PERFORMANCE OF A READING TASK BY AN ELEMENTARY PERCEIVING AND MEMORIZING PROGRAM

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The Elementary Perceiver and Memorizer (EPAM) is a computer program designed to simulate the processes used by human subjects to perform rote memory tasks--particularly learning nonsense syllables by the method of paired associates (Feigenbaum, 1959, 1961). In the present brief account, we wish to report some experiments which show that the mechanisms postulated in EPAM for the rote memory tasks are adequate for simulating, at least macroscopically, the processes employed by human beings in acquiring the ability to read and understand printed words. First, we shall provide a summary description of the EPAM program, mentioning the main processes it uses in rote memory tasks. Then we shall describe how these processes are used in learning to read.

The EPAM Program

Since the EPAM program has been described in detail elsewhere (Feigenbaum, 1959, 1961), we shall summarize it here quite briefly. It is a computer program of about 1,000 instructions, written in an interpretive language, IPL-V, and tested under a variety of conditions in some 100 runs on the IBM 704 and IBM 7090.

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.

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 <u>discrimination net</u>. (See Figure 1) It is a tree-like nexus of associations at whose terminal nodes are stored <u>images</u> of encodings of external stimuli. At the non-terminal nodes of the net are stored <u>tests</u> which examine particular bits of the encodings. The image of a stimulus is retrieved by sorting

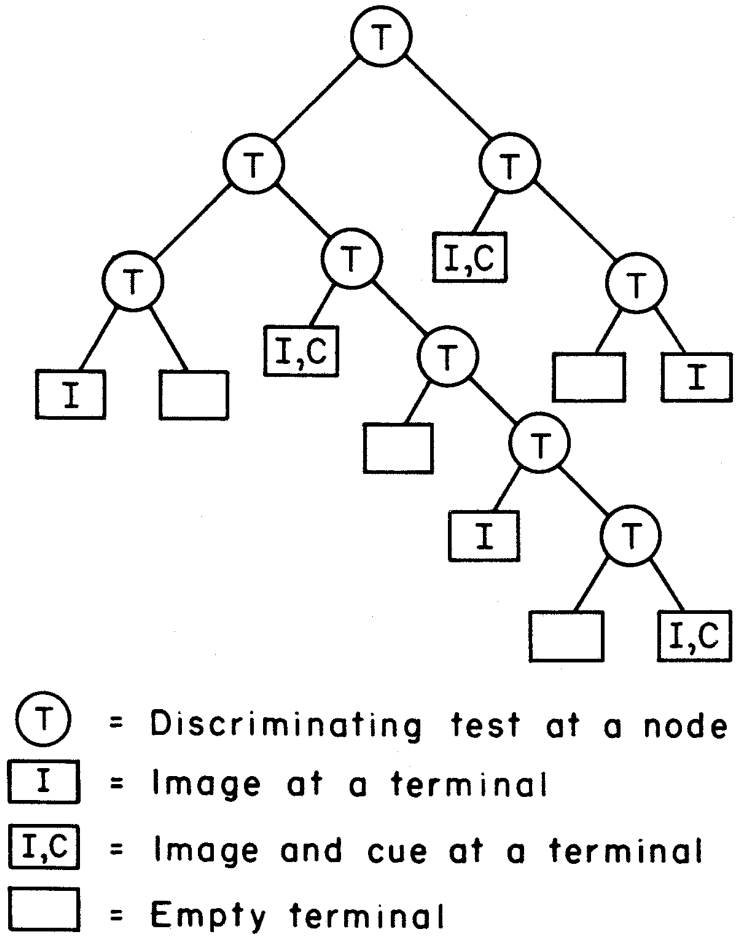

Fig. 1 — EPAM performance process for producing the response associated with a stimulus

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 <u>cue</u> <u>image</u> of y) along with the image of x. The system determines by trial and error how much 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

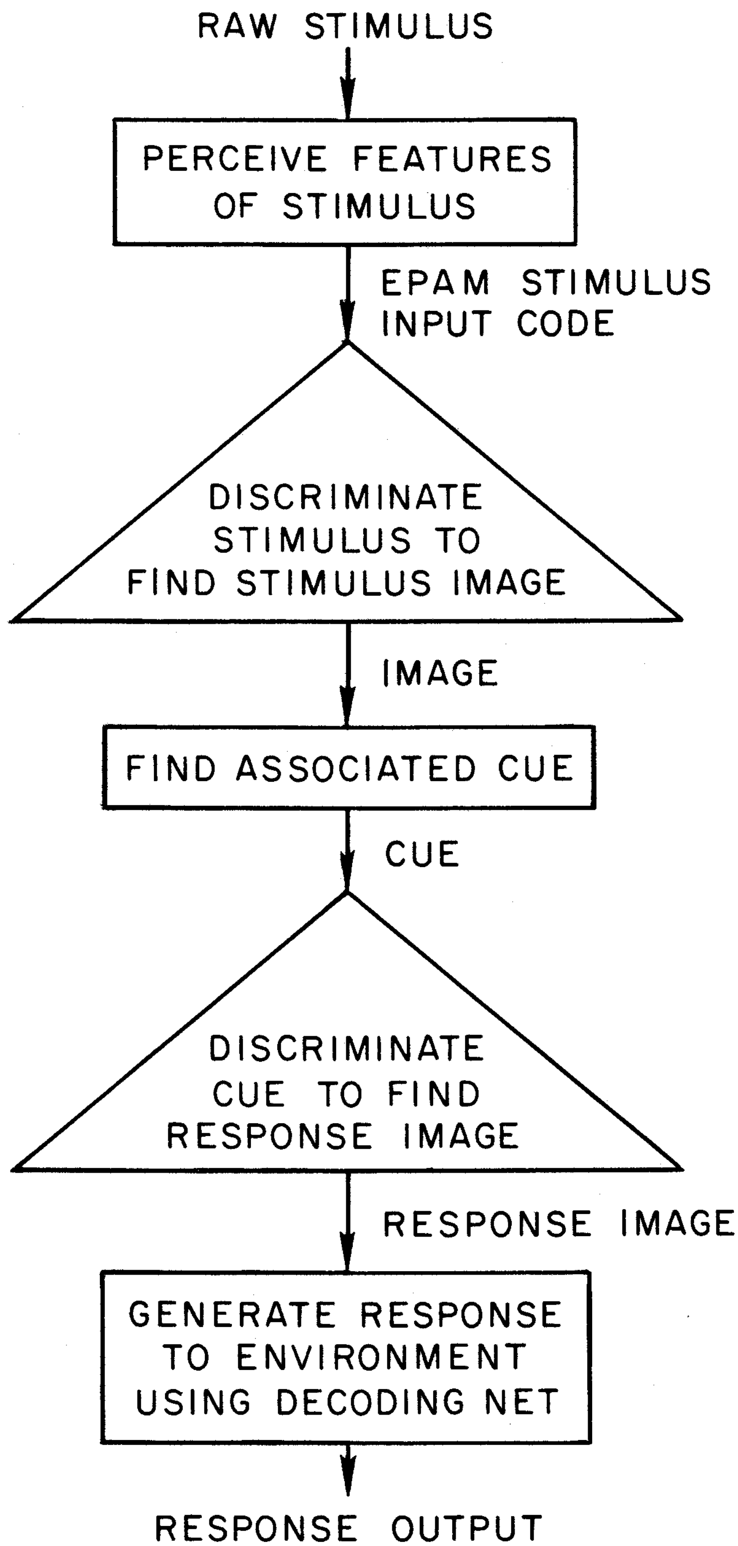

Fig. 2—A typical EPAM discrimination net

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 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.

Paired Associate Learning

A typical rote memory experiment, using the method of paired associates, is performed as follows:

A set of nonsense syllables (each, say, a sequence of three letters of the alphabet) is chosen, and the syllables are paired. The syllables are shown to the subject, one pair at a time. First the initial member of a pair (stimulus item) is shown. The subject tries to spell (or pronounce, depending on the instructions) the second member of the same pair (response item). After a short interval, the stimulus and response items of the pair are shown to him simultaneously. After a few seconds, the cycle is repeated with a new pair of syllables; this continues until all pairs have been presented (a trial). Trials are repeated, usually until the subject is able to give the correct response to each stimulus. In successive trials the syllable pairs are reordered randomly, so that they are not always presented in the same sequence.

In the form of the experiment we have described, both the stimuli and the responses were presented to the subject in the same mode--in this case, the visual literal mode. Moreover, the responses were to be made in the oral mode--either by pronouncing the syllables or by pronouncing the names of their letters. There is no reason why the stimulus and the response cannot be presented to the subject in quite different modes, and it is clear from the example that the subject's response can represent a sense modality (in this case oral) entirely distinct from the modality (in this case visual) of either the stimulus or the response presented to him. Thus, the stimulus items could be presented to the subject as aural phonemic syllables, the response items as visual objects (or visual pictures of objects). The subject could respond to the aural phonemic syllable by pointing to the corresponding object (or picture) selected from a set of objects. Let us call a paired associate task using this combination of modes a task of Type I.

Another possible combination of modes would be to present the stimuli to the subject as visual literal (printed) symbols, the responses as aural phonemic syllables, and instruct the subject to respond to the stimulus with the appropriate oral phonemic syllable. Let us call the paired associate task using this combination of modes a task of Type II.

Learning to Read

We shall now show that a system capable of performing paired-associate rote memory tasks in an appropriate range of modes is capable of reading names of objects--where "read" is understood in its usual sense of "scan visually and behave appropriately."

First, let us consider the behavior usually observed in children as they are learning spoken and written language. At an early age, a child acquires the ability to mimic simple aural phonemes. That is, he builds up associations from each aural phoneme to the oral phoneme that will produce sound corresponding, when fed back to the ear, to the aural phoneme. Also at an early stage, a child acquires the ability to "understand" simple aural phonemes that correspond to names of objects. That is, if an adult repeatedly pronounces the name of an object and then points to the object, the child gradually acquires the ability to point to the object when he hears its name. At a much later stage, the child acquires the ability to read simple printed words: that is, when he perceives a visual literal stimulus, he responds by pronouncing the appropriate word. At about the same time, he learns the "meaning" of the word: that is, when he perceives the visual literal stimulus, he can respond by pointing to the corresponding object or picture of an object.

Let us consider the case of a child who can already produce orally words that he is familiar with aurally--who can mimic familiar speech sounds. For this child, learning the meanings of aurally presented words (i.e., so that he can respond to them by pointing), is a paired associate task of Type I. For the child then to learn to read visually presented words is a task of Type II. After the child has accomplished the Type I and Type II tasks for some set of words, he will be able to perform the third task of demonstrating that he can read "meaningfully" by pointing to the objects whose printed names he encounters.

This sequence of learning experiences was simulated successfully for the first time with EPAM in November 1960. The four words "dog," "cat," "car," and "ball" were used in the experiment. Encodings were constructed corresponding to (1) characteristics of the visually-presented objects, (2) characteristics of their aurally presented names (DAWG, KAT, KAHR, BAWL), and (3) characteristics of their visually presented names (DOG, CAT, CAR, BALL). EPAM was assumed already to possess the means for producing responses associated with stimuli in a given sensory modality. That is, once EPAM had become familiar with an aural word, it could emit the corresponding oral response; once familiar with a printed word, it could emit the corresponding printed response; once familiar with an object, it could point at it. Acquiring these correlations is another learning task that was not considered in this particular experiment.

EPAM was presented with a sequence of three tasks, corresponding exactly to the sequence of learning experiences we described for the child. The first task, of Type I, presented aural phoneme syllables paired with objects, and called for a pointing response. The second task, of Type II, presented visual printed words paired with aural words, and called for an oral response. The third task presented printed words by themselves, and called for a pointing response. In the first task, EPAM learned the spoken words corresponding to printed words. In the third task, it demonstrated reading ability, responding to printed words by pointing to the objects they named. In the actual experiment, EPAM required four trials to perform the first task correctly for all four words, four trials for the second task, and performed the third task correctly on the first trial. Because the data are not voluminous, we give, below, the actual responses EPAM made on each presentation of a stimulus on each task.

FIGURE 3. PERFORMANCE OF EPAM IN READING EXPERIMENT

1. Presented Stimulus--aural phoneme (e.g., DAWG)
Presented Response--visual object (e.g., dog)
Subject's Response--pointed at object (e.g., dog)

TRIAL	PRESENTED STIMULUS	SUBJECT'S RESPONSE
1	KAHR	----
	DAWG	car
	KAT	car
	BAWL	car
2	KAHR	car
	DAWG	ball
	KAT	----
	BAWL	ball
3	BAWL	ball
	KAHR	car
	KAT	cat
	DAWG	----
4	BAWL	ball
	KAHR	car
	DAWG	dog
	KAT	cat

Figure 3 (continued)

2. Presented Stimulus--visual printed word (e.g., DOG)
Presented Response--aural phoneme (e.g., DAWG)
Subject's Response--oral phoneme (e.g., DAWG)

TRIAL	PRESENTED STIMULUS	SUBJECT'S RESPONSE
1	CAR	----
	DOG	KAHR
	CAT	KAHR
	BALL	----
2	DOG	----
	BALL	BAWL
	CAT	BAWL
	CAR	KAHR
3	DOG	DAWG
	BALL	BAWL
	CAT	----
	CAR	KAHR
4	DOG	DAWG
	CAT	KAT
	BALL	BAWL
	CAR	KAHR

3. (Reading Test)
Presented Stimulus--visual printed word (e.g., DOG)
Subject's Response--object pointed at (e.g., <u>dog</u>)

TRIAL	PRESENTED STIMULUS	SUBJECT'S RESPONSE
1	CAR	<u>car</u>
	DOG	<u>dog</u>
	CAT	<u>cat</u>
	BALL	<u>ball</u>

In performing the reading task, EPAM sorted the visual literal stimulus, finding the cue for the associated aural word. The aural cue was then sorted to find the associated visual object cue. The object cue was sorted to find the visual response image needed to activate the pointing program. Thus the association between printed word and its "meaning" was mediated via the aural mode. This mediation might explain the fact that beginning readers commonly move their lips, but it does not necessarily imply muscular oral responses, for the auditory symbols used in the mediation belong to the sensory, rather than the motor, part of the system. EPAM's associational processes could construct new direct associations between visual literal stimuli and visually presented objects, but these additional learning processes were not postulated in the version of EPAM that was tested in the reading experiment. In our culture, oral language is almost invariably acquired first, and there is some evidence that even in most adults the aural mode performs a mediating function for word associations.

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