University of California

SIMULATION OF COGNITIVE PROCESSES PROJECT

An Interim Report to the
Carnegie Corporation of New York

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This is a brief interim report on the progress of the Simulation of Cognitive Processes Project during its third year. The project has been extended until October, 1965, and a complete report will be submitted at that time.

Information Processing Models of Verbal Learning and Memory

Modeling of human verbal learning processes is inextricably intertwined with modeling of the information structures of associative memory. Many of the learning effects accurately simulated by the EPAM model, the development of which has been supported by this project, are consequences of the particular memory structure hypothesized and employed. To a greater extent than in previous years, work has been directed toward the exploration of memory processes and memory structures.

A synthesis of the implications of previous EPAM work for the theory of short-term and long-term memory appears in a paper by Feigenbaum, delivered at a symposium on Information Processing in Memory at the September, 1964 meetings of the American Psychological Association. (Elements of an Information Processing Theory of Memory, currently being revised for publication.) In this paper it is suggested that a logical
extension of EPAM, consistent with the laboratory evidence for "consolidation," would be sufficient to account for proactive inhibition.

Further experimentation with the EPAM III Model, in conjunction with Professor H. A. Simon of Carnegie Institute of Technology, led to the following explanation of the facilitation effect of high degrees of meaningfulness of verbal items upon rate of learning: that the facilitiation is a consequence of the relatively high familiarity of subjects with items that are highly meaningful, rather than a consequence of the "meaning" the symbols might have. Accurate quantitative predictions were made which support this position. The study was published in October, 1964 in the Journal of Verbal Learning and Verbal Behavior. (An Information Processing Theory of Some Effects of Similarity, Familiarization, and Meaningfulness in Verbal Learning, Vol. 3, No. 5, October 1964, pp. 385-396. Simon and Feigenbaum.)

A Ph.D. thesis by Max Allen, (Effects of Formal Similarity on Three Measures of Retention in Verbal Learning, Ph.D. Thesis, University of California, Berkeley, 1964.) done under the supervision of Postman and Feigenbaum, resulted in a new variant of the EPAM model called FREPAM, for Free Recall EPAM. It contained additional postulates concerning memory organization and retrieval processes under conditions of free recall, and was moderately successful in predicting the organizational trends in free recall output by subjects, as measured by certain indices of "subjective organization."

Nicholas Zvegintzov, a research assistant on the Carnegie project, continued work on tree structures for information storage and retrieval.

Finally, Feigenbaum participated in the Second Conference on Remembering, Learning, and Forgetting, Princeton, September 27 - 30, 1964, sponsored by the New York Academy of Sciences Interdisciplinary Communication Program. This was the second of five annual conferences bringing together psychologists, neurophysiologists, biochemists, cyberneticians, etc., to discuss the problems of memory and learning processes. The proceedings of the first two conferences are being edited now for publication. (Remembering, Learning, and Forgetting: Proceedings of the First Conference, D. Kimble, editor, Science Books, 1964 in press.)

Models of temporal concept formation.

The general goal of this project is an understanding of how humans process temporal information. This problem is a sub-problem of the more general problem of induction -- the organization of information and the development of models of information sources. The importance of this problem derives from the general importance of the problems of induction and temporal information processing, the relationship of these processes to the behavior of scientists, and the paucity of our knowledge about how humans process temporal information.

The research is taking place in the context of the study of binary choice behavior -- an experimental situation in which the subject is asked to predict a sequence of binary symbols. In earlier studies, the pattern-
seeking behavior of subjects asked to predict random sequences was studied. More recently, the experimental strategy has been to work with structured sequences.

The general procedure has been to study the behavior in the laboratory and then formulate models of the behavior as computer programs. More recently, ideas for models have come from research in artificial intelligence, and experiments have been designed to develop these ideas.

During the past year the research has been carried forward in both theoretical and empirical aspects.

The recent theoretical work has focused around a development of a discrimination net model which has been used in artificial intelligence and as a model for verbal and concept learning behavior. An experiment testing an elementary version of this model was reported in last year's research report. The appropriateness of the model was further substantiated by the behavior of an additional ten subjects. (Feldman and Hanna, The Structure of Responses to a Sequence of Binary Events, paper read at APA Meeting, September 1964.)

The discrimination net model is being extended in the thesis research of J. F. Hanna. Hanna has formulated a stochastic version of the model and has obtained some excellent fits to aggregate trial-by-trial behavior in random and non-random sequences. (A Stimulus Discrimination Model of Binary Choice Behavior, paper read as Psychometric Meetings, October 1964.)

The model is also being extended to develop a facility for building up response chains or mechanisms at the terminal nodes of the net. This aspect of the model corresponds more directly to the hypothesis proffered by subjects in binary choice experiments.
Most of the empirical work done during the past year has taken the form of presenting subjects with patterns of binary symbols in order to obtain information on (1) the effect of certain variables on temporal concept formation and (2) the process of temporal concept formation. The work is currently being documented.

Plans for future work are to continue both the theoretical and experimental progress and bring them together by extending the models to duplication of subjects in non-random sequences. Work will also be started on the induction of models from the observed behavior of subjects.

Other Work in Simulation of Cognitive Processes

Feigenbaum has been working with C. West Churchman, philosopher-of-science and operations research specialist, on the problem of constructing computer simulation models of processes of inductive inference and inquiry. The attempt is to make explicit (in the form of a program) how a person acquires and uses an internal "model" of a set of external events. The scheme presently under development is an "analogy" mechanism. A set of new events evokes a model of an "analogous" situation previously stored, which is then modified to "fit" the new situation. The question of how new events evoke old models is a difficult and interesting one, central to the problem of how innovation in general takes place, and provides the link between this work and the previously-mentioned work on the structure of associative memory.

Stephan Persson, a research assistant, has written a heuristic program (in IPL 5) that infers a model of the structure of a letter or number series, and uses this model to extrapolate the series. Others have
written programs that do similar tasks, but Persson's program is the most flexible and powerful such program yet written.

Barry Gordon, a Psychology graduate student working with Feigenbaum, conceived and executed a remarkable computer-controlled experiment on heuristic problem solving processes in humans solving "creative"-type problems, e.g., Crutchfield's problems. Since the information given to a subject at a given time is contingent, in a complex way, upon all the previous responses that particular subject has made up to that time, a computer is used (via an electric typewriter) to record and analyze subject's responses and to present stimuli. The purpose of the experiment is to elicit, as fully as possible, the heuristics by means of which a person decides how far along a search path to explore, what value particular points in the search space have, where to return to in the search space if unsuccessful, and so on. (When to Turn Back: a Proposal for the Detailed Study of One General Heuristic Simulation of Cognitive Processes Working Paper No. 23, March 1964.) The experiments were done on an SDS 930 Computer belonging to the ARPA Computer Science Project at Berkeley.

Other Professional Activities

In October, 1964 Feigenbaum visited the Soviet Union on invitation from the USSR Academy of Sciences (Scientific Council on Cybernetics) to deliver a series of lectures on heuristic programming and simulation of cognitive processes in Moscow, Leningrad, Kiev, and Novosibirsk. His visits to many cybernetics and biocybernetics research groups, Institutes, and Computer Centers will be reported on in a paper currently in preparation.