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RECENT EXPERIMENTS WITH THE EPAM SIMULATION OF VERBAL LEARNING

by

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RECENT EXPERIMENTS WITH THE EPAM SIMULATION OF VERBAL LEARNING

The Elementary Perceiver and Memorizer (EPAM) is a simulation of human verbal learning behavior. EPAM simulates the information processes by which humans discriminate and associate symbols in one or more sense modes.

EPAM is a computer program written in the list-processing language IPL 5. Its behavior has been explored under a variety of experimental conditions in some 100 runs on an IBM 704 and an IBM 7090. In the experimental procedure, EPAM qua subject is put through certain verbal learning experiments by an Experimenter program, which simulates the experimenter, the apparatus, and the stimulus environment.

The EPAM programs are precise statements of hypotheses about information processing in human learning. As with other simulations, the computer runs with EPAM (i.e., the means by which the consequences of the model are worked out for specific experimental conditions) enable us to test the adequacy and consistency of the model in explaining the phenomena of verbal learning. *

In this paper, I shall first summarize, in a very schematic way, the structure of the EPAM model. Second, I shall describe the various kinds of experiments we have performed. Third,

*At this stage, the "unsatisfactory" runs, which tell us how wrong we are, are probably as valuable as the "satisfactory" experiments, which confirm basic hypotheses.
I shall summarize a variety of results of these experiments, with examples where relevant. Fourth, I shall comment on some of the problems of the model that were revealed by the experimentation.

The EPAM Simulation*

Since the EPAM program has been described in detail elsewhere (Feigenbaum, 1959, 1961), I shall summarize it here quite briefly.

The EPAM processes perform the following four principal functions:

(a) recognize an external stimulus as one about which some information has already been memorized;

(b) add new stimulus items to the memory by building discriminations (tests) that allow the new item to be distinguished from stimuli previously learned;

(c) associate (internally) two stored items, say $x$ and $y$, by storing with $x$ some cue information about $y$;

(d) respond to an external stimulus $x$ with a response, $y$, by retrieving the cue to the response, and then retrieving the response using the cue.

*This section of the paper is substantially the same as a similar section in a paper by Feigenbaum and Simon entitled "Performance of a Reading Task by an Elementary Perceiving and Memorizing Program," The RAND Corporation, P-2358, July, 1961.
Thus EPAM has two performance processes, enabling it to respond with material already learned: the discrimination process, (a), which recognizes the stimulus, and the response process, (d), which finds the appropriate response associated with the stimulus and produces it. EPAM also has two learning processes: the discrimination learning process, (b), which elaborates the structure of discrimination tests it applies to stimuli, and the association learning process, (c), which associates response cues with stimuli.

The central memory structure, which the performance processes use and the learning processes construct, is the discrimination net. (See Figure 1) It is a tree-like nexus of associations at whose terminal nodes are stored images of encodings of external stimuli. At the non-terminal nodes of the net are stored tests which examine particular bits of the encodings. The image of a stimulus is retrieved by sorting the encoding of the stimulus down through the tests of the net to the appropriate terminal. In learning a set of stimuli, the net is grown to a size that is just large enough (roughly) to discriminate among the different stimuli that have been presented to the system.

Association of a response, $y$, to a stimulus, $x$, is accomplished by storing a small amount of the information about $y$ (an incomplete cue image of $y$) along with the image of $x$. The system determines by trial and error how much
Fig. 1—EPAM performance process for producing the response associated with a stimulus
information must be stored as a cue to retrieve the response from the net when the association is made.

EPAM responds to a stimulus (see Figure 2) by sorting it in the discrimination net, finding the associated response cue, sorting that cue in the same net, finding its image and using the response image to produce the response.

EPAM does not simulate the initial sensory and perceptual processes (the processes in Figure 2 labeled "perceive Features of Stimulus") that scan an external stimulus and extract from it encoded information that is used by the memorizing and responding processes. The EPAM program takes up at the point where the initial perceptual encoding has already been accomplished. Its "stimuli" are encodings of the external stimuli. Thus, the EPAM stimuli corresponding to letters of the alphabet hold information about whether a letter contains a curved segment, a straight segment, a closed loop, and so on. Each letter is discriminated from the others, as the discrimination net grows, by its possession of a unique combination of simple topological and metrical properties like these.

Different encodings are used to represent stimuli in the different sensory modes, and in certain submodes. Thus, there may be a net for discriminating among aural phonemes by encodings that represent elementary phonemic characteristics; another net for discriminating among visually presented syllables of letters; still another net for discriminating
Fig. 2--A typical EPAM discrimination net
among objects in terms of simple characteristics of shape and the like. We will be concerned, on the sensory side, with these three specific modes: aural phonemic, visual literal, and visual object modes.

On the response side, too, several modes are represented by different encodings. In the learning of reading, EPAM uses three response modes, paired, respectively, with the three stimulus modes. There is an oral response mode, whose images may be interpreted as the signals that activate the muscles used to produce spoken language. There is a written response mode, representing signals that activate muscles used in printing letters. There is a pointing response mode, which, as its name implies, signals the selection of an object from a set of objects by pointing. In the present EPAM program, the response modes are represented only in a rather rudimentary form—the system has been elaborated principally on the stimulus side.

**Verbal Learning Experiments with EPAM**

To facilitate experimentation with the model, an Experimenter program was written. The Experimenter is quite distinct from EPAM (the subject). It contains a simulated memory-drum apparatus commonly used in learning experiments;
timing procedures; stimulus materials of various kinds; error-checking and recording procedures; and so on.

The experiments which we have run are of the following types:

1) Serial learning of nonsense syllables

2) Learning of nonsense syllables in associate-pairs

3) Serial learning of nonsense syllables of two lists, with a retest of the first list following the learning of the second list (also two-list learning of paired-associate syllables).

4) Learning a set of associate-pairs (as in 2 above), with the stimuli in one sense mode, and the responses in another.

5) Multi-mode chaining of associations (reading). The spoken name is associated with a visual object. The written name of the object is associated with the spoken name. This learning is done for a number of objects. Without further learning, a reading test for identification of the visual objects from the written name is given.

Summary of Results of Experiments

The results of the various experiments with SIAI will be reported in detail in another place. 1 should look briefly

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1For further details, see C. L. Hovland, Human Learning and Retention, Handbook of Experimental Psychology, Wiley: 1951.
to summarize the major results.

1. Serial Position Effect. In serial list learning, subjects learn the items toward the ends of lists earlier than they learn middle items. The error curve has a characteristically bowed shape and is called the serial position curve. When errors are plotted as a percentage of total errors the curve is remarkably constant for different experimental procedures. EPAM predicts this constancy; the qualitative features of the curve; and also the quantitative values of the percentage-of-errors. EPAM also predicts the result of Rock's well-known experiment. In the learning of a list of items by a subject, Rock substituted new items into the list for items to which incorrect responses were given in the previous trial, i.e., items which subjects hadn't learned completely were replaced next time around. He found that this did not affect total number of trials to criterion of learning. EPAM is presently the only theory of verbal learning which unequivocably predicts this result.

2. Stimulus and Response Generalization. If S is associated with R, S' (similar to S) is presented, and a subject responds with R, this is a stimulus generalization error. If S is associated with R, R' in a response similar to R, and the presentation of S results in R' as response, this is a response generalization error. Generalization errors are commonplace in the behavior of both human subjects and EPAM.
Stimulus generalization is most easily seen in the first few trials of the learning of a second list of items after a first list has been learned. Stimulus items in the second list which are similar to items of the first list are responded to with the appropriate response items of the first list. Response generalization is most easily seen in the same kind of experiment. The effect of the second-list learning may be to store in the memory responses similar to first-list responses. Since the information to discriminate the similar responses will not have been stored during the first-list learning (there was no need to do it at the time the first list was learned) the similar responses may be confused and the wrong one may be produced.

3. Oscillation. If one looks at the pattern of success and failures over trials for any one syllable in a serial list learned by a human subject, one finds that this pattern is highly irregular: failures, followed by some successes, then a failure, then successes, further failure, etc. This is a feature of the behavior of EPAM. It is caused by the interference of later-learned items with earlier-learned items and associations in a growing association memory. The phenomenon is intimately related to the forgetting phenomenon to be described subsequently.

4. Effects of Intra-List Similarity of Items. Lists of highly similar items are much harder for human subjects
to learn than lists of low intra-list similarity. This is a firmly established empirical result. It is a prominent feature of EPAM's behavior. In a recent experiment (using nonsense syllable lists of high and low intra-list similarity originally used by Underwood in his experiments on the phenomenon), the low-similarity list was learned to criterion in eight trials, while the high-similarity list was learned to criterion in eighteen trials. Discrimination is a very time-consuming process in EPAM and the learning of high-similarity lists entails a great deal more discrimination between items than the learning of low similarity lists.

5. Item Duplication. EPAM cannot learn a serial list of items in which the same item appears twice. A human subject can learn such a list, though not as easily as a standard list. In responding, EPAM will continue to oscillate between the different associates of the repeated item. Human subjects learn to distinguish between different occurrences of the duplicated item (e.g., the occurrence "early in the list" as opposed to the occurrence "late in the list"). The difficulty this raises with the model is serious and was one of the factors that lead to a revision and generalization of the EPAM system. The problem is one of symbol-associations versus token-associations, and will be discussed subsequently.

6. Interference and Forgetting. In the two-list experiment described earlier (involving the learning of a list A, followed by the learning of a list B, followed by a retest of
the learning of list A), it is observed that human subjects exhibit a decrement in retention of list A responses after the learning of list B items. By the standard operational definition of forgetting, the subjects have forgotten some of the list A responses. (The loss is short-lived, however; the responses are usually entirely relearned during the retest trial). This forgetting phenomenon has been termed \textit{retroactive inhibition}, and has been ascribed to the interference of the later-learned items with the earlier-learned items.

\textbf{Retroactive inhibition is a feature of the behavior of EPAM.} The EPAM explanation of the phenomenon is described in detail in (4). Briefly, the forgetting occurs because earlier-learned association cues become inadequate to retrieve correct responses as the association memory (i.e., the discrimination net) grows to encompass new items being learned. The phenomenon has the following properties:

a) \textit{It is a pure interference phenomenon.} Forgetting occurs not because of the physical destruction of information in the memory, but because items become misplaced in a growing network of associations. To my knowledge, EPAM is the only completely specified theory of the interference phenomenon in existence.

b) \textit{Forgetting may be only temporary, and forgotten items quickly reassociated, if sufficient cue information is assembled.}
to retrieve the item that was temporarily lost in the growing net. This reassociation can happen most easily at a "trial" at which a response attempt ends in failure. The feedback that an incorrect response was made, accompanied by the presentation of the correct response, leads to the storage of more cue information, and the association is thereby reestablished.

c) There is no separate mechanism in EPAM to account for forgetting. The phenomenon is purely a consequence of a simple type of association memory structure and some basic processes for discrimination and association of symbols.

In EPAM, oscillation and retroactive inhibition phenomena are seen to be intimately related. Oscillation is caused by the intra-list interference of items; retroactive inhibition is caused, in precisely the same way, by the inter-list interference of items. This is an hypothesis which has received little attention in the body of psychological theory.

A number of hypotheses relating degree of intra-list similarity to amount of retroactive inhibition have emerged from EPAM experiments, and have yet to be tested against experimental data. They are as follows:

a) The learning of a list with low intra-list similarity of items following the learning of a list of high intra-list similarity of items produces low retroactive inhibition.

b) The reverse procedure (high similarity list following low-similarity list) produces high retroactive inhibition.
c) If two high-similarity lists are learned, there is low retroactive inhibition.

d) The learning of two low-similarity lists produces an amount of retroactive inhibition intermediate between that produced in the (a) and (b) situations.

Psychologists have identified another type of forgetting called proactive inhibition, the interference of items earlier learned with items later learned. In a typical experiment, a control group learns a list B, then is retested on B. An experimental group learns a list A; then learns a list B; then is retested on B. Any decrement in the list B retention in the experimental group is called proactive inhibition. There is no proactive inhibition observable in the behavior of EPAM. This phenomenon, we believe, derives from long-term memory processes which go beyond the scope of the present model. There is a simple heuristic argument which will account for the phenomenon in EPAM-like terms, but the problem needs further study and will be reported on elsewhere in the near future.

EPAM does, however, exhibit some proactive effects during learning. The effect is on the difficulty of learning a given list of items. A given list of nonsense syllables is more difficult for EPAM to learn if it is learned after another list has just been learned. In one experiment, using lists of high intra-list similarity, a given list was learned in fifteen
trials when learned as the first list of a pair of lists; it was learned in eighteen trials when it occurred as the second list of the pair. Processing in a small net (with only a little information stored in it) is easier than processing in a larger net (containing much stored information).

7. Reading. EPAM has simulated an elementary form of reading. The learning phase of the experiment consisted of two paired-associate tasks. In the first, EPAM learned associations between the characteristics of visually-presented objects (a dog, a cat, a car, and a ball) and the aurally-presented names of these objects (DAWG, KAT, KAHR, BAWL). In the second, EPAM learned associations between the visually-presented names (DOG, CAT, CAR, BAIL) and the aurally-presented names. In the performance phase of the experiment, the visual-symbolic names were given and EPAM successfully, on the first trial, "pointed to" the correct objects in the set of visual objects it had learned. It did this by going through a "mediating response," an internal response in the aural mode. Since humans learn a great many associations between sound-names and visual objects early in life, and since we almost always learn the visual-symbolic name of an object in association with its aural name (because we, or our teacher, pronounces it), we may be using internal aural "mediating" responses a great deal of the time in reading. The empirical data on subvocalization during reading would tend to support this argument.

A detailed treatment of the EPAM reading experiment is given in (3).
Problems Raised by the EPAM Experiments

One of the virtues of the simulation approach is that it gives the theory builder reasonably precise information on the sufficiency (or insufficiency) of his theory. Mr. Simon and I have formulated and have begun to attack some of the problems with the EPAM model revealed by the experimentation described above. I shall merely mention the major problems here, discussing them in greater detail during the conference session.

The preceding section that described experiments with item duplication on serial lists raised the question of symbol-associations versus token-associations. By an internal symbol we shall mean the memorized internal encoding of an external stimulus configuration. By an internal token we shall mean a symbol occurrence manufactured for use in a particular instance (e.g., the token might be a complete copy of the symbol, a partial copy, etc.). Symbols are basic entities to the EPAM learning system. Symbols contain the information necessary for recognition of stimuli, output of responses, etc. Symbols occur repeatedly in many different learning contexts. To allow them to be tied together in association with each other (as is done in the present EPAM model) is to allow the learning mechanism to be tied into knots, for each symbol can be associated only once with another symbol. The problem of allowing associations to and from a symbol in a variety of contexts is solved by postulating a process that creates tokens of symbols for association in particular contexts.
Tokens then become the associated entities. A token can be informationally quite sparse. All the information that is really necessary in the token is that information just sufficient to retrieve the actual symbol from the discrimination net in which the symbol is stored.²

The experiments with serial learning and paired-associate learning have led us to believe that the EPAM processes do not use enough "serial" properties in serial learning. At present EPAM treats serial learning as a special kind of paired-associate learning. We now believe serial learning and paired-associate learning to be quite different information processing tasks—that serial ordering and serial cues make serial learning much easier than the same learning done in pure paired-associate style. Perhaps this is because humans deal so much, in their symbol manipulation, with serial strings of symbols, and therefore have learned efficient serial processing mechanisms. The modification of EPAM currently in progress will have basic processes specifically designed to learn serial orderings of stimuli.

Finally, we have been forced to deal with the problem of the learning of meaningful stimuli. Objects are "meaningful" if they (or their subobjects) can be recognized as being

²The symbol-token problem is a difficulty not only with the present EPAM model but also with all other association learning theories, though the EPAM theory is the first to point up the problem in the context of psychological theory, I believe.
associated with objects already learned. Meaningful objects are learned more easily than non-meaningful objects because the former do not have to be learned completely from elementary properties (or symbols), but can be learned as structures of associated objects previously learned. A zebra, when first seen, is really quite a meaningful object. It is a horse with stripes. The emerging new EPAM system incorporates processes for building up complex objects from previously learned sub-objects. The mechanism seems to be a simple means by which previous learning can be brought to bear in a useful way on current learning.


