socrates asks Theaetetus to think of the person as "hunting once more for any piece of knowledge that he wants, catching and holding it, and letting it go again" (Hamilton, 1961, p. 904). This brings about the distinction between possessing and having knowledge. Possessing knowledge is like having a bird in the enclosure somewhere; in Tulving and Pearlstone's (1966) somewhat more recent terms, such birds are like information that is available in memory, but which may not be accessible or retrievable. Having knowledge is like recapturing the birds and holding them in hand. Thus the basic distinction is one of having something currently in consciousness or possessing it in some larger store (or aviary). The acquisition and retrieval of information is conceived as an active process. Errors are possible as when "in hunting for some particular piece of knowledge, among those that are fluttering about, he misses it and catches hold of a different one . . . as he might catch a dove in place of a pigeon" (Hamilton, 1961, p. 906).

The wax-tablet and aviary analogies are two of the best known attempts to account for human memory that have been introduced by philosophers. A great many more spatial analogies have been used by philo-

sophers and rhetoricians and are documented by Yates (1966). Thus the spatial analogies in Table 1 could easily be increased from this source. However, I will skip to a consideration of spatial analogies used by psychologists. Once again, the list is not exhaustive.

Two of the most famous early psychologists, William James and Sigmund Freud, proposed that memory could be compared to a house, with specific memories likened to objects in the house. Coupled with this spatial storage metaphor is the accompanying idea that utilization of information in memory is accomplished by a search process. As James (1890, p. 654) wrote: 'We make search in our memory for a forgotten idea, just as we rummage our house for a lost object. In both cases we visit what seems to us the probable *neighborhood* of that which we miss. We turn over things under which, or within which, or alongside of which, it may possibly be; and if it lies near them it soon comes to view."

Freud similarly proposed the metaphor of a house to clarify his ideas on the unconscious, preconscious, and conscious aspects of mind and what the concepts of repression and censorship mean in his system. Again, the metaphor is deliberately a spatial one.

"The crudest conception of these systems is the one we shall find most convenient, a spatial one. The unconscious system may therefore be compared to a large ante-room, in which the various mental excitations are crowding upon one another, like individual beings. Adjoining this is a second, smaller apartment, a sort of reception-room, in which consciousness resides. But on the threshold between the two there stands a personage with the office of doorkeeper, who examines the various mental excitations, censors them, and denies them admittance to the reception-room when he disapproves of them . . . . Now this metaphor may be employed to widen our terminology. The excitations in the unconscious, in the ante-chamber, are not visible to consciousness, which is of course in the other room, so to begin with they remain unconscious. When they have pressed forward to the threshold and been turned back by the doorkeeper, they are 'incapable of becoming conscious'; we call them then repressed. But even those excitations which are allowed over the threshold do not necessarily become conscious; they can only become so if they succeed in attracting the eye of consciousness. This second chamber therefore may be suitably called the preconscious system. In this way the process of becoming conscious retains its purely descriptive sense. Being repressed, when applied to any single impulse, means being unable to pass out of the unconscious system because of the doorkeeper's refusal of admittance into the preconscious. The doorkeeper is what we have learned to know as resistance in our attempts in analytic treatment to loosen the repressions.

"Now I know very well that you will say that these conceptions are as crude as they are fantastic and not at all permissible in a scientific presentation . . . . At the moment they are useful aids to understanding like Ampere's manikin swimming in the electric current, and, in so far as they do assist comprehension, are not to be despised. Still, I should like to assure you that these crude hypotheses, the two chambers, the doorkeeper on the threshold between the two, and consciousness as a spectator at the end of the second room, must indicate an extensive approximation to the actual reality" (Freud, 1924/1952, pp. 305-306).

Turning to theorizing of more recent times, when psychology had become an experimental science, we see that there is a remarkable carryover of the spatial storage and search metaphors that marked the prescientific period. Thorndike (1898) argued that rewards "stamped in" the preceding behavior, thus implicitly endorsing a metaphor similar to that of the wax tablet. In a variant of the wax-tablet analogy with suitable technological updating, Pear (1922, pp. 3-7) likened memory to a gramophone or record player. The registration of sounds by a needle held in contact with a revolving disk of soft wax was considered analogous to the process of "impressing an experience on the mind" (p. 3). Forgetting was seen as due to the decomposition of the wax, or to cracking the record, and recall was likened to playing the record on the gramophone and depended on the sharpness of the needle, and so on. Another popular view early in this century compared the brain to a telephone switchboard in which connections are made between stimuli and responses. John (1972) reviews and criticizes this point of view.

Since the mid-1950s, interest in the study of human memory has exploded, and with few exceptions the theories and models have embodied the spatial storage and search metaphors. Some of the analogies employed have been of local usefulness, making simply one point. For example, when G. A. Miller (1956) compared the storage of memories to carrying coins in a purse in what he described as a "farfetched analogy," he was simply making concrete the idea that the amount of information (in the technical sense) carried by the stimuli did not seem to matter much in recall. He wrote, "It is as if we had to carry all our money in a purse that could contain only seven coins. It doesn't matter to the purse, however, if these coins are pennies or silver dollars" (G. A. Miller, 1956, p. 131). Obviously, we would want, then, to carry silver dollars rather than pennies, just as when remembering we want to employ informationally rich rather than poor units. Thus the coins-in-the-purse analogy was not intended to serve as a general metaphor for memory, but only to make a limited point. The same is true for G. A. Miller's other fanciful analogies, such as his distinction among leaky-bucket, cross-talk, standing-room-only, and sabotage hypotheses for forgetting (1956, p. 133). The junk-box hypothesis must also be mentioned in this regard (G. A. Miller, 1963), as well as the implicit comparison of memory to a bottle, when it is argued that "it is not storage, but retrieval, that is

the real bottleneck in verbal learning" (G. A. Miller, Galanter, & Pribram, 1960, p. 137).

The remainder of the analogies in the A section of Table 1 were intended as more general models of memory. Many of these are based to some extent on the computer analogy for human cognition that has swept cognitive psychology. The analogy is usually between the human mind and the entire computing system, but the memory structure for such a system is always spatial. This is true not only of direct simulation theories such as that of Simon and Feigenbaum (1964), among numerous others, but also of other models that were more indirectly inspired by the computer metaphor.

One general characterization of memory that has guided research and provided theoretical dissension over the last 15 years is the idea that it is useful to describe memory as composed of separate "stores." Waugh and Norman (1965) borrowed the terms primary and secondary memory from James (1890), but most people seem to follow the terminology introduced by Atkinson and Shiffrin (1968) and Glanzer and Cunitz (1966) by referring to the two hypothetical stores as the short-term store and the long-term store. In these theories, information is generally considered as being held in the short-term store for a brief period of time, during which it has a certain probability of being transferred to a long-term store, depending on the processing it receives while maintained in short-term store. A great deal of evidence has been presented supporting this dichotomy (e.g., Glanzer, 1972), but most of it can be interpreted more neutrally as agreeing with the idea that there are two components in recall (Craik, 1968), without necessarily identifying these components as reflecting separate stores.

The idea of separate stores in human memory has been derived partly from the various memory stores found in computers. Psychologists have found it quite difficult to confine their explanatory efforts to only two stores. It is common to postulate peripheral iconic and echoic stores to briefly hold visual and auditory information, respectively (Atkinson & Shiffrin, 1968). Hunt (1971) also added an "intermediate-term memory" to his system. Tulving (1972) has pointed out that "in a recent collection of essays on human memory edited by Norman (1970) one can count references to some twenty-five or so categories of memory if one is willing to assume that any unique combination of an adjectival modifier with the main term refers to something other than any of the referents of other such unique combination . . . . Although it may be difficult to determine the exact number of items in a complete list of categories of memory, we would probably not be far off the mark if we doubled the number found in Norman's volume" (p. 382). Tulving then adds two more categories, episodic and semantic memory. While all these categories are not considered different memory stores, many are.

With information residing in all these different memory stores, it is quite natural to conceive of the process whereby needed information is retrieved as a search process guided by an "executive" or homunculus (e.g., Shiffrin, 1970; Shiffrin & Atkinson, 1969). The executive or homunculus must *look* through the various memory *stores,* attempting to *find* information if it has been *lost.* Thus one of the most popular conceptions of memory over the last few years, the one assuming separate memory stores, embodies both the spatial storage and search metaphors.

An anticipation of the distinction between short-term and long-term storage other than that of James (1890) was provided in Freud's (1940/1950) metaphor of memory as a mystic writing pad. The mystic pad that Freud referred to is familiar to most of us as a child's toy on which one can write on a piece of celluloid that rests on top of a hard slab. A faint imprint is also made on the slab. When one lifts the sheet, the writing disappears, but the imprint on the slab remains. Freud proposed that this might serve as a suitable analogy for two different systems of memory traces. "According to this view, we possess a system [perception-consciousness], which receives perceptions but retains no permanent trace of them, so that it can react like a clean sheet to every new perception; while the permanent traces of the excitations which have been received are preserved in 'mnemic systems' lying behind the perceptual system" (Freud, 1940/1950, pp. 176-177). The celluloid sheet is thus like the perception-consciousness system (short-term store) that stores information briefly but then is wiped clean. The underlying tablet corresponds to the permanent system of traces (long-term store).

Three other metaphors have been used more recently to make much the same distinction between short- and long-term storage systems. Broadbent (1971, pp. 376-377) compared memory to the situation of a person sitting at his or her desk with an "in basket" on the desk and a file cabinet near the desk. The in basket corresponds roughly to short-term store, holding things briefly on the basis of their order of occurrence; the file cabinet corresponds to long-term store, where information is classified. The desk top itself corresponds to consciousness or working memory, where the burden of mental work is done, such as transferring information from the in basket to the file cabinet. Similarly, Klatzky (1975, pp. 66-67) likened memory to a workbench in her text. Shelves surrounding the bench contain things as in long-term store, and the bench itself provides the work space of short-term store. Items falling off the bench correspond to those that are forgotten, and so on. (Lest there be any misunderstanding among the students reading her book, Klatzky provided a picture of a workbench.) In a delightful spoof on these types of two-store views, Hintzman (1974) compared memory to a cow's stomach. Functionally, the cow has two stomachs, which Hintzman labeled the short-term

stomach and the long-term stomach, with food transferred from one to the other. This metaphor is invoked when we speak of *digesting* information or *ruminating* over ideas, or when we refer to unpalatable information as *crap* or good ideas as *food for thought*. Hintzman argued that the actual, although unconscious, source of Atkinson and Shiffrin's (1968) theory was the digestive system of the cow.

Bernbach (1969) assumed only one memory store, but he postulated that storage and rehearsal of an experience produced a number of copies, or replicas, of the experience. A loss of replicas was assumed to underlie forgetting, but as long as one replica remained at the time of retrieval, remembering was assumed to occur. "This is analogous to the stack of plates behind a luncheonette counter, which is pushed down as plates are added so that its visible level does not depend on the number of plates in the stack, but only whether or not the stack is empty" (Bernbach, 1969, p. 203). This idea of memory (usually short-term memory) operating like a pushdown stack is represented in other theories, too. Both the replica and pushdown-stack notions are further examples of the spatial storage metaphor.

Another metaphor introduced to explain forgetting in short-term memory was the acid-bath theory of Posner and Konick (1966). By this chemical analogy, storing items in memory was likened to storing objects in a vat of acid, where the traces of the items would tend to lose precision over time. Interference effects were assumed to be reflections of the amount of acid in the vat (the number of other items stored) and its concentration (the similarity of other items to that being interfered with). The analogy may be considered spatial to some degree, since memories were considered objects in the vat. However, in this case the spatial component of the theory is not a central feature.

One of the most persistent questions facing memory psychologists has been an adequate characterization of long-term memory, either memory for personal experiences that are temporally dated or memory for general knowledge (Tulving's, 1972, episodic and semantic memory systems). Both types of memory are generally characterized as very large and complex storage systems. For example, the memory system has been compared to a library (e.g., Broadbent, 1971, pp. 464-466, 473-475; also G. A. Miller et al., 1960, p. 138), in which memories are considered to be stored like books on the shelves and can be searched for and found by having the appropriate addresses for their locations. Similarly, Loftus (1977; see also Katz & Fodor, 1963) argued that semantic memory could be considered to hold the mental equivalent of a dictionary, in which each word that a person knew was stored. According to Loftus, these words or concepts were stored not only in the internal dictionary, but also in associative networks of a hierarchical nature. In a similar vein, Brown and McNeill (1966) argued that words in the mental dictionary "are entered on keysort cards instead of pages and that the cards are punched for various features of the words entered. With real cards, paper ones, it is possible to retrieve from the total deck any subset punched for a common feature by putting a metal rod through the proper hole. We will assume that there is in the mind some speedier equivalent of this retrieval technique" (p. 333). Of course, the computer metaphor for memory that has already been mentioned has similar characteristics, in that there is a large space in which information may be stored.

Two other ingenious models of long-term memory have also been proposed, one for personal experiences (episodic memory) and the other for general knowledge (semantic memory). Murdock (1974, pp. 266-285) proposed that personal experiences (in particular, words presented on a list) could be likened to placing suitcases on a conveyer belt. As each suitcase is placed on the moving belt, it is automatically carried away, with the representation of these experiences thus gradually receding into the distance (past). When a person needs to retrieve information about an experience, such as when a word is presented and the judgment must be made about whether or not the item occurred on the list, Murdock assumed that a person searches from the most recent item backward until the sought-after experience is found, if it was presented in the list. The backward scan is thought to occur at the rather breathtaking rate of 3-5 msec/item, or at about the rate of 200 items/sec. A number of experimental facts taken from recognition memory paradigms agree with Murdock's conceptualization (e.g., Murdock & Anderson, 1975; Murdock, Hockley, & Muter, 1977), although there are difficulties as well. However, the main point for present purposes is that the conveyer-belt model is yet another characterization of memory that fully embodies both the spatial storage and search metaphors. It should also be noted that the conveyer-belt model is similar to other models that assume that experience is coded into memory in a strict temporal order. The gramophone analogy of Pear (1922) has already been mentioned, and the idea that memory storage can be represented as a literal tape recording, an idea considered and rejected by Posner and Warren (1972), among others, is of the same sort.

Another model, this time of our general knowledge, is based on another unusual analogy, this time of the subway maps in the Paris metro (Collins & Quillian, 1970). Collins and Quillian were attempting to model how activation spread within a memory network when people were asked to respond to simple true-false statements as rapidly as possible (e.g., "Oaks have acorns," "Coca-Cola is blue"). In the maps of the Paris metro, if one is in one location and wants to journey to another represented on the map, two buttons on the map are pushed, representing one's present location and desired location. The map lights up briefly with the most direct route between the two points. For various reasons, Collins and Quillian found it useful

to assume that a similar operation occurs in semantic memory. They, among numerous others, find it useful to conceive of the representation of a word in semantic memory as a "node," with various paths linking the nodes. When one is asked to respond "true" or "false" as fast as possible to the statement "Oaks have acorns," it is assumed that the nodes for the two nouns are activated and that the associative path between them lights up as in the Paris metro map. This model allows accurate predictions for some reaction time data, at least for "true" responses to statements. Yet again, the more general point is that the spatial storage metaphor is employed, although a conscious search process is not necessarily implied.

As a final and unflattering example, let us consider Landauer's (1975) comparison of memory to a garbage can. Unlike G. A. Miller's (1963) junk-box notion, Landauer's theory is meant as a general theory of human memory. The memory store is conceived as a large three-dimensional space with numerous storage locations, as in a computer memory. Memories are assumed to be stored randomly, as may be imagined if they are stored by a pointer that moves about erratically in a three-dimensional space. The only order is provided by time; the pointer will leave memories closer to each other if they occur in temporal proximity. Thus when the memory space is searched, there will be no structure to guide the homunculus. The search will occur in all directions from the pointer location. Thus information in memory is not considered highly organized, as in a library; it is thrown in haphazardly like refuse into a garbage can. The model can mimic several types of data from the psychology of memory, but given the assumptions of random storage and nondirected retrieval, it may prove difficult to account for other well-known phenomena, such as organizational factors in recall (but see Landauer, 1975, pp. 522-523). Yet the garbage can theory, despite some of its unusual features, nonetheless conceives of memory in the usual way as distributed in spatial locations, with a search process used for recovery of information.

Other Spatial Theories

The analogies discussed in the previous section employed some particular object to represent a likeness to memory. The usual assumption was that memories could be conceived as discrete objects distributed across some space (the spatial storage assumption) for which one must then search during recall (the search assumption). There are several other popular theories of memory that embody these same assumptions, but they do not specify any particular objects to which memory is compared. Most generally, these theories could be cast under the umbrella of organizational theories of memory. Organization theory was initiated primarily by Tulving (1962; but also G. A. Miller, 1956). The basic tenet of organization theory is that in order to learn information, even a list of apparently unrelated words, it is necessary to organize these words into "chunks," or higher order memory units. This approach assumed that the arrangement of information in memory is critical in determining recall. Although early organizational theories did not elaborate on the processes underlying utilization of the stored information, more recently it has been assumed that the organization at storage also guides a search process at retrieval. G. Mandler (1967), among numerous others, has found it convenient to represent the organization of information in terms of a mental hierarchy of elements. People are thought to employ subjective categories in storing and retrieving information. The general representation of these categories is assumed to occur at one level of the mental hierarchy, with particular elements of the category nested underneath the general representation. Thus one particular spatial organization is assumed to underlie storage and guide retrieval.

When organizational theories of memory were first advanced, their proponents went to rather great lengths to dissociate this "new" approach from traditional associative accounts of learning and memory. However, with a liberalization of some aspects of associative theory, it has been rather convincingly argued that organizational theories and associative theories have more in common than was originally thought (Postman, 1971, 1972). At any rate, there are currently very explicit associative theories that embody, as do the organizational theories, the spatial storage and search assumptions (e.g., Anderson & Bower, 1972, 1973). Typically, these theories assume that memory can be represented, much as in the subway-map model, as a great network of nodes that represent word concepts and are linked by associative paths. Experiences are encoded by marking appropriate nodes and their connecting associative paths. Retrieval consists of searches through the associative network for the desired information. Thus the organizational, hierarchical, and associative theories are all similar in containing the spatial storage and search metaphors, despite the fact that none of them makes an explicit comparison between memory and particular objects.

Further Examples of Space and Search in Cognitive Psychology

There are at least several other uses of the ideas of mind as a space and of retrieval as a search process that are not captured in any of the analogies listed in Table 1.

One dominant conception of the information processing approach to cognition is that consciousness can be considered as a mental space in which various mental operations are performed. "If some task cannot be performed simultaneously with another processing task, then some aspect of both tasks is said to take space" (Keele, 1973, p. 3). Employing a slightly different, but still spatial metaphor, Kahneman (1973) refers to a

"pool of effort" that may be tapped. These examples are concrete representations of the more abstract idea, borrowed from information theory, of information channels having capacity that may be overloaded. In experimental psychology this has led to many studies concerned with subjects' abilities to process information when the "space" of consciousness is overloaded by two tasks (see Kantowitz, 1974, for a review and discussion). This is but one other example of how the concept of consciousness as a space pervades cognitive psychology.

The concept of memory search is similarly pervasive, as is evident from a perusal of models and theories listed in Table 1. Other ideas not listed in Table 1 also embody the search assumption. One example is the great amount of research conducted during the past decade employing a paradigm developed by Sternberg (1966, 1969). Sternberg (1966) modified the typical recognition memory procedure so that people were presented short, subspan lists of material (e.g., the digits 6, 3, 7, and 1) and were then given a test digit that either was or was not a member of the set. The person was to respond as quickly as possible to indicate whether or not the test item was a member of the set. Sternberg (1966) reported that reaction time to decide whether or not the test item was a member of the set increased linearly with set sizes from one to six, with a slope of about 38 msec. How are we to account for this fact?

Sternberg's (1966) paradigm has spawned a vast amount of research and theorizing in the intervening 14 years. However, until recently, every proposed explanation of the phenomena from this paradigm employed the search metaphor. In fact, the more general statement can be made that until recently there has been no way to think of the retrieval process underlying reaction time differences other than as a matter of search, or "scanning." If it takes longer to respond to one test item than to another, surely this is a reflection of the different amounts of time involved in finding the item. The theoretical arguments have revolved around whether the search process terminates when the desired item is found or the process grinds on exhaustively even after the sought-for item is discovered.

Both of these arguments are predicated on the assumption that the search process is sequential or serial, or that items are searched individually in some order. The other source of controversy has been about whether the search is in fact serial or occurs simultaneously, in parallel. By the latter idea, the subject "searches" all items at the same time, attempting to accumulate evidence regarding whether any of them is the same as the test item. Thus the theoretical controversy has been about what type of search process occurs, not whether or not the phenomena are best explained by the search metaphor in the first place. The title of Sternberg's (1966) original paper was "High-Speed Scanning in Human Memory," and the general area has come to be referred to as "memory scanning." As noted by Jaynes (1976), a perceptual analogy is used for mental operations, so that we are "seeing" or "scanning" the contents of our mental space, or memory.

EVALUATION OF THE SPACE AND SEARCH METAPHORS

The conception of the mind as a mental space in which memories are stored and then retrieved by a search process has served as a general and powerful explanation of the phenomena of human memory. There is currently no other general conception of the mind or memory that rivals this view. As we have seen, a great number of memory theories embody the spatial storage and search assumptions. These ideas have been taken so much for granted that few investigators have criticized the general framework. Two important exceptions to this statement are represented by the papers of Bransford, McCarrell, Franks, and Nitsch (1977) and Wechsler (1963). Some of Wechsler's (1963) ideas are discussed below, but in general he simply dismissed the spatial storage and search assumptions without arguing against them.

Bransford et al. (1977) refer to the spatial storage and search metaphors as "the memory metaphor," and they argue that "the 'searching for traces' conceptualization of memory (hereinafter called the *memory metaphor*) may simply be one of many possible metaphors, and it may not be the most fruitful metaphor" (p. 432). As critics of the customary ways of conceptualizing memory, they do not argue, of course, that experience does not have effects on the nervous system that persist and affect behavior. In this limited sense, there is certainly "storage" of the experience. The argument is about whether or not the best way to conceive of this persistence and utilization is the deposit of discrete entities (traces, engrams, tagged nodes, etc.) that are later searched out and used.

Bransford et al. (1977) refer to several types of experimental results that they believe embarrass the spatial storage and search assumptions. One of the most telling difficulties for search theories is the problem of "knowing not" (Kolers & Palef, 1976), or knowing that one does not know some fact. By most assumptions of memory search, ignorance of some fact should be signaled by a search of memory for the fact and a failure to find it. If such were the case, then people should take longer to respond that they do not know something than that they do. In general, this is true, but several experiments have shown that people can reject false information with high confidence faster than they can respond to true facts. This has been shown in recognition memory for words in recently presented lists (Murdock & Dufty, 1972), as well as for facts from semantic memory (Kolers & Palef, 1976). For example, one might be faster in rejecting the word "granite" as a bird than one would be in verifying "ostrich." Such a

result would be difficult to reconcile with theories maintaining that we decide that a term does not refer to a bird by searching through all the types of birds we know and failing to find the sought-for term (but see Atkinson, Hermann, & Westcourt, 1974, for a possible solution to this type of problem within a memory search framework).

Kolers and Palef (1976) proposed that recognition occurred by performing a set of analytical operations of the stimulus in an orderly manner, with later operations contingent on the successful completion of earlier ones. The analogy was made to a series of locks and keys for the operations, as noted in Table 1 in the "Other Analogies" category. If a point were reached at which a key did not fit the corresponding "lock" in the stimulus representation (an operation could not be carried out), then "this would result in a block to further analysis, which would signal 'unable to recognize beyond this point.' . . . On this proposal, ignorance could be signalled more rapidly than is allowed for by an exhaustive scan of positive instances" (Kolers & Palef, 1976, p. 557).

Other phenomena discussed by Bransford et al. (1977) may also be difficult to reconcile with spatial storage and search assumptions, but it seems likely that, with modifications of certain assumptions, virtually any fact can be accommodated by some theory employing the spatial storage and search assumptions. Perhaps the main argument for alternative theories is simply that competitors to the dominant theory may lead to interesting new experiments and facts that would not be discovered by following the predominant way of thinking. Such a fruitfulness criterion is one of the main arguments of Bransford et al. (1977) for an alternative to the memory metaphor. However, the spatial storage and search assumptions are so ingrained in our language that such an enterprise may be difficult. At the outset of their chapter, Bransford et al. (1977, p. 432) say that "we shall eventually raise questions designed to prompt *search* for an alternative to the memory metaphor." Two pages later, they suggest "that a different, more fruitful metaphor might be *found*" (italics added in both cases). Unless they were thinking of looking about Nashville for such an alternative, which seems unlikely, they must be referring to a mental search. The search is likely to be difficult, indeed.

ALTERNATIVES TO THE SPATIAL METAPHOR

The spatial and search metaphors have dominated theorizing about human memory, but there are other approaches to the problems of memory, and some of these are currently gaining in popularity and may serve to challenge the spatial metaphor. Two general approaches will be discussed here. In one approach, theorists have based their ideas on analogies that do not embody the spatial storage and search assumptions. However, these other analogies still provide a comparison between the workings of memory and some physical process. In the other approach, theorists have developed abstract theories that do not rest upon a concrete analogy. Such theories may be stated verbally or mathematically. (Of course, there may also be combinations of these approaches, such as when an analogic model is made more specific through quantifying its terms).

Nonspatial Analogies

Listed in Section C of Table 1 are analogies to memory that do not necessarily imply a spatial conception. One idea with a long history is that memory can be usefully compared to muscles, with both varying in strength (e.g., Woodworth, 1929). Just as strong muscles can support heavy objects, strong traces can support good memory performance. The idea that the products of learning (associations, habits, memory traces) can be considered to vary in strength has a venerable history. For example, the concept of habit strength was central to Hull's (1943) theory. The concept of memory trace strength is also a central component to some modern theories (e.g., Wickelgren, 1970; Wickelgren & Norman, 1966). However, it seems fair to say that the idea that memory traces vary in terms of some unidimensional strength is not regarded as useful by most cognitive psychologists. The strength view has been criticized by Anderson and Bower (1972) and Fisher and Craik (1977), among others. With a different intent, the concept of strength is often used in spatial types of theories, as, for example, when one postulates that the strength of representation of an item in long-term store depends upon the amount of processing it received while in short-term store (e.g., Atkinson & Shiffrin, 1968). However, in such uses of strength, the term usually refers simply to the probability of recall or recognition and not to some theoretical entity.

Another historically important theory of memory, and one that has again become an important force in current cognitive psychology, is the construction metaphor introduced by Bartlett (1932, Chapter 10). The basic idea is that remembering involves a construction of memories from available information, rather than a verbatim reproduction of the contents of memory. From remembering a general theme and some details, we construct our memory of an event, such as a story that has been read to us. "Remembering is not the re-excitation of innumerable fixed, lifeless and fragmentary traces. It is an imaginative reconstruction, or construction" (Bartlett, 1932, p. 213). Bartlett used Head's (1920) concept of schema to discuss how memories are represented and used. Bartlett's (1932) idea of schemata seems to have been deliberately abstract, and he did not imply a spatial metaphor in the use of the term. He even complains (Bartlett, 1932, p. 200) about Head's referring to the sensory cortex as "the storehouse of past impressions." According to Bartlett (1932, p. 201), "schema refers to an active organization of past reactions, or of past experiences, which must be supposed

to be operating in any well-adapted organic response. That is, whenever there is any order or regularity of behaviour, a particular response is possible only because it is related to other similar responses which have been serially organized, yet which operate, not simply as individual members coming one after another, but as a unitary mass." Obviously, he intended to keep the schema concept abstract, if not vague.

These abstract ideas of Bartlett (1932) were captured by Neisser (1967) in an interesting analogy put forward in his influential book, in which he argued strongly for a constructivist approach to many of the problems of cognitive psychology. Neisser (1967, pp. 285-286) likened the process of remembering to a paleontologist reconstructing a dinosaur. Just as a paleontologist can construct a complete model of a dinosaur from a few pieces of bone and some knowledge of how they should be put together, so we may reconstruct the memory of a complex event from a few details and the general theme. Neisser (1967, Chapter 11) argues that our original perception of the world is a construction and that what we remember is the constructive act of the initial perception and comprehension. "The present proposal is, therefore, that we store traces of earlier cognitive acts, not the product of those acts. The traces are not simply 'revived' or 'reactivated' in recall; instead, the stored fragments are used as information to support a new construction. It is as if the bone fragments used by the paleontologist did not appear in the model he builds at all—as indeed they need not, if it is to represent a fully fleshed out, skin-covered dinosaur. The bones can be thought of, somewhat loosely, as the remnants of the structure which created and supported the original dinosaur, and thus of sources of information about how to reconstruct it" (Neisser, 1967, pp. 285-286).[1]

What is it that the person constructs in perception and from which the experience is later reconstructed? "Cognitive structures," of course. Neisser (1967, pp. 286-292) discussed such cognitive structures and specifically cautioned against a spatial interpretation of the term when he warned that it "probably is unwise to think of them as filing systems into which specific memories can be put" (p. 287). However, more recently, psychologists who have utilized schemata for representations of connected discourse have used spatial concepts for their representations. Generally, these schemata theories take the form of a hierarchical memory representation that is similar in conception to that of G. Mandler (1967), already discussed under "Other Spatial Theories." Several investigators have attempted to devise grammars for simple stories that include a hierarchical arrangement of the elements of the story that are meant to represent in some sense the way the story is stored (e.g., J. M. Mandler & Johnson, 1977; Rumelhart, 1975; Thorndyke, 1977). The schemata are thought to provide "slots" in memory that are then filled when the story is read or heard (e.g., Thorndyke, 1977, p. 83). As it has been put by others, "comprehension of a message entails filling the slots in the relevant schemata with particular cases in such a way as to jointly satisfy the constraints of the message and the schemata" (Anderson, Pichert, Goetz, Schallert, Stevens, & Trollip, 1977). As in memory for categorized lists of words, such hierarchical schemes are thought to guide memory search at the time of recall. The general point is that the notion of schemata, which was originally quite abstract, has now been developed into another spatial analogy.

Another nonspatial analogy that has been quite influential in recent years is Craik and Lockhart's (1972) levels-of-processing framework. They proposed that memory could be considered a by-product of perceptual processing. Perception of a stimulus was regarded as proceeding through a series of analyses or processing stages, from early sensory processing to later semantic and associative operations. The resultant memory trace may be more or less elaborate or durable, depending on the nature of the perceptual analyses carried out on the stimulus. Thus the basic proposal depends on processing stages' being more or less advanced in a series. The original levels-of-processing formulation has undergone considerable modification and development since the original 1972 proposal (e.g., Craik & Tulving, 1975; Jacoby & Craik, 1979). Although the term "levels" is used, there is no association with levels in some conceptual space, as in the other theories. Terms such as depth of processing and shallow and deep processing that are used in this context refer to the stage of processing in a temporal sequence that is not necessarily distributed across some conceptual space.

The next three analogies in the C section of Table 1 are all based in one way or another on auditory imagery. The spatial analogies of the A section are almost entirely of concrete objects, of things that can be seen and visually imagined. It is not surprising that nonspatial metaphors are sometimes based on auditory imagery, since the stimuli in audition are usually spread out in time rather than in space. There are also a few terms associated with memory that are based on auditory imagery, such as rehearse and recall.

The primary use of signal detection theory in psychology has been for the modeling of psychophysical processes involved in detection of auditory signals in a noisy environment. The application of signal detection theory to problems of human memory (e.g., Bernbach, 1967) has had a certain utility, especially in the study of recognition memory. However, rather than provide an alternative to search and spatial storage theories, the signal detection process has been incorporated into these theories as that process by which a subject decides whether or not a memory that has been "found" should be recalled (e.g., Anderson & Bower, 1972). This is supposedly accomplished by comparing the strength of the memory and some hypothetical noise distribution

with the distribution of noise alone. Depending on the location of the subject's criterion, the decision is reached that the experience is either "old" or "new." Thus signal detection theory, although not necessarily implicating a search process in retrieval, has been easily integrated into such an approach.

One auditory metaphor that does not assume search and is gaining currency today is the resonance or broadcast metaphor. This can be traced back at least to David Hartley's concept of vibratiuncles, which were "diminutive vibrations" and are "the physiological counterpart of ideas" (Boring, 1950, p. 196). The lasting impression created by external experience was thought to reside in these small vibrations. A similar view was expressed by Semon (1921) in his concept of homophony (see Schacter, Eich, & Tulving, 1978), but more modern conceptions of the same idea have been introduced by Wechsler (1963), among others. Wechsler explicitly rejected the storage and search metaphors for memory: "Memories, like perceptions and eventually sensations, have no separate existences. The memory of what you saw yesterday has no more existence until revived than the pain you felt in your arm before it was pinched . . . . In short, for the experiencing individual, memories do not exist before they are revived or recalled. Memories are not like filed letters stored in cabinets or unhung paintings in the basement of a museum. Rather, they are like melodies realized by striking the keys on a piano. Ideas are no more stored in the brain than melodies in the keys of a piano" (1963, pp. 150-151).

Wechsler's (1963) ideas seem rather extreme, since we are so accustomed to the spatial storage and search metaphors for memory. What does it mean to say that memories are not stored? The same basic idea of retrieval as a matching or resonance process has been used by a number of other psychologists (e.g., J. A. Anderson, 1973; Bower, 1967, 1972; Flexser & Tulving, 1978; Lockhart, Craik, & Jacoby, 1976; Norman, 1968; Ratcliff, 1978). For example, Lockhart et al. (1975) argued that information presented as cues at retrieval could be conceived as resonating with appropriate information to produce the desired memory. They compared the process of retrieval to the operation of a tuning fork. When a tone of a particular frequency is sounded in the presence of a bank of different-sized tuning forks, the appropriate one will vibrate sympathetically. Similarly, a retrieval cue may be thought to resonate to past episodes of the same "frequency." (There is a counterpart to the resonance metaphor in common language expression: When we hear something that serves as an effective retrieval cue for some information, we say that it "rings a bell.") Ratcliff (1978) has employed the same tuning-fork analogy to make quite detailed predictions as to how retrieval occurs in several different recognition memory paradigms. The resonance metaphor will certainly be developed further and may become a genuine competitor to the search metaphor in explaining retrieval from memory. However, it may be argued that theories based on resonance are formally identical to spatial storage and search theories if one assumes an unlimited capacity, parallel search process. This may turn out to be so; certainly, the problem of identifiability of structures and processes in cognitive psychology is not easily solved (J. R. Anderson, 1978; Townsend, 1974). Nonetheless, the idea of matching or resonance processes in memory may provide a new perspective and lead to experimental approaches that would not have been thought of in the absence of this idea.

A final interesting analogy representing memory operations is the holographic (or optical filter) analogy of Pribram (1971, Chapter 8). When a film record is properly exposed, it "constitutes an *optical filter* in which information from each point in the visual field is stored throughout the filter itself" (Pribram, 1971, p. 145). We may similarly assume that information is represented in all, or at least many, parts of the brain and that successful retrieval will depend on access to any part. This approach thus embodies the spatial metaphor, but with the assumption that storage occurs in numerous locations. The reason for not placing the holographic analogy in the section labeled "Spatial Analogies With Search" in Table 1 is that the retrieval process involved is not a search process, but one more akin to a resonance process. "Thus when transilluminated by a coherent light source, an optical filter reconstructs the wavefronts of light which were present when the exposure was made. As a result, a virtual image appears exactly as did the visual scene during the exposure" (Pribram, 1971, pp. 146-147). It remains to be seen, as in the case of the resonance metaphors, whether or not the holographic analogy will eventually provide us with a coherent account of numerous memory phenomena, as do the spatial storage and search metaphors. Cavanaugh (1976) has made a start in this direction.

Abstract Theories

Most of the ideas about memory discussed thus far have been based on concrete analogies between particular objects or systems and memory. The most typical sort of explanation in cognitive psychology seems to be based on just such analogical reasoning. There has long been a debate over the proper role of models and analogies in scientific explanation (e.g., Hesse, 1966), although there has been surprisingly little carryover of this debate into psychology. On the one hand, it has been argued that proper scientific theories should be formal and abstract; on the other, it has been argued that concrete analogies and models are crucial to the theoretical endeavor. Quotations from two physicists should serve to clarify these positions. Duhem (1914/1954, Chapters 4 and 5) contrasted abstract,

systematic theories and mechanical models in electrostatics:

"This whole theory of electrostatics constitutes a group of abstract ideas and general propositions, formulated in the clear and precise language of geometry and algebra, and connected with one another by the rules of strict logic.

"[On the other hand,] here is a book intended to expound the modern theories of electricity and to expound a new theory. In it are nothing but strings which move around pulleys, which roll around drums, which go through pearl beads . . . toothed wheels which are geared to one another and engage hooks. We thought we were entering the tranquil and neatly ordered abode of reason, but we find ourselves in a factory."

Other physicists have argued that concrete analogies or models have a proper role in the genesis of theoretical speculation but may then be discarded once they have led to the abstract theory. Campbell (1920) argued against this logic from the example of the billiard-ball model of the kinetic theory of gases. He concluded that "analogies are not 'aids' to the establishment of theories; they are an utterly essential part of theories, without which theories would be completely valueless and unworthy of the name. It is often suggested that the analogy leads to the formulation of the theory, but that once the theory is formulated the analogy has served its purpose and may be removed or forgotten. Such a suggestion is absolutely false and perniciously misleading" (Campbell, 1920, p. 129).

Although there has been little debate concerning the relative merits of abstract theorizing to concrete modeling in the psychology of memory (but see Tulving, 1979), there are a number of abstract characterizations of the phenomena of human learning and memory. It is not possible to review these here in any exhaustive manner, but only to point out a few examples. It may be profitable to consider the more abstract theories as belonging to one of two classes, verbal theories or mathematical theories. Verbal theories provide an abstract description of memory and allow one, at best, to make only qualitative predictions of behavioral phenomena. Examples of influential verbal theories would include Tulving and Thomson's (1973) encoding specificity hypothesis, Paivio's (1969) dual coding hypothesis, and the venerable interference theory of forgetting (e.g., Postman & Underwood, 1973). Many of the theories based on analogies listed in Table 1 are, of course, also stated only in verbal form, although often these theories are further specified through mathematical terms as they are developed.

The other class of abstract theories is mathematical models, which have the advantage of providing quantitative as well as qualitative predictions. Perhaps the most notable example of this approach in the study of learning and memory is the stimulus-sampling theory of Estes (1955, 1959), which has been applied in diverse situations (e.g., Bower, 1967, 1972; Flexser & Tulving, 1978). The heart of this approach is that during learning there is a sampling of elements (or features) that underlie the learning experience. Such elements or features are represented abstractly, and thus no particular concrete analogy is embodied. Thus the stimulus-sampling theory and other abstract mathematical theories do not necessarily utilize the same assumptions as the spatial storage and search assumptions, although it is probably possible to recast them in terms of space and search.

Most theoretical efforts in cognitive psychology today are derived from analogies such as those in Table 1. Abstract theorizing does not seem as popular an approach as concrete model building. An inquiry into why this is so would be of interest. Kaplan (1964, Chapter 31) has pointed out a number of useful features of models, not the least of which is that they can usually be easily understood and readily communicated to others. As Freud (1924/1952, p. 306) argued, in the passage quoted earlier, analogies "in so far as they do assist comprehension, are not to be despised."

THE PROLIFERATION OF MENTAL MECHANISMS

The growth of numerous analogies and models for cognition in general and human memory in particular has provided for a proliferation of the number of unobservable entities and processes that are believed to populate the human mind in the service of mediating between stimuli and responses. Some years ago, Underwood (1972) contributed a chapter intended to answer the question posed by its title: "Are we overloading memory?" He began with these sentences:

"Ten years ago it might have been said that most conceptualizations of memory were impoverished or simplistic in that they did not at all reflect the variety of memory phenomena evident even to the casual observer. If an increase in the size of the technical or semitechnical behavioral vocabulary signals escape from conceptual poverty, we have become liberated. Memories now have attributes, organization, and structure; there are storage systems, retrieval systems, and control systems. We have iconic, echoic, primary, secondary, and short-, medium-, and long-term memories. There are addresses, readout rules, and holding mechanisms; memories may be available but not accessible (or is it the other way?). Our memories are filled with T-stacks, implicit associational responses, natural-language mediators, images, multiple traces, tags, kernel sentences, markers, relational rules, verbal loops, and one-buns" (Underwood, 1972, p. 1).

After reviewing work in five different areas concerned with coding theory in one way or another, Underwood (1972, p. 21) summarized: "One possible conclusion kept emerging, a conclusion that might characterize many of our theoretical approaches: Our models and

theories are overloading the subject's memory." If one doubts Underwood's statement, let me invite him or her to peruse the mechanisms involved in the models listed in Table 1, which are only a fraction of those available in cognitive psychology.

Cognitive psychologists attempt to account for the relations between input and output events (stimuli and responses) by postulating a variety of mental mechanisms intervening between stimulus and response. Often, these explanations are based on some sort of correspondence metaphor. It is assumed that the intervening processes or structures correspond to others that are more directly observable. The observed relations between the environmental manipulations and behavior are then "explained" by reference to these structures and processes. The list of putative physical processes and structures intended to correspond to mental events is discouragingly long. Many of the hypothetical processes have the unfortunate character of referring to human-like activities. Theorists repeatedly have something or someone in the mind storing, searching, matching, locating, identifying, detecting, discriminating, making decisions, and so on. Tulving (1979, p. 29) has argued that "because of their failure to reduce uncertainty and their typical lack of plausibility, correspondence models do not bring us any understanding of memory or its phenomena. They may provide a sense of accomplishment to their creators and some feeling of closure to those who do not question their rationale, but it is difficult to imagine how they would contribute to conceptual progress in our field."

Such complaints as those of Tulving (1979) and Underwood (1972) apparently are not being heeded by many other cognitive psychologists. At least, there seems to be no tendency to check the proliferating mental mechanisms.

Early in the history of cognitive psychology, mental constructs were introduced on the basis of introspective reports. The fate of this endeavor is well known. Yet today we see a return, in some ways, to these earlier times, because it is again considered permissible to introduce mental constructs on intuitive or rational grounds. On rational grounds, constructs have been borrowed from linguistics and, especially, computer programs simulating human thought. Others have proposed theories with numerous mental constructs based only on intuitive grounds (e.g., Rumelhart, Lindsay, & Norman, 1972). In some areas the theoretical enterprise of cognitive psychology is becoming top-heavy with constructs that bear little relation to the data base.

This proliferation of mental entities may eventually cause another thorough examination of the rationale of attempting to explain behavior in such a manner. What is the necessity for these proliferating mental fictions? Of course, Skinner and others have argued for years that there is no need for them whatsoever, that mentalistic constructs were appropriately dismissed from psychology and that the renaissance of cognitive psychology is a red herring (e.g., Skinner, 1978, Chapter 8). Although Skinner and others who share his view have not undertaken a detailed analysis of the kinds of memory experiments that cognitive psychologists perform, the outline of their interpretation of such results is fairly predictable. "The extensive experiments by cognitive psychologists on accessibility can all be reinterpreted in terms of probability . . . . Techniques of recall are not concerned with searching a storehouse of memory but with increasing the probability of responses . . . . The metaphor of storage in memory, which has seemed to be so dramatically confirmed by the computer, has caused a great deal of trouble. The computer is a bad model—as bad as the clay tablets on which the metaphor was probably first based. We do make external records for future use, to supplement defective contingencies of reinforcement, but the assumption of a parallel inner record-keeping process adds nothing to our understanding of this kind of thinking" (Skinner, 1976, p. 122).

The argument against internal constructs is that they add nothing new to the observations under study and simply involve circular reasoning. For example, if an experimental manipulation increases recall over some other set of conditions, why say that the manipulation encouraged better storage or search for the stimuli? With only one operational way of defining some concept, such as memory storage, the construct is used in a circular manner and is superfluous.

When mental constructs were reintroduced into experimental psychology in the 1950s, they were used sparingly and only when ancillary requirements were met. Garner, Hake, and Eriksen (1956) introduced the concept of converging operations as an appropriate logic for supporting mental constructs. They considered the problem of perception, but the case is similar for the existence of any other construct that cannot be observed directly and therefore must be inferred. The basic argument is that it is useful to introduce a mental construct—or any unobservable construct in any area of science—when there are several independent measuring operations, all of which converge on the same construct. If several different types of evidence can all be explained by introducing an unobservable construct, then it is useful to do so. In physics, there has never been direct observation of an electron or a black hole in space, but assuming the existence of these entities serves to account for a number of different kinds of phenomena. In both physics and psychology, the inferred existence of the unobservable construct is indirect, but it is based on several different types of observations. N. E. Miller (1959, pp. 276-297) argued with similar logic for the introduction of intervening variables in the study of behavior.

The logic of converging operations has been widely

used in supporting the existence of a variety of mental constructs. Paivio (1975) has referred to what is essentially the use of converging operations in studying mental representations as "neomentalism." This approach differs from behaviorism by emphasizing the study of mental operations and representations, and it differs from the old introspective mentalism by employing objective, behavioral methods that provide converging evidence for the mental constructs. Paivio (1975) illustrated the approach of neomentalism with reference to the variety of different techniques that have been employed to study mental imagery.

If the general approach that Paivio (1975) refers to as neomentalism were rigorously applied throughout cognitive psychology, a dramatic change would be evidenced in a number of theoretical positions. At a bare minimum, it should be necessary before proposing any mental construct to specify the operations by which the construct can be observed, or at least to point to several types of evidence that support the usefulness of the construct. It seems fair to say that even this simple requirement would eliminate a great proportion of the hypothetical mechanisms currently discussed in cognitive psychology, which are now often introduced on intuitive, logical, or rational grounds. Even with the careful use of behavioral evidence and converging operations, it is no simple matter to identify a particular mental representation or process, as has been pointed out by J. R. Anderson (1978) and Townsend (1974). It seems likely that issues concerning the logic and necessity of introducing mental constructs are once again due to receive critical attention.

CONCLUSIONS

I have tried to make five main points. First, the language people use to describe memory embodies the assumptions that have been referred to as the spatial storage and search metaphors. Second, this way of thinking about memory has spilled over into numerous psychological theories and models of memory. Third, there are few alternatives to the dominant spatial storage and search metaphors. Fourth, while these metaphors have served as useful explanations of memory phenomena, it would be fruitful to have alternatives that employ different assumptions that may lead to new kinds of experiments and ways of thinking. The construction, levels-of-processing, and resonance metaphors may serve these purposes. Finally, the increasing number of analogical models have produced a superabundance of hypothetical mental representations or processes that are tied only loosely (if at all) to behavior.

The analogies that could be used to account for memory processes are potentially diverse and unlimited. Although the analogies for cognitive processes could be drawn from any number of sources, one obvious and dominant source is the technology of keeping records. A number of the most prominent analogies listed in Table 1 have been derived from the technology of record keeping and human communication. We may note a progression from the imprint of seals on wax to the gramophone, tape recorder, switchboard, dictionary, library, keysort cards, and, most recently, the computer and the hologram. Advances in theories of human memory parallel, and perhaps depend on, advances in technology. 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 a metaphor to the human mind as the wax-tablet or telephone-switchboard models do today. Unless today's technology has somehow reached its ultimate development, and we can be certain it has not, then we have not reached the ultimate metaphor for the human mind, either.

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NOTE

1. Hebb (1949, p. 47) also used the paleontologist-and-dinosaur analogy when discussing the perception and report of tachistoscopic displays.

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