Information processing (psychology)

The coding, retrieval, and combination of information in perceptual recognition, learning, remembering, thinking, problem solving, and performance of sensory-motor acts.
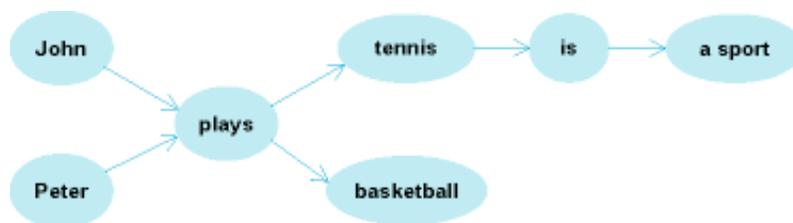
Coding

Information is coded in some type of memory by having something in the memory represent the information. In books, recording tapes, and almost all digital computer memories, the memory consists of a long one-dimensional series of memory locations. The encoding of a piece of information such as the proposition "John plays tennis" consists of imposing the patterns representing "John," "plays," and "tennis" into adjacent locations in the memory. Any other piece of information, such as the proposition "Tennis is a sport," learned at a different time would be coded in a similar manner in a totally different set of locations in memory. The same pattern would be used to represent the concept "tennis," which is common to both propositions, but this pattern would be stored in two separate places, and an information processor using the memory would not have direct access to both facts about "tennis" when it had retrieved one fact. An additional search of memory would be required. Such a memory is called nonassociative, because there are no direct associations linking all instances of the same concept or idea in memory.

Human memory is not at all like a tape recorder or computer memory. Human memory is associative. From a coding standpoint, the defining property of an associative memory is the use of specific node encoding, in which each idea is represented only once by a designated node (location). The representative of an idea is a particular location in memory, rather than a particular pattern that can be, and often is, stored in a variety of locations. There are many different types of associative memories; two of these are considered below: horizontal associative memory and vertical associative memory.

In a horizontal associative memory, the coding of propositions consists of forming a strong association directly from each concept node to the following concept node (Fig. 1). From a semantic viewpoint, the association from one node to another means "is followed by." Careful study of Fig. 1 reveals the two primary deficiencies of a horizontal associative memory. First, there is no encoding of where one proposition ends and another begins, a difficulty which might be referred to as "run-on propositions." Second, there is a serious associative interference problem. For example, there is no way to know whether John plays tennis, basketball, or both, and similarly for Peter. The ability of an associative memory to integrate information that involves the same concepts can produce excessive and erroneous integration in the case of a horizontal associative memory.

Fig. 1　Horizontal associative memory with a serious associative interference problem (who plays tennis—John, Peter, or both?) and no encoding of where each proposition begins and ends.

Vertical associative memories solve these problems while retaining the desirable feature of specific node encoding. They associate atomic concepts to higher-order chunk (phrase) concepts. These associations mean that the lower-order concept "is a constituent of" the higher-order (phrase or propositional) concept. All of the concepts in a single proposition are associated directly or indirectly to a single higher-order node that represents the entire proposition (Fig. 2). In this way both the run-on proposition and associative interference problems are solved by a hierarchical tree-structure encoding of exactly which concepts belong in each proposition.

Fig. 2　Vertical associative memory where concepts are grouped into phrases and propositions by associating each concept to a higher-order node that represents the entire group.
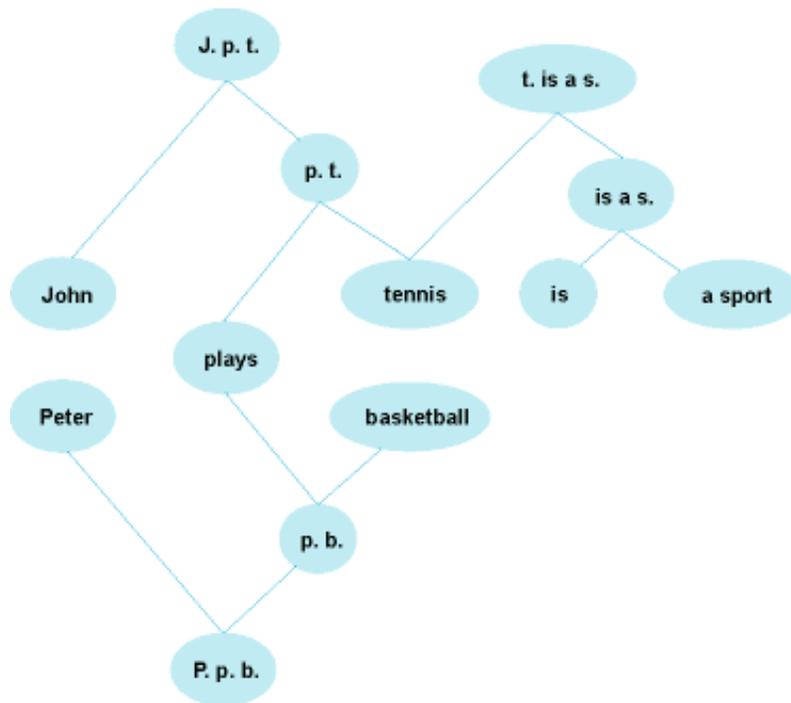
Associations are assumed to be unidirectional, that is, from one node to another. Information processing in an associative memory requires the ability to get from a chunk node to its constituents, and vice versa. Semantically, the associations from a chunk to its constituents mean "has as a constituent." Since the meaning of vertical associations in the two directions is logically opposite, it seems likely that these associations are represented in the mind (brain) by structurally dissimilar types of links that function somewhat differently when information is retrieved from a person's memory. Many theories of associative memory assume an even larger variety of links than this, but at least these two types appear to be necessary.

Order and context-sensitive coding

There are many chunks whose constituents have no unique ordering, such as the members of a family or the features of many objects. Although the sentences used to communicate propositions to others have a definite word order, the same proposition can be communicated using virtually any ordering of the constituent concepts, provided the proper syntactic plan is used. Semantically, there does not appear to be any unique ordering of the constituents of a proposition. Hence, it is likely that the encoding of propositions is another example of the encoding of an unordered set.

However, there are numerous examples of chunks encoded in the mind whose constituents are uniquely ordered, for example, the episodes of a story or the letters in a word. How are these ordered sets coded? A number of possibilities have been suggested, but the one that appears to have the most evidence supporting it is context-sensitive coding. According to this theory, the constituents of a chunk representing an ordered set such as the word "clank" are nodes representing overlapping triples of the component segments. In the case of "clank" the constituents would be "#Cl," "cLa," "lAn," "aNk," and "nK#." The reason for distinguishing the middle element in each triple is that it is the central or focal element and the two on each side are the context. In speech production, the node "lAn" would control the speech musculature to produce the particular "a" that is preceded by "l" and followed by "n." If horizontal associations are added to the constituents of a chunk as a third type of link in vertical associative memory, then horizontal associations between pairs of context-sensitive nodes will produce a unique ordering of constituents when there is one and no such ordering when there is not. In the "clank" example, sufficient information has been encoded to know the first constituent of the set, given that the entire set is active in the mind due either to bottom-up activation by stimulus presentation of the word "clank" or to top-down activation of the segmental constituents by the word node for "clank." In both recognition and production of the work "clank," there is only one segmental node of the form "#Xy." Since "#" represents the junction between words, this must be the first node in the word. Given that "#Cl" is the first node, "cLa" will have the strongest horizontal association from "#Cl," so one knows it is the second node, and so forth.

Learning

All learning in an associative memory can be considered to be the strengthening of different associations between nodes. Thinking of a set of ideas at about the same time (within approximately a second) activates the nodes representing the ideas at about the same time. In a way that is not understood, this strengthens vertical associations gluing these idea nodes to higher-order chunk nodes and probably also strengthens horizontal associations among the idea nodes. If a set of idea nodes is simultaneously activated, then all horizontal associations are equally strong on the average (all orders are encoded), and no unique ordering is encoded. If the set of idea nodes is activated in a simple linear order, than a unique set of horizontal associations will be encoded to represent the sequence (ordered set).

For certain purposes it may be useful to distinguish among three types of learning: chunking (forming new vertical associations from a set of old nodes to a new node, specifying that node to represent the set of old nodes); sequencing (forming new horizontal associations between adjacent pairs of nodes in an ordered set); and strengthing (increasing the strength of existing associations). Forming new associations refers to the initial increase in strength above the baseline, or zero, value, so all learning consists of the strengthening of associations in the most general sense.

However, the initial strengthening of associations appears to require more thinking than does the further strengthening of previously learned associations. Chunking and sequencing are greatly facilitated by coding new material so as to integrate it with stored material as much as seems relevant and as consistently as possible. When such integration uses relationships that are true and of considerable general value, it is called understanding. When such integration uses fictional relationships or relationships of little general value, it is called a mnemonic trick. Either way, new learning is made easier by integration with prior knowledge. The difference is that all associations formed or strengthened by understanding are true and useful, as opposed to only a few of the associations formed or strengthened by mnemonic tricks.

Further strengthening of learned associations requires much less thinking effort—just retrieval of the associations to be rehearsed. However, this does not mean that such review is of no value. Review can serve to counteract the effects of prior forgetting, to overlearn so as to retard future forgetting, to increase retrieval speed for the reviewed material in the future, and to reduce the attentional demands of such retrieval.

Retrieval

Information that is currently being thought about is said to be in active memory. All of the rest of the information that is stored in long-term memory is said to be in passive memory. Retrieval refers to the cognitive processes that allow one to make use of stored information by converting the memory traces for particular pieces of information from the passive to the active state. Retrieval can be analyzed into two components: recognition, which is the activation of the nodes in memory that encode the cue information. Every act of retrieval requires recognition of the retrieval cues, and probably every act of retrieval involves recall of some information beyond that given in the retrieval cues.

The basic information-retrieval process in an associative memory is direct-access, that is, direct activation of the nodes encoding the cue and closely associated information. No search is required when the retrieval cues are sufficient to identify a unique memory node (location). When the retrieval cues are inadequate, there is sometimes information stored in long-term associative memory that would be adequate to retrieve a unique answer to the question. In such cases, a sequence of direct-access retrieval processes is initiated. For example, sometimes the associations from an acquaintance's face to his or her name is too weak to retrieve the name from the face cues. However, when the backward associations from the name to the face cues are added in, the information stored in memory is sufficient to recognize which name goes with that face. So one can engage in a memory search process that consists of recalling various names and judging the strength of association of each name with the face. The entire sequence is a search process, but each elementary act of retrieval in this complex sequence is a direct-access process. The whole purpose of having an associative memory is to make direct-access retrieval possible, by encoding every idea in one specific location that can be identified from the cue input without having to search through sets of alternative locations.

Retrieval dynamics

While retrieval from memory is direct, it is not instantaneous. One elementary act of retrieval requires approximately 1 s of time to reach completion, with a range from 0.3 to 3 s. Retrieval can be analyzed into three temporal phases: latent, transition, and terminal (Fig. 3). The latent phase extends from the time the retrieval cues are first presented until the initial time (I) that any response can be made which is at all influenced by the memory traces activated by the retrieval cues. The terminal phase is the period of time after retrieval is complete during which the retrieved set of memory traces is fully activated and able to control behavior and thought. In the terminal phase, retrieved memory strength is equal to the limit set by the passive strength level stored in long-term memory (L). The transition phase is the period in between, when retrieved memory strength increases from zero to L. This transition phase is not abrupt, as if retrieval occurred all at

once. Instead, memory retrieval appears to occur incrementally over a period of many tenths of a second. If people respond to retrieval cues after some retrieval has occurred, but before the retrieval of the memory trace is complete, they respond at a level of accuracy which is greater than chance but less than they could achieve had they delayed their response until retrieval was complete. A plot of accuracy as a function of reaction time is called a speed-accuracy tradeoff function. The accuracy of a recognition or recall response to retrieval cues measures the strength of the retrieved memory trace. The increase in the strength of the retrieved memory trace as a function of the time allowed for processing the retrieval cues (retrieval time) is called the retrieval function. Empirical speed-accuracy tradeoff functions for recognition or recall thus provide measures of the theoretical retrieval functions for these tasks.

Fig. 3   Memory-retrieval functions for conversion of stored long-term memory strength L into active short-term memory strength S as a function of retrieval time T. Note that the time to achieve 95% accuracy is greatly affected by stored strength L, even when retrieval dynamics parameters (I + R) are identical.
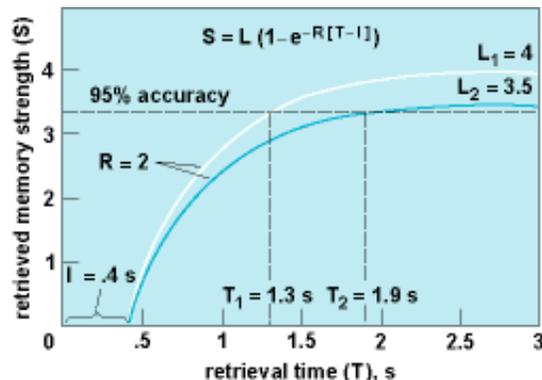
The dynamics of memory retrieval appears to be closely approximated by an exponential approach to a limit L at rate R after the initial delay time I (Fig. 3). Exponential approach to a limit means that in every very small increment of time (after delay time I), a constant percentage of what stored trace remains to be retrieved is retrieved. That percentage is the retrieval rate R. In Fig. 3, two retrieval functions are displayed that have identical retrieval dynamics (identical I and R parameters) but different limits set by their different levels of stored strength in long-term memory (L_1 and L_2). Note that the time required for memory retrieval to reach a certain level of accuracy (95% in Fig. 3) is considerably less for the trace with the greater strength in storage ($T_1 < T_2$). Thus, even without altering the dynamics of memory retrieval, one can decrease reaction time considerably in recall or recognition simply by increasing the strength of the stored trace in long-term memory, with no loss in accuracy.

Retrieval dynamics (I and R parameters) is not affected by memory strength. It is primarily affected by the hierarchical level of encoding of the memory trace being retrieved — the higher the coding level (that is, the longer the chain of upward vertical associations from the sensory periphery to the highest level chunk node), the slower the retrieval dynamics (that is, the greater the I value and the smaller the R value). Thus, the retrieval dynamics for recognizing letters is faster than that for words, which is in turn faster than that for sentences. The more simply one codes material in terms of hierarchical depth, the faster it can be retrieved, provided the strength of the trace is the same in both cases.

Attention and parallel processing

There are limits to how many things a person can attend to at once. The laws of attention are not completely understood, but the following appear to be true: A very large number of retrieval cues can be processed at once, provided they all converge on a single stored memory trace, regardless of complexity, which has been previously unified by vertical associations to a single chunk node at the top of its trace hierarchy; this is called convergent parallel processing. Two or three separate sets of retrieval cues can probably be processed, provided that the traces they retrieve are very strong; this is called divergent parallel processing. Divergent parallel processing is easier if the traces are stored in different memory modalities, for example, verbal versus spatial. Thus, a person can carry on a conversation and sign letters simultaneously, with little loss of effectiveness in either task, because the memory traces are in somewhat different modalities and the signature trace is very strong. One of the important aspects of increasing skill in sports, for instance, is the increasing ability to perform several information-processing tasks in parallel. Part of this skill is due simply to increased practice at each component skill and part is due to explicit coordination of these components under unified, higher-order chunk nodes. See also: Cognition; Memory

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For Further Study

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