

UNCLASSIFIED

AD 296 522

*Reproduced
by the*

**ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA**



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

296 522

CATALOGED BY ASTIA

AS AD NO. 296

522

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY

BUFFALO, N. Y.

ANNUAL REPORT

Project PARA
(Perceiving and Recognition Automata)

1 January 1962 - 31 December 1962

Contract Nonr-2381(00)

Prepared by:

J. L. Muerle
J. L. Muerle
Project Engineer

JLM:pjw-7

Approved by:

H. R. Leland
H. R. Leland, Head
Cognitive Systems BranchW. S. Holmes
for W. S. Holmes, Head
Computer Research Department

CORNELL AERONAUTICAL LABORATORY, INC.

BUFFALO, N. Y.

PREPARED BY J. L. Muerle

REPORT NO. _____

1.0 Project Objectives

The objective of Project PARA is to pursue applied research in the application of perceptrons to practical pattern recognition and control problems.

2.0 Project Activity and Accomplishments

The major areas of project activity and accomplishments in each of these areas during the reporting year were: character recognition, cataloging potential applications, and perceptrons as dynamic controllers.

2.1 Recognition of imperfect, mixed-font, alpha-numeric characters

The feasibility of the recognition of mixed-font, alpha-numeric characters in the presence of noise using a three-layer, simple perceptron was experimentally verified. Character recognition experiments were performed, using perceptrons simulated on CAL's IBM-704, with characters taken from real life. The perceptron simulation programs (written just prior to this reporting year) provide retinal matrices up to 128 elements square, up to 50,000 A-units, and as many R-units as are desired. The characters used as stimuli for the experiments are taken from the two local newspapers and a CAL addressograph. Both retouched clean versions and the real-life noisy versions were used.

Experimental results indicated that a perceptron having only 100 to 200 A-units could be trained to perfect recognition of a training stimulus set which contains three different fonts of clean characters. Included in this set are upper and lower case letters and the numerals. Perceptrons trained on these clean characters to recognize one of the characters (single R-unit perceptrons) were able to distinguish about

two thirds of the noisy characters from the character on which they were trained.

Two sources of difficulty in attaining high character recognition capability were discovered during these experiments. The first problem is the obvious one of how to handle the recognition of noisy characters with a perceptron. Training with clean characters is not adequate. Training with noisy characters is a possibility, but is expensive in both stimulus preparation time and training time. The second problem is the recognition of characters translated on the retina to a position different from that on which training was carried out. It was determined that a very small amount of translation can cause poor recognition.

The problem of the recognition of noisy characters prompted a review of some work started late in 1961 on building a mathematical model of the noise present around the characters and then generating A-unit to R-unit weights based on the statistics of the noise model and the frequency of A-unit activity associated with each stimulus class. A more complete description of this noise theory is given in Appendix B.

2.2 Perceptron applications catalog

A lengthy list of potential perceptron applications was prepared in mid-1962 for the dual purposes of uncovering feasible new applications which might be of broad interest to the Navy and of selecting areas for future research on this project. The initial list was purposely prepared without any actual consideration of feasibility and was then refined by discussion at CAL, and, later, discussions with ONR personnel. One of the most interesting applications was that of using a perceptron to control a physical system having a number of parameters interrelated dynamically in such a way as to tend to make the system unstable. A problem of this type is now being investigated on the project.

2.3 Multi-dimensional, adaptive control system

The technique for using a perceptron to provide control of a dynamic system is to train it during human control of the system and then, after training, allow the trained perceptron to make corrective control movements and adjustments without human intervention. Of particular interest is the control of a system which has a number of performance requirements interrelated in such a way as to tend to make it unstable. Control of a helicopter is such a problem, but it is much too complicated to be tractable for a modest, exploratory experiment. The helicopter control problem can be simplified, however, to the point where it still remains a challenging control problem for a human controller and at the same time simple enough for a small perceptron. Such a simplified but still challenging problem has been isolated and initial work on an experiment was started during the reporting year. Planning for this research constituted a major effort during the reporting year and, therefore, the experimental plans and equipment are discussed in some detail in the following paragraphs.

The experimental plan is to simulate the dynamics of a system having control problems similar to those of a hovering helicopter on a computer, in real time, with external controls for a human operator. Provision for real time calculations is made by adding a clock input to the computer. A joy stick will be used for input and a visual display for output, with the joy stick controlling the rotor tip plane angle of the simulated simplified helicopter and the visual display indicating pitch and roll of the tip plane and the position of the helicopter.

The perceptron simulation which will be used in the control experiments will be essentially the same as that used for the character recognition experiments discussed above, but the input patterns will be coded

information concerning course to be traveled or position to be reached, pitch and roll of the simplified helicopter, and some time history of position, pitch, and roll. The R-unit output corresponds to commands such as those provided by the joy stick with a human pilot (rotor tip plane angle). We will attempt to find the parameters of the perceptron providing good control.

The experiments to be performed will consist of a training sequence followed by a testing sequence. Initially a goal will be established. The goal will consist of "flying" to a given destination starting from a reference starting position or of "flying" along a fixed course starting from a reference starting position. During training the human operator will "fly" to the given destination or on the given course using the joy stick and the vehicle dynamics simulated in the computer. The perceptron will observe the patterns of inputs and its R-unit commands will be compared with the command actions of the human pilot. After training, testing will consist of perceptron control of the "flight" using the same simulated vehicle dynamics. Successful training of the perceptron can be measured by the accuracy and speed with which the goal is attained. Figures 1 and 2 in Appendix A are block diagrams of the experimental system under training and testing, respectively.

The experimental runs will range over about 10 seconds, and the range of position, displayed on 5" cathode ray oscilloscope, will be defined by a 64 x 64 point grid. A bright spot on the screen will indicate position, a line segment connected to the bright spot will indicate pitch, and tick marks on the edge of the screen will indicate roll.

The electrical design of the equipment necessary to read pitch and roll from a joy stick and time from a clock into the CAL IBM-704 computer has been completed. The electrical design of the equipment necessary to

display pitch and roll and position on an oscilloscope has been completed and construction of the first chassis is started. Planning the modifications of the perceptron simulation programs, the generation of the simplified helicopter simulation program, the data handling and conversion programs, and the master program to monitor the whole system is under way.

3.0 Publications

The paper "Recognition of Mixed-Font Imperfect Characters" by W. S. Holmes, H. R. Leland, and J. L. Muerle was published in the book Optical Character Recognition edited by G. L. Fischer, Jr., D. K. Pollock, B. Raddack, and M. E. Stevens and published in 1962 by Spartan Books of Washington, D.C.

APPENDIX A
BLOCK DIAGRAMS OF PERCEPTRON
CONTROLLING A DYNAMIC SYSTEM

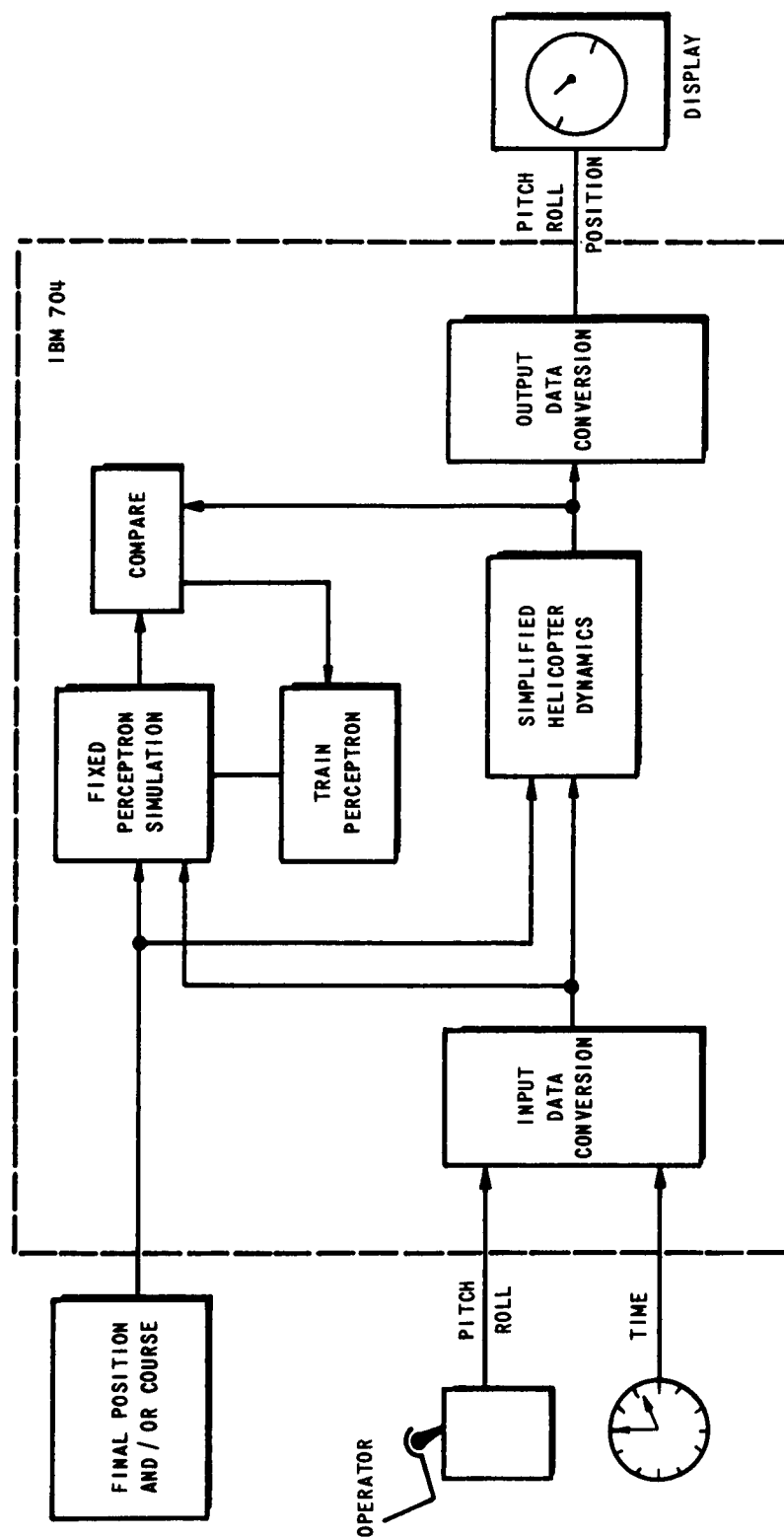


Figure 1 BLOCK DIAGRAM OF EQUIPMENT DURING TRAINING OF PERCEPTRON

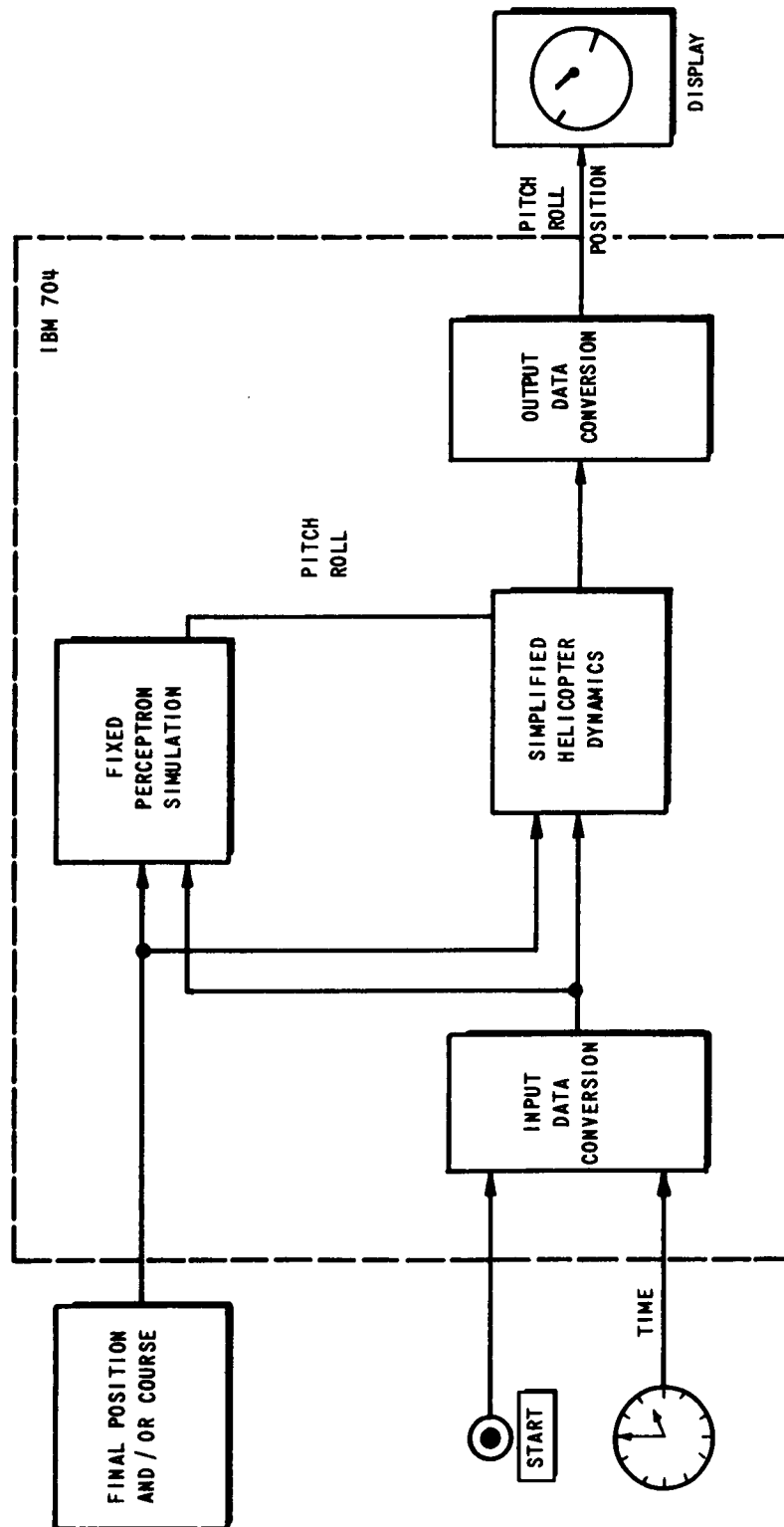


Figure 2 BLOCK DIAGRAM OF EQUIPMENT DURING TESTING OF PERCEPTRON CONTROL

APPENDIX B
WEIGHTS AND ERRORS PROBABILITY
FOR DISCRIMINATION IN A NOISY ENVIRONMENT

APPENDIX B

WEIGHTS AND ERRORS PROBABILITY FOR DISCRIMINATION IN A NOISY ENVIRONMENT

B. 1 Summary

This Appendix describes a method for calculating the A-unit weights to be used in a simple perceptron operating in a noisy environment. The (binary) patterns to be discriminated consist of a set of prototypes divided into two classes and corrupted by noise. The noise is characterized by two parameters: the probability that a cell which is a one in the prototype will become a zero, and the probability that a cell which is a zero in the prototype will become a one. Using appropriate independence assumptions, the statistics of the retinal output, the input to an A-unit before thresholding, and the output of an A-unit are computed in turn. The latter provides sufficient information to compute Bayes' rule weights. These results are then used to derive the probability of misclassification.

B. 2 Introduction

Previous attempts to introduce the effects of noise in pattern recognition apparatus of the perceptron class have assumed that noisy versions of the stimuli will be used in training, thus implicitly introducing the effects of noise, or have assumed that a system trained on noise-free patterns will operate satisfactorily in the presence of noise. The first method suffers from the need for a very large sample and consequently long training periods in order to have some assurance of satisfactory performance. The second method is less satisfactory than the first.

This discussion follows the lead of current statistical communication theory and proceeds as follows:

- 1) Set up a mathematical model of the noise.
- 2) Derive the statistical properties of the proposed discrimination technique in the presence of the noise.

Training is not discussed - in fact it is ignored. Recent experimental results obtained at CAL show that, at least in the absence of noise, very satisfactory discrimination is obtained using weights derived from Bayes' rule. Here we will attempt to describe performance with Bayes' rule weights. If better performance is desired, it is probably easier and cheaper to add A-units than to use a training technique.

B. 3 Noise Model

We consider that the classes to be discriminated consist of binary prototype patterns fixed with respect to the retina, with noise. Specifically excluded in this analysis are the effects of translation, rotation, and scale change, and any interactions of noise with such transformations, or with mechanisms designed to remove their effects. Transformed patterns can, of course, be included as additional prototypes.

The noise is defined by two parameters:

- p_{01} , the probability that a retinal point which is a zero in the prototype will be changed to a one by noise;
- p_{10} , the probability that a retinal point which is a one in the prototype will be changed to a zero by noise.

It is also assumed that the noise at each retinal point is statistically independent. We justify this assumption below.

Using this model we find expressions for some useful quantities.

Let r be the output from some specific retinal point.

For a point for which $r = 1$ in the prototype:

$$E(r) = 1 - p_{10} \tag{B-1}$$

$$E(r^2) = 1 - p_{10} \tag{B-2}$$

$$V(r) = p_{10} (1 - p_{10}) \tag{B-3}$$

For a point for which $r = 0$ in the prototype:

$$E(r) = p_{01} \quad (\text{B-4})$$

$$E(r^2) = p_{01} \quad (\text{B-5})$$

$$V(r) = p_{01}(1 - p_{01}) \quad (\text{B-6})$$

Here $E(u)$ is the expected value of u and $V(u)$ the variance of u over an ensemble of stimuli derived from the same prototype.

B. 4 Machine Model

The pattern recognition machine studied here is familiar as the simple perceptron. It consists of a number of A-units, whose inputs are randomly selected and have unit positive or negative weights. These inputs are summed and compared against a threshold. If the threshold is exceeded, the output of the A-unit is 1, otherwise it is zero. The A-unit outputs are collected in a weighted sum which is again thresholded to produce a classification output.

The symbols used are as follows:

N = total number of inputs to an A-unit

N_e = number of positively weighted inputs to an A-unit

N_i = number of negatively weighted inputs to an A-unit

A = total input to the A-unit for the prototype pattern

a = total input to the A-unit for an arbitrary pattern

$N_{e,0}$ = number of positively weighted inputs which are zero in the prototype

$N_{e,1}$ = number of positively weighted inputs which are one in the prototype

$N_{i,0}$ and $N_{i,1}$ are defined similarly

$$\text{Note that } N_{e,0} + N_{e,1} = N_e \quad (\text{B-7})$$

$$N_{i,0} + N_{i,1} = N_i \quad (\text{B-8})$$

$$N_e + N_i = N \quad (\text{B-9})$$

$$A = N_{e,1} - N_{i,1} \quad (\text{B-10})$$

X = output from the A-unit

Some of the above symbols may acquire additional subscripts when it is necessary to distinguish various prototype patterns.

Since the inputs to the A-unit are selected at random over the retina, any strictly local dependence of the noise will have no effect on the assumed independence of the noise on the various inputs.

The A-unit input a is a random variable which can assume only integral values. Its probability density (for a particular A-unit) can be defined rigorously in terms of the parameters given above and the binomial distribution. The work is tedious and not very illuminating. Let us pass directly to a Gaussian approximation to this probability density. The work is facilitated by the following table which summarizes the A-unit input situation using data from: Equations B-1 through B-6.

Weight	Value of r in Prototype	$E(r)$	$V(r)$	Number of Occurrences
1	0	p_{01}	$p_{01}(1-p_{01})$	$N_{e,0}$
1	1	$1-p_{10}$	$p_{10}(1-p_{10})$	$N_{e,1}$
-1	0	p_{01}	$p_{01}(1-p_{01})$	$N_{i,0}$
-1	1	$1-p_{10}$	$p_{10}(1-p_{10})$	$N_{i,1}$

From the above we compute the expected value and variance of a .

$$E(a) = N_{e,0}P_{01} + N_{e,1}(1-P_{10}) - N_{i,0}P_{01} - N_{i,1}(1-P_{10}) \quad (B-11)$$

$$V(a) = N_{e,0}P_{01}(1-P_{01}) + N_{e,1}P_{10}(1-P_{10}) + N_{i,0}P_{01}(1-P_{01}) + N_{i,1}P_{10}(1-P_{10}) \quad (B-12)$$

The relations (B-7) to (B-10) can be used to reduce the above to the following forms:

$$E(a) = A(1 - p_{10} - p_{01}) + (Ne - N_i)p_{01} \quad (\text{B-13})$$

$$V(a) = Np_{01}(1 - p_{01}) + (2Ne - A)[p_{10}(1 - p_{10}) - p_{01}(1 - p_{01})] \quad (\text{B-14})$$

Other forms are of course possible. If we assume that a Gaussian distribution having the parameters given in (B-13) and (B-14) can be used to evaluate the cumulative probability for a we can pass directly to the probability of activity of the A-unit for this prototype.

$$\text{Prob } (\chi = 0) = G\left(\frac{\theta - E(a)}{(V(a))^{1/2}}\right) \quad (\text{B-15})$$

$$\text{Prob } (\chi = 1) = 1 - \text{Prob } (\chi = 0) \quad (\text{B-16})$$

Where θ is the A-unit threshold and must be an integer + $\frac{1}{2}$

$$G(u) = \int_{-\infty}^u \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt, \text{ a tabulated function.}$$

B.5 Weight Analysis

Equations (B-15) and (B-16) define completely the probability density for a single A-unit output given that the input is derived from a specific prototype, in terms of the noise statistics and the A-unit connection parameters. We now assume the existence of two sets of prototypes which this machine is to attempt to classify correctly using a Bayes' rule classification function. The only other assumption necessary to derive what follows is that the A-unit outputs are statistically independent. This is much harder to accept than the previous independence assumption, but it is supported by recent experimental work at CAL.

The independence assumption leads by a well-known route to the classification function

$$f = \log \frac{\pi_1}{\pi_0} + \sum \log \frac{p_1^{(i)}(x_i)}{p_0^{(i)}(x_i)} \quad (\text{B-17})$$

Where π_1 is the prior probability of class 1

π_0 is the prior probability of class 0

$p_1^{(i)}(x_i)$ is the probability density for the i th A-unit output given that the input belongs to class 1

$p_0^{(i)}(x_i)$ is defined similarly.

If $f > 0$ we say the input belongs to class 1; otherwise to class 0.

Since the x_i are binary, the function

$$\log \frac{p_1^{(i)}(x_i)}{p_0^{(i)}(x_i)}$$

can be written in the form $W_i x_i + b_i$, where

$$W_i = \log \left[\frac{p_1^{(i)}(1) p_0^{(i)}(0)}{p_0^{(i)}(1) p_1^{(i)}(0)} \right] \quad (\text{B-18})$$

$$b_i = \log \frac{p_1^{(i)}(0)}{p_0^{(i)}(0)} \quad (\text{B-19})$$

Thus (B-17) reduces to

$$f = \log \frac{\pi_1}{\pi_0} + \sum_i b_i + \sum_i W_i x_i \quad (\text{B-20})$$

We wish now to use previously developed expressions to define w_i and b_i in terms of A-unit parameters and prototype data.

Let X_{ij} = probability that the i^{th} A-unit output (x_i) is 1 for the j^{th} prototype

R_j = prior probability of the j^{th} prototype

C_0 = set of indices of those prototypes belonging to class zero

C_1 is similarly defined

$$\text{Now } X_{ij} = 1 - G \left(\frac{\theta - E(a_{ij})}{[V(a_{ij})]^{1/2}} \right) \quad (\text{B-21})$$

from (15) and (16)

$$p_0^{(i)}(1) = \frac{1}{\pi_0} \sum_{j \in C_0} R_j X_{ij} \quad (\text{B-22})$$

$$p_0^{(i)}(0) = 1 - p_0^{(i)}(1) \quad (\text{B-23})$$

$$p_1^{(i)}(1) = \frac{1}{\pi_1} \sum_{j \in C_1} R_j X_{ij} \quad (\text{B-24})$$

$$p_1^{(i)}(0) = 1 - p_1^{(i)}(1) \quad (\text{B-25})$$

$$\pi_0 = \sum_{j \in C_0} R_j \quad (\text{B-26})$$

$$\pi_1 = \sum_{j \in C_1} R_j \quad (\text{B-27})$$

$$\pi_0 + \pi_1 = 1 \quad (\text{B-28})$$

Equations (B-13), (B-14), and (B-21) through (B-28) define all the quantities necessary to compute w_i and b_i from Equations (B-18) and (B-19).

B.6 Error Probability

The intent of the following is to develop an expression for the probability of misclassification using the results already obtained.

Assumptions:

- 1) The x_i are independent
- 2) The probability density of f can be approximated by a Gaussian.

Let E = probability of misclassification

f_0 = the classification variable when the input belongs to class 0

f_1 = is similarly defined.

$$E = \pi_0 (\text{Prob. } f_0 > 0) + \pi_1 (\text{Prob. } f_1 < 0) \quad (\text{B-29})$$

The means and variance of f_0 can be found from (B-20) using the following relations:

$$\left. \begin{aligned} E(x_i) &= p_0^{(i)}(1) \\ V(x_i) &= p_0^{(i)}(0)p_0^{(i)}(1) \end{aligned} \right\} \quad \begin{array}{l} \text{when the input} \\ \text{belongs to class 0} \end{array} \quad (\text{B-30})$$

$$E(f_0) = \log \frac{\pi_1}{\pi_0} + \sum_i b_i + \sum_i W_i p_0^{(i)}(1) \quad (\text{B-32})$$

$$V(f_0) = \sum_i W_i^2 p_0^{(i)}(0)p_0^{(i)}(1) \quad (\text{B-33})$$

Similarly,

$$E(f_1) = \log \frac{\pi_1}{\pi_0} + \sum_i b_i + \sum_i W_i p_1^{(i)}(1) \quad (\text{B-34})$$

$$V(f_1) = \sum_i W_i^2 p_1^{(i)}(0)p_1^{(i)}(1) \quad (\text{B-35})$$

Using (B-32) - (B-35) in (B-29) yields

$$E = \pi_0 \left[1 - G \left(\frac{-E(f_0)}{[V(f_0)]^{1/2}} \right) \right] + \pi_1 G \left(\frac{-E(f_1)}{[V(f_1)]^{1/2}} \right) \quad (\text{B-36})$$

which is the desired result.

B. 7 Special Case of Discrimination in a Noisy Environment

Special cases are often useful in furthering understanding. With this objective, we consider the following specialization of the general results described above.

B. 7. 1 Assumptions

The following additional assumptions are used:

- 1) The noise is symmetric $p_{01} = p_{10} = p$ (B-37)
- 2) The number of excitatory connections is equal to the number of inhibitory connections.

$$N_e = N_i = N/2 \quad (\text{B-38})$$

- 3) There are only two input prototypes, one of each class

It is interesting to note that the reduced problem is very much like signaling over a binary symmetric channel, a much-analyzed problem of communication theory.

B. 7. 2 Results

Using the assumptions, key results of the reference become as follows:

$$(\text{B-13}) \quad E(a_{ij}) = A_{ij} (1-2p) \quad (\text{B-39})$$

$$(\text{B-14}) \quad V(a_{ij}) = Np(1-p) \quad (\text{B-40})$$

$$(\text{B-21}) \quad X_{ij} = 1 - G \left(\frac{\theta - E(a_{ij})}{[V(a_{ij})]^{1/2}} \right) \quad (\text{B-41})$$

$$(B-22) \quad p_o^{(i)}(1) = X_{i0} \quad (B-42)$$

$$(B-24) \quad p_i^{(i)}(1) = X_{i1} \quad (B-43)$$

Using (B-41), (B-42), (B-43), (B-23), and (B-25):

$$p_o^{(i)}(0) = G\left(\frac{\theta - E(a_{i0})}{[V(a_{i0})]^{1/2}}\right) \quad (B-44)$$

$$p_1^{(i)}(0) = G\left(\frac{\theta - E(a_{i1})}{[V(a_{i1})]^{1/2}}\right) \quad (B-45)$$

Equation (B-18) may be transformed as follows:

$$W_i = \log\left[\frac{1}{p_i^{(i)}(0)} - 1\right] - \log\left[\frac{1}{p_o^{(i)}(0)} - 1\right] \quad (B-46)$$

Substitution of (B-44) and (B-45) in (B-46) leads to functions of the form $\log\left[\frac{1}{G(\mu)} - 1\right]$. Some computation supplemented by a small amount of analysis yields the following surprisingly good approximation:

$$\ln\left[\frac{1}{G(\mu)} - 1\right] \approx -2\sqrt{\frac{2}{\pi}} \mu \quad (B-47)$$

Using (B-47) and henceforth taking all logarithms to the base e :

$$W_i = -2\sqrt{\frac{2}{\pi}}\left(\frac{\theta - E(a_{i1})}{[V(a_{i1})]^{1/2}}\right) + 2\sqrt{\frac{2}{\pi}}\left(\frac{\theta - E(a_{i0})}{[V(a_{i0})]^{1/2}}\right) \quad (B-48)$$

We may now use (B-39) and (B-40) in (B-48) and note a gratifying amount of cancellation.

$$W_i = 2\sqrt{\frac{2}{\pi}} \frac{1 - 2\rho}{\sqrt{N\rho(1-\rho)}} [A_{i1} - A_{i0}] \quad (B-47)$$

Note that any positive multiple of f , the classification function, is as good as the original. Let us, therefore, let

$$f^* = \frac{\sqrt{\pi N p (1-p)}}{2\sqrt{2} (1-2p)} f \quad (\text{B-50})$$

Note that we must make the restriction $p < \frac{1}{2}$.

Then (B-20) becomes:

$$f^* = T + \sum_i (A_{i1} - A_{i0}) x_i \quad (\text{B-51})$$

$$T = \frac{\sqrt{\pi N p (1-p)}}{2\sqrt{2} (1-2p)} \left(\log \frac{\pi_1}{\pi_0} + \sum_i b_i \right) \quad (\text{B-52})$$

B.7.3 Intepretation

Note that the weights as expressed in (B-51) depend only on the pre-threshold A-unit input for the two prototypes. Thus, if the assumptions are met, we can readily fix the weights in advance without knowledge of the degree of noisiness of the environment. The decision threshold T is a complex expression whose significance is not yet known. It is possible that it depends only weakly upon p .

DISTRIBUTION LIST

Assistant Secretary of Defense for Research and Engineering Information Office Library Branch Pentagon Building Washington 25, DC	(2)	Naval Electronics Laboratory San Diego 52, California ATTN Technical Library	(1)
Armed Services Technical Information Agency Arlington Hall Station Arlington 12, Virginia	(10)	University of Illinois Control Systems Laboratory Urbana, Illinois ATTN D. Alpert	(1)
Chief of Naval Research Department of the Navy Washington 25, DC ATTN Code 437, Information Systems Branch	(2)	University of Illinois Digital Computer Laboratory Urbana, Illinois ATTN Dr. J. E. Robertson	(1)
Chief of Naval Operations OP-07T-12 Navy Department Washington 25, DC	(1)	Air Force Cambridge Research Laboratories Laurence C. Hanscom Field Bedford, Massachusetts ATTN Research Library, CRX2-R	(1)
Director, Naval Research Laboratory Technical Information Officer, Code 2000 Washington 25, DC	(6)	Technical Information Officer U.S. Army Signal Research and Development Laboratories Fort Monmouth, New Jersey ATTN Data Equipment Branch	(1)
Commanding Officer, Office of Naval Research Navy #100, Fleet Post Office New York, New York	(10)	National Security Agency Fort George G. Meade, Maryland ATTN R-4, Howard Campaigne	(1)
Commanding Officer, ONR Branch Office 346 Broadway New York 13, New York	(1)	U.S. Naval Weapons Laboratory Dahlgren, Virginia ATTN Head, Computation Division, G. H. Gleissner	(1)
Commanding Officer, ONR Branch Office 495 Summer Street Boston 10, Massachusetts	(1)	National Bureau of Standards Data Processing Systems Division Room 239, Building 10 Washington 25, DC ATTN A. K. Smilow	(1)
Bureau of Ships Department of the Navy Washington 25, DC ATTN Code 607A NTDS	(1)	Aberdeen Proving Ground, Ballistic Research Laboratory	(1)
Bureau of Naval Weapons Department of the Navy Washington 25, DC ATTN RAAV Avionics Division	(1)	Aberdeen Proving Ground, Maryland ATTN J. H. Giese, Chief Computation Laboratory	
Bureau of Naval Weapons Department of the Navy Washington 25, DC ATTN RMWC Missile Weapons Control Division	(1)	Commanding Officer ONR Branch Office John Crerar Library Building 86 East Randolph Street Chicago 1, Illinois	(1)
Bureau of Naval Weapons Department of the Navy Washington 25, DC ATTN RUDC ASW Detection and Control Division	(1)	Commanding Officer ONR Branch Office 1030 East Green Street Pasadena, California	(1)
Bureau of Ships Department of the Navy Washington 25, DC ATTN Communications Branch Code 686	(1)	Commanding Officer ONR Branch Office 1000 Geary Street San Francisco 9, California	(1)
Naval Ordnance Laboratory White Oaks Silver Spring 19, Maryland ATTN Technical Library	(1)	National Bureau of Standards Washington 25, DC ATTN Mr. R. D. Elbourn	(1)
David Taylor Model Basin Washington 7, DC ATTN Technical Library	(1)	George Washington University Washington, DC ATTN Prof. N. Grisamore	(1)

Syracuse University Electrical Engineering Department Syracuse 10, New York ATTN Dr. Stanford Goldman	(1)	University of Illinois Urbana, Illinois ATTN Electrical Engineering Department Prof. H. Von Foerster	(1)
Princeton University Electrical Engineering Department Princeton, New Jersey ATTN Prof. F. S. Acton	(1)	University of California Institute of Engineering Research Berkeley 4, California ATTN Prof. A. J. Thomasian	(1)
Burroughs Corporation Research Center Paoli, Pennsylvania ATTN R. A. Tracey	(1)	National Science Foundation Program Director for Documentation Research Washington 25, DC ATTN Helen L. Brownson	(1)
Office of Naval Research Washington 25, DC ATTN Code 455	(1)	Wayne State University Detroit, Michigan ATTN Department of Slavic Languages Prof. Harry H. Josselson	(1)
Cornell University Cognitive Systems Research Program Hollister Hall Ithaca, New York ATTN Dr. Frank Rosenblatt	(1)	University of California - LA Los Angeles 24, California ATTN Department of Engineering Prof. Gerald Estrin	(1)
Lockheed Missiles and Space Company 3251 Hanover Street Palo Alto, California ATTN W. F. Main	(1)	Columbia University New York 27, New York ATTN Department of Physics Prof. L. Brillouin	(1)
Communications Sciences Laboratory University of Michigan 180 Frieze Building Ann Arbor, Michigan ATTN Gordon E. Peterson	(1)	Hebrew University Jerusalem, Israel ATTN Prof. Y. Bar-Hillel	(1)
University of Michigan Ann Arbor, Michigan ATTN Department of Psychology Prof. Arthur Melton	(1)	Massachusetts Institute of Technology Cambridge, Massachusetts ATTN Prof. V. H. Yngve	(1)
University of Michigan Ann Arbor, Michigan ATTN Department of Philosophy Prof. A. W. Burks	(1)	Massachusetts Institute of Technology Research Laboratory of Electronics ATTN Prof. W. McCulloch	(1)
University of Pennsylvania Philadelphia 4, Pennsylvania ATTN Department of Psychology Mr. R. Duncan Luce	(1)	University of Illinois Champaign Urbana, Illinois ATTN John R. Pasta	(1)
Carnegie Institute of Technology Department of Psychology Pittsburgh 13, Pennsylvania ATTN Prof. Bert F. Green, Jr.	(1)	Naval Research Laboratory Washington 25, DC ATTN Security Systems, Code 5266 Mr. G. Abraham	(1)
Massachusetts Institute of Technology Research Laboratory for Electronics Cambridge, Massachusetts ATTN Dr. Marvin Minsky	(1)	Zator Company 140 $\frac{1}{2}$ Mt. Auburn Cambridge 38, Massachusetts ATTN R. J. Solomonoff	(1)
Stanford University Stanford, California ATTN Electronics Laboratory Prof. John G. Linvill	(1)	National Aeronautics and Space Administration Goddard Space Flight Center Washington 25, DC ATTN Arthur Shapiro	(1)
Stanford University Stanford, California ATTN Electronics Laboratory Prof. Gene Franklin	(1)	Professor Marc Kac Rockefeller Institute New York, New York	(1)
	(1)	Cornell University Ithaca, New York ATTN Department of Psychology Prof. Robert B. MacLeod	(1)

Cornell University Ithaca, New York ATTN Department of Psychology Prof. Julian Hochberg	(1)	Commanding Officer and Director U. S. Naval Training Device Center Port Washington Long Island, New York ATTN Technical Library	(1)
Western Reserve University Cleveland 6, Ohio ATTN Department of Anatomy - School of Medicine Prof. Marcus Singer	(1)	Office of Naval Research Washington 25, DC ATTN Code 450, Dr. R. Trumbull	(1)
Cornell University Ithaca, New York ATTN Division of Modern Languages Prof. Charles Hockett	(1)	The University of Chicago Institute for Computer Research Chicago 37, Illinois ATTN Mr. Nicholas C. Metropolis, Director	(1)
Cornell University Ithaca, New York ATTN Department of Physics Prof. Phillip Morrison	(1)	Wright Air Development Division Electronic Technology Laboratory Wright-Patterson Air Force Base, Ohio ATTN Lt. Col. L. M. Butsch, Jr. ASRUEB	(1)
University of Illinois Urbana, Illinois ATTN Department of Electrical Engineering Dr. W. Ross Ashby	(1)	Laboratory for Electronics, Inc. 1079 Commonwealth Avenue Boston 15, Massachusetts ATTN Dr. H. Fuller	(1)
National Physical Laboratory Teddington, Middlesex England ATTN Autonomics Division Dr. A. M. Uttley, Superintendent	(1)	Stanford Research Institute Computer Laboratory Menlo Park, California ATTN H. D. Crane	(1)
University College London Gower Street London, W. C. 1, England ATTN Department of Electrical Engineering Dr. W. K. Taylor	(1)	The Rand Corporation 1700 Main Street Santa Monica, California ATTN Numerical Analysis Department Willis H. Ware	(1)
United Aircraft Corporation Research Laboratories East Hartford 8, Connecticut ATTN Dr. George B. Yntema	(1)	University of Oregon Portland, Oregon ATTN Medical School Dr. Tunturi	(1)
Swarthmore College Swarthmore, Pennsylvania ATTN Department of Electrical Engineering Prof. Carl Barus	(1)	Zator Company 140½ Mt. Auburn Street Cambridge 38, Massachusetts ATTN Calvin N. Mooers	(1)
Neurological Institute of McGill University 3801 University Street Montreal, Canada ATTN Dr. Herbert Jasper	(1)	Massachusetts Institute of Technology Cambridge 39, Massachusetts ATTN Prof. John Mc Carthy, 26-007B	(1)
Harvard University Memorial Hall Cambridge 38, Massachusetts ATTN Dr. Jacob Beck	(1)	Office of Naval Research Washington 25, DC ATTN Code 430	(1)
University of Michigan Ann Arbor, Michigan ATTN Department of Psychology Dr. James Olds	(1)	Carnegie Institute of Technology Pittsburgh, Pennsylvania ATTN Director, Computation Center Alan J. Perlis	(1)
Diamond Ordnance Fuze Laboratory Connecticut Ave. & Van Ness St. Washington 25, DC ORDTL-012, E. W. Channel	(1)	Rome Air Development Center, RCOR DCS/Operations, USAF Griffiss Air Force Base, New York ATTN Irving J. Gabelman	(1)
Harvard University Cambridge, Massachusetts ATTN School of Applied Science Dean Harvey Brook	(1)	Air Force Office of Scientific Research Directorate of Information Sciences Washington 25, DC ATTN Dr. Harold Wooster	(1)

Hunter College New York 21, New York ATTN Dean Mina Rees	(1)	Royal Aircraft Establishment Farnborough, Hampshire, England ATTN Mathematics Department Mr. R. A. Fairthorne Minister of Aviation	(1)
Stanford Research Institute Menlo Park, California ATTN Applied Physics Laboratory Dr. Charles Rosen	(1)	IBM Research Yorktown Heights, New York ATTN Hans Peter Luhn	(1)
University of California Berkeley, California ATTN Department of Mathematics Prof. H. J. Bremermann	(1)	Library of Congress Washington 25, DC ATTN John Sherrod	(1)
National Bureau of Standards Washington 25, DC ATTN Miss Ida Rhodes, 220 Stucco Building	(1)	National Biomedical Research Foundation, Inc. 8600 16th Street, Suite 310 Silver Spring, Maryland ATTN Dr. R. S. Ledley	(1)
University of Saskatchewan College of Engineering Saskatoon, Canada ATTN H. C. Ratz	(1)	National Bureau of Standards Washington 25, DC ATTN Mrs. Ethel Marden	(1)
Northeastern University 360 Huntington Avenue Boston, Massachusetts ATTN Prof. L. O. Dolansky	(1)	Department of Commerce U. S. Patent Office Washington 25, DC ATTN Mr. Herbert R. Koller	(1)
IBM Corporation Federal Systems Division 326 E. Montgomery Avenue Rockville, Maryland ATTN Dr. Stanley Winkler	(1)	Thompson Ramo Woolridge Inc. 8433 Fallbrook Avenue Canoga Park, California ATTN D. R. Swanson	(1)
L. G. Hanscom Field/AF-CRL-CRRB/ Bedford, Massachusetts ATTN Dr. H. H. Zschirnt	(1)	Rand Corporation 1700 Main Street Santa Monica, California ATTN Library	(1)
Rome Air Development Center Griffiss Air Force Base Rome, New York ATTN Mr. Alan Barnun	(1)	University of Chicago Committee on Mathematical Biology Chicago, Illinois ATTN Prof. H. D. Landahl	(1)
Armour Research Foundation 10 West 35th Street Chicago 16, Illinois ATTN E. E. Research Department Mr. Scott Cameron	(1)	University of Pennsylvania Moore School of Electrical Engineering 200 South 33rd Street Philadelphia 4, Pennsylvania ATTN Miss Anna Louise Campion	(1)
Department of the Army Office of the Chief of Research and Development Pentagon, Room 3D442 Washington 25, DC ATTN Mr. L. H. Geiger	(1)	Department of the Army Office of the Assistant COFD for Intelligence Room 2B529, Pentagon Washington, DC ATTN John F. Kullgren	(1)
Cambridge Language Research Unit 20 Millington Road Cambridge, England ATTN Mrs. Margaret M. Braithwaite	(1)	Mr. Robert F. Samson Directorate of Intelligence and Electronic Warfare Griffiss Air Force Base Rome, New York	(1)
Carnegie Institute of Technology Systems and Communication Sciences Pittsburgh 13, Pennsylvania ATTN Dr. Allen Newell	(1)	Army Research Office OCR & D Department of Army Washington 2, DC ATTN Mr. Gregg McClurg	(1)
Cornell University Cognitive Systems Research Program Cornell Computing Center Ithaca, New York ATTN Prof. H. D. Block	(1)	Division of Automatial Data Processing/AOP/ Department of State Washington 25, DC ATTN F. P. Diblasi, 19A16	(1)

Mr. Paul W. Howerton Room 1053 M. Building Code 163 CIA Washington, DC	(1)	Stanford University Stanford, California ATTN Department of Mathematics Prof. George E. Forsythe	(1)
University of Pennsylvania Mechanical Languages Projects Moore School of Electrical Engineering Philadelphia 4, Pennsylvania ATTN Dr. Saul Gorn, Director	(1)	University of Chicago Chicago, Illinois ATTN Committee on Mathematical Biology Peter H. Greene	(1)
Arthur D. Little, Inc. Acorn Park Cambridge 40, Massachusetts ATTN Dr. Vincent Giuliano	(1)	Federal Aviation Agency Bureau of Research and Development Washington 25, DC ATTN RD-375, Harry Hayman	(1)
Mr. Bernard M. Fry, Deputy Head Office of Science Information Service National Science Foundation 1951 Constitution Avenue, N. W. Washington 25, DC	(1)	Veterans Administration Department of Medicine and Surgery Washington 25, DC ATTN Research and Development Division H. Frieburger	(1)
International Business Machines Corporation Advanced Systems Development Division San Jose 14, California ATTN I. A. Warheit	(1)	Federal Aviation Agency Bureau of Research and Development Center Atlantic City, New Jersey ATTN Simon Justman	(1)
Cornell University Ithaca, New York ATTN Department of Mathematics Harry Kesten	(1)	Cornell Aeronautical Laboratory, Inc. P. O. Box 235 Buffalo 21, New York ATTN Systems Requirements Department A. E. Murray	(1)
Applied Physics Laboratory Johns Hopkins University 8621 Georgia Avenue Silver Spring, Maryland ATTN Document Library	(1)	Institute for Space Studies 475 Riverside Drive New York 27, New York ATTN Mr. Albert Arking	(1)
Bureau of Supplies and Accounts, Chief Navy Department Washington, DC ATTN Code W3	(1)	Mr. Donald F. Wilson Code 5144 Naval Research Laboratory Washington 25, DC	(1)
Officer in Charge U. S. Naval Photographic Interpretation Center 4301 Suitland Road Suitland, Maryland ATTN Mr. J. Pickup	(1)	University of California Berkeley 4, California ATTN Department of Engineering Prof. J. R. Singer	(1)
University of Pennsylvania Moore School of Engineering Philadelphia 4, Pennsylvania ATTN Dr. Noah S. Prywes	(1)	Navy Management Office Data Processing Systems Division Department of the Navy Washington 25, DC ATTN Mr. J. Smith	(1)
National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland ATTN Chief, Data Systems Division C. V. L. Smith	(1)	Lincoln Laboratory Massachusetts Institute of Technology Lexington 73, Massachusetts ATTN Library	(1)
Rabinow Engineering Company, Inc. 7712 New Hampshire Avenue Washington 12, DC	(1)	University Di Milano Centro Di Cibernetica Via Festa Del Perdono, 3 Milano, Italy ATTN Prof. Silvio Ceccato	(1)
National Security Agency Fort George G. Meade, Maryland ATTN R. -42, R. Wiggington	(1)	Brookhaven National Laboratory Upton, Long Island, New York ATTN Dr. Yoshio Shimamoto	(1)
		Sperry Phoenix Company Phoenix, Arizona ATTN Technical Librarian	(1)

Instituto Di Fisica Dell Universita Genova, Italy ATTN Prof. A. Gamba	(1)	Commanding Officer Rome Air Development Center Griffiss Air Force Base Rome, New York ATTN Lt. Roger Geesey, RCWID	(1)
Ryuichi Kono Mitsubishi Electric Manufacturing Company, Ltd. Kamakura Works 325 Kamimackiya Kumakura Kanagawa-Ken, Japan	(1)	Institute for Space Studies 475 Riverside Drive New York 27, New York ATTN Dr. Hong Yee Chiu	(1)
Howard University Washington 1, DC ATTN Psychology Department Dr. C. R. Porter	(1)	Institute for Defense Analysis Communications Research Division 76½ Nassau Street Princeton, New Jersey ATTN Prof. J. B. Rosser, Director	(2)
Advanced Systems Research Group North American Aviation Company 4300 E. 5th Avenue Columbus, Ohio ATTN Dr. George N. Omstein	(1)	Dr. B. Mandelbrot Littaver G-51 Harvard University Cambridge 38, Massachusetts	(1)
Mr. Gordon Stanley 7685 South Sheridan Court Littleton, Colorado	(1)	Advanced Research 3946 Fabian Way Palo Alto, California ATTN W. W. Bledsoe	(1)
University of California Berkeley, California ATTN Lawrence Radiation Laboratory Dr. Milton E. Rose	(1)	Aeronautics Ford Road Newport Beach, California ATTN J. K. Hawkins	(1)
The Johns Hopkins University 8621 Georgia Avenue Silver Spring, Maryland ATTN Applied Physics Laboratory A. J. Cote, Jr.	(1)	Cornell University Library Ithaca, New York ATTN Central Serial Record Department	(1)
University of Michigan Ypsilanti, Michigan ATTN Willow Run Laboratories Mr. Paul Metzelaar	(1)	University of Rochester Center for Brain Research Rochester 20, New York ATTN Prof. E. R. John	(1)
Cornell University Ithaca, New York ATTN Department of Psychology Prof. T. A. Ryan	(1)	Massachusetts Institute of Technology Lincoln Laboratory Lexington 73, Massachusetts ATTN Dr. B. Farley	(1)
Mc Gill University Montreal, Quebec Canada ATTN Department of Psychology Prof. Donald Hebb	(1)	Massachusetts Institute of Technology Lincoln Laboratory Lexington 73, Massachusetts ATTN Dr. Oliver Selfridge	(1)
Swarthmore College Swarthmore, Pennsylvania ATTN Department of Psychology Prof. Hans Wallach	(1)	Dr. John Hay 62 Kensington Avenue Northampton, Massachusetts	(1)
California State Polytechnic College San Luis Obispo, California ATTN Dr. James T. Culbertson	(1)	University of California Western Management Science Institute Graduate School of Business Administration Los Angeles 24, California ATTN Mr. Earl B. Hunt	(1)
Stanford Research Institute Menlo Park, California ATTN Computer Laboratory W. H. Kautz, Sr., Research Engineer	(1)	Astropower, Inc. 2968 Randolph Street Costa Mesa, California ATTN Dr. R. D. Joseph, Principal Mathematician	(1)
Rechts-U. Staatsu Fakultat D. Universitat Worthmannsplatz 1, Freiburg 1, Br. Germany ATTN Prof. F. A. Hayek	(1)	Philco Corporation Philadelphia, Pennsylvania ATTN Dr. Peter M. Kelly	(1)

Ryuichi Kono Mitsubishi Electric Manufacturing Co., Ltd. Electronics Works 80 Nakano, Minami Shimizu Amagasaki Hyogo Prefecture, Japan	(1)
ONR Special Representative c/o Hudson Laboratories Columbia University 145 Palisade Street Dobbs Ferry, New York	(1)
Radio Corporation of America RCA Laboratories David Sarnoff Research Center Princeton, New Jersey ATTN Mr. Saul Amarel	(1)
Research Division Kollsman Instrument Corporation 80-08 45th Avenue Elmhurst 73, New York ATTN Mr. Seymour T. Levine	(1)
Ohio State University 1314 Kinnear Road Columbus 12, Ohio ATTN Mr. Don Meyer	(1)
Operations Research Incorporated 8605 Cameron Street Silver Spring, Maryland ATTN Mr. Howard Eisner	(1)
Office of Research and Development U. S. Department of Commerce Patent Office Washington 25, DC ATTN Allan Kiron	(1)
U. S. Naval Ordnance Test Station Pasadena Annex 3202 E. Foothill Boulevard Pasadena 8, California ATTN L. Freinkel	(1)
Air Force Office of Scientific Research Information Research Division Washington 25, DC ATTN R. W. Swanson	(1)
Sandia Corporation Sandia Base Albuquerque, New Mexico ATTN Mr. William Michael Dante	(1)
Texas Instruments Incorporated Corporate Research and Engineering P. O. Box 5474 Dallas 22, Texas ATTN Technical Reports Service	(1)
Sandia Corporation Sandia Base Albuquerque, New Mexico ATTN Dr. G. William Rollosen Head, Advanced Development Division Organization 7223	(1)