STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

June 15, 1962

Mr. Richard H. Wilcox, Head
Information Systems Branch
Department of the Navy
Office of Naval Research
Washington 25, D. C.

Proposal for Research

SRI No. ESU 62-60

Extention of Contract Nonr 3438 (00)

RESEARCH ON SELF-ORGANIZING MACHINES

Dear Mr. Wilcox:

In accordance with our discussions held on May 15th, we are submitting, herewith, a proposal to extend Contract Nonr 3438 (00) to provide funds for the continuation of work in several important areas of learning-machine research. In particular, it is proposed that the major part of the future effort be concentrated in studies of:

I. Interpolation or function-modelling in multi-variable systems, using learning machine organizations of combined fixed and adaptive networks of threshold logic elements.

II. Learning machine structures composed of cascaded adaptive layers, with prime emphasis on the development of methods and criteria useful in obtaining convergence in iterative "teaching" processes.

PROPOSED WORK

I. Interpolation and Function Modelling

In initial studies it was found that a simple learning machine structure embodying one layer of adaptive networks and a layer of determinate output wiring could be made to closely model one class of functions of several variables. More powerful classes of functions could be modelled by increasing the number of adaptive weights and threshold units together with increased complexity of the determinate input wiring. A better approach, which is as yet unproven, appeared to be the use of cascaded adaptive layers. Unfortunately, this latter

approach could not be suitably investigated until some algorithm could be devised to ensure convergence of several layers of adaptive weights arranged in cascade. Thus a major part of the effort has been devoted to improving the single-layer (adaptive) structure as a prerequisite to further progress in multi-layer structures. Concurrently, studies have been going on continuously to devise the required convergence procedure for multi-layered adaptive networks.

In addition to the obvious applications of function modelling machines to problems of prediction and control, such machines could be useful as scientific research tools. For example, in the study of meteorology, one may be able to obtain empirical functional relationships amongst important variables as temperature, pressure, humidity, etc., by dissecting the terminal state of a learning machine which has been trained to model a particular weather situation.

It is proposed to continue this work utilizing essentially the following procedure:

(1) Several different organizations of single-adaptive-layer structures will be evaluated and compared using digital computer simulation.

(2) Mathematical analyses of the known structures will be made to ascertain, if possible, the class of functions which can be modelled by each of these structures. Ideally, such analyses would include studies of methods for obtaining useful approximations of the functional relationships using the converged values of all the adaptive weights and the known structural connections.

(3) Guided by the results of the above studies, modified and new structures will be devised and similarly investigated.

(4) If and when promising results are obtained in the cascaded adaptive-layer studies, the above procedures will be applied to these new structures for comparison and for optimization based on the results of the two sets of studies.

II. Cascaded Adaptive Layers

For simplicity this discussion will be limited to learning machines which contain only two cascaded layers of adaptive weights. The central problem consists in discovering the dynamics of change in the weights of both layers, operating either sequentially or simultaneously, such that under an iterative error-correction procedure, convergence to desired solutions is guaranteed, if convergence is possible. Prior work in single-adaptive-layered structures, while helpful in providing

considerable insight into the various facets of this problem, does not lead directly, by extension, to a solution. There have, however, been built up some mathematical tools which are useful for analysis, including the matrix formulation of the structure and dynamics of a learning machine, and the use of binary n-dimensional hyperspace geometry. While application of these tools does not yet permit the charting of a clear path to solution, they do serve as conceptual springboards for synthesizing new structures and dynamics.

Several interesting two-layer systems have been devised and tested with partial success. It is not known, at present, whether failure to converge was due to a poor choice in the dynamics of weight change or because no solution did in fact exist for the particular structure and input pattern set chosen for this problem. These will be investigated further.

It is proposed to continue this work with major emphasis in the following areas:

(1) Promising schemes will be further elaborated and tested by digital computer simulation.

(2) Mathematical tools will continue to be developed and applied to the solution of such problems as they arise, hopefully leading to rigorous proofs of convergence (or non-convergence) of postulated models.

PERSONNEL

This work will be conducted by members of the Applied Physics Lab, Mathematical Sciences Department and General Systems Department. The following key personnel will be involved on this program:

N. J. Nilsson - Research Engineer, Applied Physics Laboratory

Dr. Nilsson received an M.S. degree in Electrical Engineering in 1956 and a Ph.D. degree in 1958, both from Stanford University. While a graduate student at Stanford, he held a National Science Foundation Fellowship. His graduate field of study was the application of statistical techniques to radar and communications problems.

In July 1961 Dr. Nilsson completed a three-year term of active duty as a Lieutenant in the U.S. Air Force. He was stationed at the Rome Air Development Center, Griffiss Air Force Base, New York. His duties entailed research in advanced radar techniques, signal analysis, and the application of statistical techniques to radar problems. He has written several papers on various aspects of radar signal processing. While stationed at the Rome Air Development Center, Dr. Nilsson held an appointment as Lecturer in the Electrical Engineering Department of Syracuse University.

In August 1961 he joined the staff of Stanford Research Institute, where he is participating in the studies of pattern recognition and self-organizing machines.

Dr. Nilsson is a member of Sigma Xi, Tau Beta Pi, and the Institute of Radio Engineers.

Albert B. J. Novikoff - Mathematician, Mathematical Sciences Department

Dr. Novikoff received an A.B. degree from Brown University in 1945 and a Ph.D. degree from Stanford University in 1949, both in Mathematics. He was an Atomic Energy Commission Pre-Doctoral Fellow in Mathematics. From 1950 to 1952 he was an Instructor of Mathematics at Johns Hopkins University. In 1952 he became a Research Associate in the Radiation Laboratory of that University, where his work included the applications of probability and Fourier methods to noise problems and also the study of signal analysis. From 1956 to 1958 he was an Instructor of Mathematics at the University of California, especially concerned with Lie theory and differential geometry.

In June 1958 Dr. Novikoff joined the staff of Stanford Research Institute, where he has been working on probability applications to antenna measurements, theoretical network analysis, equipment location, and classical mechanics, signal discrimination, and character recognition.

In 1961 he was for the third summer an invited lecturer at the Intensive Course in Random Processes given at the University of Michigan, and participated in the Second Symposium on Self-Organizing Systems at the University of Illinois.

At present he is devoting one-third time to assisting Professor S. Karlin of Stanford University in preparation of a book on "Total Positivity," a theory with applications to mechanics, differential equations, probability, and statistics.

Dr. Novikoff is a member of Sigma Xi, the American Mathematics Society, the Mathematics Association, the Canadian Mathematics Congress, the Societie Mathematique de France, the Society for Industrial and Applied Mathematics, and the Institute of Mathematical Statistics.

Jack W. Machanik - Research Engineer, Systems Engineering Department

In January 1962 Mr. Machanik joined the staff of Stanford Research Institute, where he is currently engaged in engineering systems studies, including applications of adaptive systems. He received his B.S. degree in Electrical Engineering from the University of the Witwatersrand, Johannesburg, South Africa in 1954; his M.S. degree in Electrical Engineering from Stanford University in 1957; and is now completing work on a Ph.D. degree from Stanford University, specializing in Management Science.

During 1955 and 1956 Mr. Machanik was an International Exchange Fellow in the General Electric Company's training program for graduate engineers, while employed in the High Voltage Laboratory at Pittsfield, Massachusetts; the Radio and TV Department at Syracuse, New York; and the Advanced Circuit Section of the Electronic Laboratory at Syracuse, New York. He worked on standards, printed circuit techniques,and circuit development with solid-state compounds.

While at Stanford University Mr. Machanik was a Research Assistant in the Physics Department, working on infrared microspectroscopy. Rejoining the General Electric Company at Palo Alto in 1958, he worked on circuit and logic design of the ERMA computer program. During 1960 he served as a research officer in the National Physical Research Laboratory of the Council for Scientific and Industrial Research in South Africa, where he was responsible for the design of electronic systems and instrumentation.

Mr. Machanik has served as a consultant to the General Electric Computer Laboratory in the application of adaptive system techniques to improve the reliability of systems with mass fabricated components.

Richard C. Singleton - Research Mathematical Statistician, Mathematical Sciences Department

Dr. Singleton received both B.S. and M.S. degrees in Electrical Engineering in 1950 from the Massachusetts Institute of Technology. In 1952 he received the M.B.A. degree from Stanford University Graduate School of Business. He holds also the degree of Ph.D. in Mathematical Statistics from Stanford University, conferred in 1960. His Ph.D. research was in the field of stochastic models of inventory processes, applying the general theory of Markov processes.

Dr. Singleton has been a member of the staff of Stanford Research Institute since January 1952. During this period, he has engaged in operations research studies, in the application of electronic computers to business data processing, and in general consulting in the area of mathematical statistics.

His experience at the Institute includes: (1) a study of the market and possible applications for a new digital computer; (2) a study of the potential computer applications in a large bank; (3) a computer feasibility study and implementation project for an electric utility firm; (4) a study of the equipment requirements for the mechanization of the passenger reservation system for a major airline; (5) a computer feasibility study and implementation project for an insurance company; (6) an operations research study of the supply system of one of the military services; (7) research on the theory of self-organizing machines, and (8) research on the theory of magnetic core switch design. He has written several articles for professional journals.

Before joining the Institute staff in 1952, Dr. Singleton's industrial experience included work in the product engineering and industrial engineering departments at Philco Corporation in Philadelphia,and employment as the chief engineer for a radio broadcasting station. He acted as an instructor while doing graduate work at M.I.T.

Dr. Singleton is a member of a number of professional societies, including the Institute of Mathematical Statistics, the Institute of Radio Engineers, the Operations Research Society of America, the Research Society of America, Eta Kappa Nu, and Sigma Xi.

Charles A. Rosen - Manager, Applied Physics Laboratory

Dr. Rosen received a B.E.E. degree from the Cooper Union Institute of Technology in 1940. He received an M. Eng. in Communications from McGill University in 1950, and a Ph.D. degree in Electrical Engineering (minor, Solid-State Physics) from Syracuse University in 1956.

During 1940-1943 he served with the British Air Commission as a Senior Examiner dealing with inspection, and technical investigations of aircraft radio systems, components, and instrumentation. From 1943 to 1946 he was successively in charge of the Radio Department, Spot-Weld Engineering Group, and Aircraft Electrical and Radio Design at Fairchild Aircraft, Ltd., Longueuil, Quebec, Canada. During the period 1946-1950 he was a co-partner in Electrolabs Reg'd., Montreal, in charge of development of intercommunication and electronic control systems. During this period he also acted as a self-employed consulting engineer in these fields. In 1950 he was employed at the Electronics Laboratory, General Electric Co., Syracuse, New York, where he was successively Assistant Head of the Transistor Circuit Group, Head of the Dielectric Devices Group, and Consulting Engineer, Dielectric and Magnetic Devices Subsection. In August 1957 Dr. Rosen joined the staff of Stanford Research Institute, where he has been working on applied physics projects.

His fields of specialty include dielectric and piezoelectric devices, electro-mechanical filters, and a detailed acquaintance with the solid-state device field. He has contributed substantially as co-author to two books, Principles of Transistor Circuits, R. F. Shea, editor (John Wiley and Sons, Inc., 1953) and Solid State Dielectric and Magnetic Devices, H. Katz, editor (John Wiley and Sons, Inc., 1959).

Dr. Rosen is a Senior Member of the Institute of Radio Engineers, a member of the American Physical Society, American Institute of Electrical Engineers, and the Research Society of America. He has helped to organize and has been the co-chairman of the Dielectric Devices Subcommittee (28.5 IRE).

ESTIMATED TIME AND CHANGES

Attached is a detailed cost estimate for the proposed amended contract. It is proposed that the present contract termination date,

August 31, 1962, be extended to August 31, 1963, thus providing one year to perform the proposed new work and to report its results.

CONTRACT FORM

It is requested that any contract resulting from this proposal be written on a cost-plus-fixed-fee basis.

ACCEPTANCE PERIOD

This proposal will remain in effect until August 15, 1962. If consideration of this proposal requires a longer period, the Institute will be glad to consider a request for extension of time.

Respectfully submitted,

C. A. Rosen

C. A. Rosen, Manager
Applied Physics Laboratory

Approved:

J. D. Noe

J. D. Noe, Director
Engineering Sciences Division

Office of Naval Research
SRI No. ESU 62-60

BREAKDOWN OF COSTS

Personnel	Man-Months	Rate	Total
Supervisory	1/2	[redacted]	$ [redacted]
Research Engineer	3	[redacted]	[redacted]
Research Mathematician	2	[redacted]	[redacted]
Research Mathematician	3	[redacted]	[redacted]
Research Engineer	3	[redacted]	[redacted]
Editor	1/2	[redacted]	[redacted]
Secretarial and Report	1 1/4	[redacted]	[redacted]
*Total Direct Labor			[redacted]
**Overhead at 100% of Direct Labor			[redacted]
Direct Costs			
Travel and Subsistence			
1 1/2 r/t to East Coast	@ [redacted]		[redacted]
Telephone and Telegraph			[redacted]
Reports			[redacted]
Computer Time			[redacted]
Total Direct Costs			[redacted]
Total Estimated Cost			[redacted]
Fixed Fee at 7% of Total Estimated Cost			[redacted]
TOTAL COST			[redacted]

*Included in direct labor are all salary base costs such as vacation, holiday and sick leave pay, social security taxes and contributions to employee benefit plans.

**The overhead rate quoted represents current cost experience. It is requested that the contract provide for reimbursement at this rate on a provisional basis, subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. The contract should also specifically provide for the inclusion of general research costs as an allowable indirect expense to the extent determined reasonable. (In accordance with ASPR 3-704.)