University of California

SIMULATION OF COGNITIVE PROCESSES PROJECT

A Progress Report to the
Carnegie Corporation of New York

Edward A. Feigenbaum and Julian Feldman

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This is a report on the progress of the Simulation of Cognitive Processes Project during its second year. The activities reported are primarily the research activities having as their goal the advancement of models and model-building techniques in the area of information processing theories of human mental processes. The project continues to have an education orientation seeking to stimulate interest and activity in simulation of cognitive processes (both student and faculty) on the Berkeley campus.

1. The Research Program

1.1 Computer simulation of verbal learning behavior

Work on EPAM (Elementary Perceiver and Memorizer), an information processing theory of human verbal learning behavior, continued as a major focus of attention in this project. The work consisted of further experimentation with the EPAM II model, continued development of the EPAM III model, and the study of processes of long-term memory and associative retrieval of information in such a memory.

Much of the recent literature in verbal learning has been concerned with the phenomena of the so-called "short-term" memory. A study was made of the relation of EPAM II
to this experimental literature, and a simulation was done of a key experiment, that of Shepard & Teghtsoonian (Jour. Exp. Psych., Sept., 1961) on continuous, short-term recognition memory (extended by Melton).

Using EPAM II, a simulation was made of a complex paired-associate transfer experiment done by Postman involving the various effects inter-list identity of stimuli, responses, and both (but different pairings). In connection with these simulation efforts, and in an attempt to simplify the model, changes were made in the EPAM II executive programs. A forthcoming EPAM monograph will contain complete reports of these simulations.

Of primary importance in the EPAM work was the further development of the EPAM III model, a generalization of the earlier models. This work has been carried out jointly with Professor H. A. Simon of Carnegie Institute of Technology. EPAM III is described in Working Papers 8 and 13. A number of simulated experiments were run with an initial version of the EPAM III model. These experiments dealt with effects of intra-list and inter-list similarity of verbal materials; familiarization processes; and the relation between familiarity and meaningfulness (see Working Paper 13). Recent work on EPAM III has moved in the direction of producing a carefully polished and "clean" version of the program in IPL-V so that the actual detail of the model can have "public" availability.

During the past year, the project sponsored a Psychology Department Ph.D. thesis effort related to EPAM III. The
thesis, by Max Allen (still in process), will contain an EPAM-like information processing model for generating "free-
recall sequences.

The development of EPAM III has led to a number of interesting and important theoretical questions concerning the discrimination net as a classification and memory structure. For example, one set of questions concerns net-growing processes in which a node could contain not only a discriminating test but also an image of the class of objects discriminated below the node. Another set of questions, suggested by the "token" system for building images used by EPAM III (see Working Paper 8), concerns the growth of large, richly interconnected net structures as models of long-term associative memory. Problems of forming and searching these nets have been studied during the year by Zvegintzov with his ZEPAM network retrieval schemes (see Working Papers 15 and 16); by Gordon on the heuristics of search in memory networks; and by Churchman and Feigenbaum on EPAM-like memory and retrieval processes as a source of "ideas" for the model-building processes of an Inquiring System (IS-1).

1.2. Computer models of Binary choice behavior

Our efforts in this area during the past year have been directed toward the development of more flexible models of behavior in binary choice experiments and toward a better understanding of temporal concept formation.
The theoretical development has taken as a starting point Foulkes' program for determining the structure as a source of binary events. Foulkes' program develops a representation of the source in the form of a net. The original program is incomplete as a model of human behavior because it does not specify the behavior at the terminal nodes of the net. However, its general form permits modification in desired directions. Furthermore, the resemblance of Foulkes' model to computer models of learning (Feigenbaum and Simon) and concept formation (Hunt) is encouraging.

We have completed one experiment in which a 1000 trial sequence of binary events, generated from the source used by Foulkes as an example, was presented to subjects. The structure of the subjects' responses at the completion of the experiment is, as the model predicts, very similar to that of the source. However, there are discrepancies between model and behavior in the development of the structure. Our analysis has also revealed information about behavior at the terminal nodes of the net that will be useful in making the Foulkes' program a complete model of human behavior.

Hanna has been developing a class of eclectic models to predict aggregate trial-by-trial behavior in two-choice experiments. The models include ideas from stimulus sampling theory, Foulkes' program, and hypothesis testing models. In these models the prediction process has two parts: the selection of a state and the selection of a response appropriate
to the state. The states are sequences of preceding events. The selection of states and appropriate responses are determined by processes that are reinforced independently. The trial-by-trial behavior of the models is remarkably similar to that of human subjects. Hanna is pursuing this work in his doctoral dissertation.

We have also been conducting experiments designed to gather some basic information on temporal concept formation. In preliminary experiments we have presented subjects with a large set of 8-bit sequences to determine the repertoire of responses. The use of a smaller set of these 8-bit sequences and their complements indicates that subjects make the same response to both the original sequence and its complement. We have recently concluded an experiment designed to measure the difficulty of various two-symbol, cyclic patterns. Difficulty is a function of cycle length, number of runs in a cycle, and whether cycles begin at the beginning of a run. We have several other experiments planned in this series, among them an investigation of the relationship between temporal concepts and symbol alphabets.

1.3. Inquiring Systems Project

The Inquiring Systems project is a long-term effort that was begun during the year by C. W. Churchman and R. A. Feigenbaum. In general, it is concerned with studying the processes by means of which information processing systems inquire intelligently about objects and events in their environments. The following kinds of questions are being asked:
How shall the Inquiring System build an internal symbolic model of its external environment (a "cognitive map", in Tolman's language)?

What are the processes of human inductive inquiry?
How shall we construct a simulation model of theory-making behavior?

More particularly, what are the processes that relate prior experience, as stored in a large, highly-interconnected associative network, to model building and theory formation? How can the EPAM memory model be extended to serve as a model of such an experience network? What can we find out about human creativity and innovation by studying the interaction of associative memory with inquiring processes?

Presently, an initial formulation of a system, called IS-1, is being developed.

1.4. Relationship between the organization of computer programs and human organization

The development of large-scale computing systems and large scale programs has led to problems not unlike those encountered in human organizations. Our current thinking is that some interaction between the work of organization theorists, computer designs, and program designers might well be mutually beneficial. Some of our work during the past year
has been directed into this area. In one paper, Feldman has considered the organization as a problem solver and suggested that the two basic forms of problem-solving programs—working forward and working backward—might well have corresponding forms in organizational structures. A review of organizational decision making by Feldman and Kanter makes use of these ideas and analogies. Zvegintzov’s paper suggests that computer programs that incorporate some of the features of real organizations might well be superior to present programs which tend to resemble only formal organizations.

1.5. Real-time interaction with computers

Since the computer is our primary working tool, we feel it is important to keep abreast of the state-of-the-art in computers as it progresses. Therefore, this year, as in the past, we have continued to be active in advanced computer techniques.

In particular, we have been studying the methods and problems in real-time communication with a large computer. Zvegintzov and Feigenbaum have programmed for and experimented with an existing real-time system on the RAND Johnniac (using IPL-4). A system that will allow “instant access” to a large computer from many remote consoles will shortly come into being on the Berkeley campus, partly through our efforts.

Real-time computing has important implications for this project. It will greatly amplify individual productivity in
the programming, debugging, and empirical exploration of our simulation models (since "turn-around time" will be counted in seconds and minutes rather than hours and days). And it will allow complex experiments on human information processing to be performed in the laboratory under computer control.

The new laboratory of the Management Science Center (the research center in which our project is housed) will have the most advanced real-time computing facilities. Construction of the laboratory will start in the Summer of 1964.

2. Educational Activities

We have continued to offer a graduate course in artificial intelligence and simulation of cognitive processes. The publication of our collection of readings (Computers and Thought; see Section 5.2) and other pedagogical material (IPL problem lists and a detailed manual on the Logic Theorist, both produced at RAND) will enable us and others to teach such courses more effectively.

Non-credit courses in list processing languages were also offered. However, in the future, we hope to experiment with TIPL — a teaching program for IPL-V developed by R. Dupchek.

3. Research in Computer Languages

Robert Hsu has specified a natural-language-type source language that will compile into IPL-V. Karen Young has made a comparison between various simulation languages. We have also
been forced to spend some effort in incorporating IPL-V into various monitor systems as the Berkeley Computer Center adopts various systems.

4. Fellows and Research Assistants

Dennis Allen, undergraduate in Mathematics: Programmer
Max Allen, graduate student in Psychology: Thesis-Completion Fellow.
Janet Cornsweet, experimental psychologist: Graduate Research Associate.
Joseph Hanna, graduate student in Logic and Methodology of Science: Thesis-Completion Fellow.
Howard Sturgis, graduate student in Mathematics: Research Assistant (Programmer).
Nicholas Zvegintzov, graduate student in Business Administration: Research Assistant.

5. Papers, Publications and Presentations

5.1. Working Papers


5.2. Other Publications


5.3. Some Related Professional Activities and Presentations

5.3.1. E. A. Feigenbaum:

Co-Chairman, discussion panel on Inquiring Systems at the 1963 national meeting of the Operations Research Society of America.

Participant in the First (of six) Princeton Conference on Remembering, Learning, and Forgetting, sponsored by the American Institute of Biological Sciences.

Faculty member at the SSRC-NSF summer institute in Simulation of Cognitive Processes at the RAND Corporation, June-July, 1963.

Director of a small summer program, for graduate students, in Simulation of Cognitive Processes, held at the RAND Corporation in summer, 1963 (sponsored by the Carnegie Corporation of New York).

Talk at Psychology Department Colloquium, University of Michigan, "Information Processing Theory of Verbal Learning."

Talk at University of Oregon, "Information Processing Models of Memory and Verbal Learning."
5.3.2. **Julian Feldman:**

Talk at University of Texas, March, 1963, "Toward a Theory of Temporal Concept Formation."

Talk at University of Colorado, April, 1963, "Some Implications of Computer Models of Binary Choice Behavior."

Chairman, research session at ORSA Meeting, Cleveland, May, 1963 — "Decision-Making Behavior Under Conditions of Risk and Uncertainty—What Have We Learned From Experimental Studies?"