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SUMMARY

The Elementary Perceiver and Memorizer (EPAM) is a computer model of human associative memory and the processes of verbal learning. Analysis of the failures of one earlier version of the model (EPAM II) to simulate certain features of human verbal learning behavior led the authors to formulate a more general model of verbal learning processes (EPAM III), which is discussed in this paper.

In this model, EPAM information processes and structures have been generalized to deal with stimulus objects of arbitrary complexity. Discrimination processes discriminate objects on the basis of properties of the objects themselves or on the basis of properties of constituent subobjects. The cue-token is an associative link between the references to an object and the image of that object stored in the association memory.

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The learning processes of EPAM III provice an associative mechanism by means of which earlier learning can be brought to bear in a useful way on later learning.

Exploration of the EPAM III model is concerned with simulating the behavior observed in psychological experiments on meaningfulness in verbal learning.

1. INTRODUCTION

The Elementary Perceiver and Memorizer (EPAM) is a computer model of human associative memory and the processes of verbal learning.* A version of the model, called EPAM II, has been reported previously [2]. The behavior of EPAM II, generated by using the model *qua* subject in simulated psychological laboratory experiments, has been explored under a variety of experimental conditions in some 100 runs on an IBM 704 and IBM 7090. Analysis of the failures of the EPAM model to simulate certain features of human verbal learning behavior led us to formulate and program EPAM III, a more general model of verbal learning processes. Sections 2 and 3 of this paper describe the EPAM III model. Section 4 discusses the inadequacies of the earlier model and reports some preliminary results in the simulation of behavior with EPAM III.

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*EPAM is a model of psychological rather than neurophysiological processes. It is concerned with behavior at an *information-processing level* intermediate between neuronic behavior and observable human behavior. EPAM programs are statements of hypotheses at the information-processing level about symbol manipulation and storage in humans during symbolic learning. No attempt is made to model neurophysiological processes which would realize the hypothesized information processes.

2. AN OVERVIEW--SOME CONCEPTS AND TERMS

Consider a task in which a human subject is shown a complex stimulus configuration and is instructed to memorize as much information as possible about it. After a reasonable amount of exposure time, the subject is asked to draw (or describe) what he has seen.

In the subject's behavior we observe the following:

a. He fragments the complex stimulus object into simpler subobjects which are recognizable and familiar (e.g., a landscape is broken down by the subject into trees, houses, clouds, etc.).

b. Subobjects are themselves further fragmented.

c. In describing what he has seen, the subject lists in some reasonable "scanning order," familiar subobjects he has identified and remembered. When pressed to describe an individual subobject in greater detail, he may describe the "normal" properties of that familiar stimulus. His ability to describe the particular details of the complex stimulus increases with the memorizing time available to him in the experiment.

EPAM III is a model of the learning process which underlies the behavior just described. Our primary goal is to simulate verbal learning behavior with EPAM III.

We shall call any stimulus configuration in the environment of the learner a stimulus <u>object</u>. Stimulus objects are in general

[redacted]

compound, i.e., they are made up of subobjects, for example, the verbal symbol CAT is made up of the letters C, A, and T. Non-compound objects are elementary and consist of an unordered set of properties.

In terms that will subsequently become clearer, we hypothesize that a stimulus object is memorized by building and storing an encoded image of the object in an association memory. The image of an object contains or refers to all the information memorized by the learner about the object. When the image-building is completed, the presentation of the stimulus object [redacted] evokes from the association memory the image (the learner's internal representation) of the object. Such an object can then be termed familiar or recognizable.

Images may also be evoked upon presentation of partial stimulus objects (as C-T may evoke CAT). In the same way, by a process entirely internal to the learner, images may be evoked by other partial images. Partial images which "cue" the internal evocation of other images are called cue-tokens. In associating images together to build a more complex image, it is sufficient to associate cue-tokens since the full images themselves are evocable when necessary. An image may be associated in the context of any number of more complex images by the storage of a cue-token in each context.

To summarize, we hypothesize that the learning of compound stimulus objects by humans consists of the following processes:

I. Fragmentation of the object into subobjects that are familiar (the learner perceives the landscape as consisting of trees, houses, clouds, etc.).

II. Construction of an internal image of the object in the association memory as a set of cue-tokens of the familiar, recognizable sub-objects (the subject stores a token reference to his previously-learned image of a tree, house, cloud, etc., in the image of the landscape he is currently memorizing).

Performance in such a learning task consists of the evoking of the compound object; evoking of images of the familiar sub-objects using the cue-tokens; and if these images are compound, the possible further evoking of lower-level subobjects.

Hypotheses I and II are assumptions about the nature of <u>meaningful learning</u>. They specify a process by which symbol-structures built up in previous learning are used in subsequent learning to build up more complex structures.

The EPAM III program, a precise specification of the processes so loosely sketched out above, will be described in the next section.

3. INFORMATION STRUCTURES AND PROCESSES OF EPAM III

EPAM III is programmed in the list-processing language IPL-V [6]. For brevity in the exposition, we assume a modest familiarity by the reader with list-processing terminology.

<u>Objects</u>. A <u>compound stimulus object</u> is a list of the stimulus subobjects plus a set of properties. Subobjects of a

compound object may be compound or elementary. An <u>elementary</u> object is described by a set of properties and has no subobjects. As in the earlier EPAM II [2], the perceptual scanning process necessary to encode real external stimuli has not been programmed but has been simulated external to the model.

<u>Cue-tokens</u>. A cue-token is an incomplete copy of an object. The utility of the cue-token derives from a property of its use in the EPAM association memory: namely that, though it generally contains far less information than the object for which it is a token, it is capable of evoking the internal image of the object from the memory.

<u>Images</u>. The image of an object is a list of cue-tokens of the familiar subobjects, plus an unordered set of properties of the object. The image is the "unit" of information about a memorized stimulus object evocable from the memory.

<u>Discrimination Net</u>. The memory structure which organizes stored images and allows object-to-image and token-to image associations is the discrimination net. It is a branching tree whose terminal nodes are storage locations for images. At the non-terminal nodes are stored tests--programs which provide branch signals to guide movement through the net either by examining object (or cue-token) properties or by requesting recognition of particular subobjects.

<u>Association Process</u>. This is the process by means of which images are evoked from the discrimination net. Given an object or a token as input, the association process sorts it through the net to the terminal node at which its image is stored,

activating the tests along the path and branching appropriately.

Performance Processes. In the discussion of learning systems, it is useful to distinguish the task-performance processes from the learning processes. EPAM III has two kinds of performance processes, stimulus recall and response anticipation.

In the stimulus recall process, the image of the stimulus object is evoked. In sequence, the image of each subobject ("cued" by a token) is evoked. Recursively, lower-level subobject images are evoked, and so on. Images of elementary objects are fed to a responder which generates (decodes) the elements to the environment. The performed response thus has the hierarchical structure which characterizes stimulus objects.

In the response anticipation process, the performance task is to give a particular learned response to a presented stimulus. For example, suppose that a list of words, L, (consisting of words W_1, W_2, ... , W_n) has been learned, and suppose that correct performance requires giving W_{n+1} as the response to the presentation of a stimulus W_n. The response anticipation process evokes the image of the stimulus context (the image of L) and the image of the stimulus (the image of W_n); searches the image of the stimulus context (image of L) for a cue-token which matches the stimulus image to the extent of the information in the token (i.e., the cue-token of W_n is located in the image of L); gets the next cue-token on the image list (hence, the cue-token of W_{n+1} in the image L); uses it to evoke the associated image (the image of W_{n+1}); and performs a response from this image using the stimulus recall process (the response W_{n+1} is output to the environment).

Learning Processes. EPAM learning processes are basically of two kinds: discrimination learning processes, which grow the discrimination net to provide a unique terminal for the image of each new object learned; and image building processes.

The discrimination learning process is similar to that of EPAM II (see [1, 2]) and is given in Table 1.

Two major innovations are worth noting. First, in EPAM III, tests added to the net to distinguish an object from others may be tests of properties of the object itself or tests on the properties of its subobjects. Thus two objects which do not differ in their "overall" properties can still be discriminated by reference to their substructure. Second, the attention-focusing mechanism of EPAM III, which orders the search for differences between objects, operates in two modes. When scanning properties of objects, it consults a noticing order (which EPAM reorders as experience shows which properties were most successful in revealing differences between objects). When searching substructure for differences, no special "substructure noticing order" is used. Instead, the discrimination net itself is used as the noticing order to guide discovery of differences between subobjects.

Image Building. The image building process constructs a list of subobject tokens during the course of learning an unfamiliar object. Since response is performed by sequencing

Table 1

EPAM Discrimination Learning Process

Discriminate object, X, in discrimination net, N.

Apply association process to X in net N, evoking image I at terminal node t.

Match: extract differences between X and I

Scan properties of X and I for differences.

If necessary,

Scan subobjects of X and I for differences.

If no differences can be found (where information exists in both I and I), terminate.

Construct subnet of tests based on differences found, inserting I at appropriate terminal node.

Append subnet to the discrimination net at node t.

Insert a first image of X at appropriate terminal node (now available), and terminate.

image lists, the order in which the subobject tokens are entered into the image is important. The order is dictated either by the nature of the task (as in the serial learning of syllables) or by an environment-scanning order imposed by a higher level process.

In human serial learning behavior, one observes characteristic phenomena which are related to the organization of the learning task by the learner. Since our primary goal is to simulate human behavior, we have introduced severe constraints on the image-building process--constraints which our previous work [5] indicates are necessary for a good simulation. In particular, in the construction of image lists, we allow only the operations of adding a cue-token before or after another cue-token, thereby forcing image lists to be built from the ends toward the middle.

Other Mechanisms. We should like to mention two additional mechanisms, although for brevity some important EPAM mechanisms will not be discussed in this paper.

First, EPAM is capable of simulating learning involving more than one sense mode. A discrimination net for each mode is used. Inter-mode associations are possible by storing in the net of one mode a cue-token to an image in the net of another mode.

Second, feedback from the environment plays an important part in directing learning and relearning of stimuli. EPAM has a simple problem-solving mechanism that analyzes responses in relation to "correct" responses to determine causes of response error and to take corrective action.

4. SIMULATING HUMAN BEHAVIOR

The dimensions of learning that we are currently exploring actively are: stimulus structure, stimulus familiarity, and stimulus meaningfulness. A detailed report on empirical exploration with the model will be the subject of another report. We should like here to indicate a few early results.

The learning task studied is serial anticipation learning, in which a list of syllables or words is learned by a subject. The subject's task is to respond correctly with the (n + 1)st item on the list when he is shown the nth item. The list is cycled repeatedly until the subject is able to perform correctly all the anticipations (or at least a criterion number). The EPAM II model failed to simulate certain important features of subjects' behavior in this experiment. In particular, it was totally incapable of learning a serial list in which the same item occurred more than once (though human subjects do this after some difficulty). Also, if two items were different in their overall properties (e.g., one was printed in black, the other in red) but were composed of the same letters (or phonemes), EPAM could neither discriminate them nor learn a list of which they were part.

The first failure was a result of the inability of the model to allow for the association of a learned symbol in more than one associative context. The second failure obtained because EPAM was able to discriminate items only on the basis of information "within" items, not "about" items (i.e., information about the constituents, not overall properties).

The EPAM III model corrects these inadequacies. Learned objects can be associated in any number of contexts, as described earlier. And objects are discriminated not only on the basis of the subobject structure but also on the basis of object properties.

In experiments on the memorization of meaningful items, we use the following working definition of meaningfulness: a stimulus object is meaningful if it is recognized (i.e., has a well-formed image) as consisting of subobjects which are familiar and well-learned. A list of Chinese ideograms is meaningless to the average Occidental; but to the Oriental, both the symbols and the sequence may be meaningful. Note that under this definition of meaningfulness almost no learning can be considered truly non-meaningful. The "nonsense" syllables of which psychologists are so fond are, under this conception of meaningfulness, not "nonsense" at all, for they are composed of familiar letters of phonemes.

From the many experiments on meaningfulness of stimuli in rote learning, these results (among others) are important:

a. Lists of items of high average meaningfulness are learned more quickly than lists of items of low average meaningfulness.

b. Items of similar meaning tend to interfere with each other to a greater degree than lists of items of dissimilar meaning (by interference is meant the forgetting of items previously learned due to interpolated later learning).

c. In experiments on the learning of stimulus-response pairs, learning time is significantly affected by response meaningfulness but not significantly affected by stimulus meaningfulness.

Preliminary results of explorations with EPAM III indicate that the above phenomena are implied by the model.* The first is a general result of the learning of complex structures (like a list of items) by collecting and ordering tokens of familiar subobjects. To the extent that the subobjects have previously been familiarized (or, in psychological parlance, "the responses have been integrated"), total learning time is decreased. The second phenomenon is not obvious, and relates to the interruption of associations in an association net which grows over time. We have discussed this property of EPAM in another place [4]. Growing the discrimination net makes response cues (once sufficient to evoke a correct response) inadequate for correct responding at a later time. The more detailed the elaboration of the net over time, the greater in general will be the interference among items. The discrimination of items similar in meaning (i.e., having overlapping subobject structure) results in a more detailed elaboration of the net than the discrimination

*At the time of writing (March, 1962), the EPAM III program in IPL-V was being debugged. Preliminary results were obtained by hand-simulation of the model.

of items dissimilar in meaning. Hence, interference is greater when the learned items have similar meaning than when they are dissimilar in meaning.

The differing effects of stimulus and response meaningfulness in paired associate learning by EPAM is due to an asymmetry between the roles of the stimulus item and the response item. The response item must be given as output; hence, it must be "well integrated", i.e., its image must be highly elaborated. Stimulus items need only be recognized and are not part of the required output of a subject. Therefore, it matters a great deal whether response items are meaningful (i.e., their images are already highly elaborated) whereas the presence or absence of an elaborate stimulus image makes little difference in the learning.

5. CONCLUSION

We have presented an information processing model of certain human memorization and verbal performance processes. The model is realized in the form of a computer program in the list-processing language IPL-V. The validity of the model is determined by comparing its behavior in simulated laboratory experiments with the behavior of human subjects in the same experiments. Preliminary results in the empirical exploration of the model were reported.

The EPAM III model is an attempt to generalize the information structures and processes of earlier EPAM models to deal with complex, meaningful stimulus configurations. A complex stimulus object is defined to be meaningful if it is recognized by the learner as consisting of familiar, well-learned subobjects. The learning processes of the EPAM III model provide an associative mechanism by means of which earlier learning is brought to bear in a useful way on later learning.

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