Proposal for Research
SRI No. ESU 68-111

September 4, 1968

SURVEY OF ARTIFICIAL INTELLIGENCE

Extension of Contract N0014-68-C-0266

Mr. Marvin Denicoff
Information Systems Branch
Office of Naval Research
Room 4208
Main Navy Building
Washington, D. C. 20360

Dear Mr. Denicoff:

This is a proposal to continue work on a survey of the field of artificial intelligence now in progress under ONR Contract N0014-68-C-0266. The work will be performed by Dr. Nils J. Nilsson and Dr. Richard O. Duda of the Artificial Intelligence Group, Information Science Laboratory. The end product of the proposed continuation would be a report or reports in which the major techniques and subject matter of Artificial Intelligence are presented and explained in a coherent and logical manner.

I BACKGROUND

Work on the present project has resulted in a tentative outline of a portion of the field, and three draft "chapters" have already been written covering the first items in the outline. (The present version of the outline is included as Appendix A of this proposal.) It is expected that first-draft chapters of most of the items in the outline will be substantially complete by the end of the present project (10 January 1968).

The portion of the field that is being surveyed during this first year includes those Artificial Intelligence problems for which "search" plays a major role. The survey is attempting to provide a clear exposition of:

(1) How such problems can be initially represented as "search" problems, and
(2) The various methods for carrying out search efficiently.

Within this framework we shall be able to describe the principles underlying such Artificial Intelligence projects as: The General Problem-Solver (GPS), the Logic Theory Machine (LT), Symbolic Integration (SAINT), Geometry Theorem Proving, Theorem Proving in the propositional and the predicate calculus, and game playing.

II PROPOSED NEW WORK

Representation and Search processes cover a wide range of topics in Artificial Intelligence, but there are additional important areas that do not fit completely under this framework. One is the subject of pattern recognition and another is the subject of large Artificial Intelligence systems such as robots. It is proposed that the survey of Artificial Intelligence be continued for an additional year to cover work on these two areas specifically and also to cover work on the final version of material already written. We would regard the consideration of Artificial Intelligence systems as a proper addition to the originally conceived outline. This subject would be covered by Items VIII and IX of the outline in Appendix A.

It is proposed that the subject of pattern recognition be treated separately from the other material, first because it is a large field in its own right, and second because its important theoretical and conceptual ideas do not seem to relate intimately with the Representation-Search processes of other Artificial Intelligence subjects. The conclusion of the survey and writing outlined in Appendix A would be conducted by Dr. Nilsson, and the initiation of the separate survey of pattern recognition would be the responsibility of Dr. Duda. It is anticipated that roughly equal project resources would be allotted to each of these two subtasks.

In the next section of this proposal we will briefly outline the approach to be taken in the pattern-recognition survey.

III PATTERN-RECOGNITION SURVEY

In its broadest sense, pattern recognition is the discovery of regularity in the midst of confusion. In this sense, pattern recognition is involved in any scientific or intellectual activity, and its mechanization falls clearly within the domain of artificial intelligence.

Defined in terms of the activities of most of the workers in the field, pattern recognition usually refers to identifying physical objects or events. Typical applications include optical character recognition, signature verification, fingerprint identification, blood cell classification, electrocardiogram analysis, speech recognition, radar and sonar signal detection, cloud pattern recognition, and automatic aerial photo-interpretation. Thus, in surveying work in the field of pattern recognition, we shall restrict our attention to what might be called the mechanization of perception.

Although much of the work in this field is still in the research phase, the published literature is vast. A recent bibliography by

Calvert[1] lists 306 published articles on pattern recognition generally, and Munson[2] lists 36 references on the recognition of hand-printed characters alone. Furthermore, a large amount of significant information is only available in the form of memos, reports, or theses.

Fortunately, several attempts have already been made at organizing this field of knowledge. The best of these have focussed on the mathematics of pattern classification, a topic which is particularly well suited for systematic exposition. Sebestyen[3] concentrated on certain aspects of decision theory, and stimulated much of the later work on clustering. Nilsson[4] emphasized the role of discriminant functions, and gave a unified treatment of machine learning. A recent survey of classification algorithms by Ho and Agrawala[5] helps to bring this work up to date.

The other available surveys of pattern recognition cover the mathematical methods in a more cursory fashion, but include the vitally important material on preprocessing and feature extraction.[6-10] All of these papers should be valuable for the proposed work, and should simplify the task of identifying the important literature.

The main goal of the proposed survey is to give a systematic presentation of the field of pattern recognition by viewing it as an attempt to mechanize perception. Major emphasis will be placed on the mechanization of visual perception, thereby allowing a more orderly treatment of subject matter in the progression from mathematical foundations, which are broadly applicable, to preprocessing techniques, which are highly specialized.

A tentative outline for the survey is included in Appendix B, along with representative references for each chapter. The survey progresses from the well understood aspects of the field to topics that are currently the subject of active research, and it is anticipated that the organization of the later chapters may be subject to considerable modification as the survey is being written. It is hoped that early drafts of the survey will be used in a course on pattern classification to be taught at the University of California at Berkeley.

REFERENCES

1. T. W. Calvert, "A Descriptor Indexed Bibliography on Pattern Recognition," IEEE Computer Group Repository, R-68-129 (April, 1968).

2. J. H. Munson, "Experiments in the Recognition of Hand-Printed Text: Part I--Character Recognition," Proc. FJCC, San Francisco, California (December, 1968).

3. G. Sebestyen, Decision-Making Processes in Pattern Recognition (Macmillan, New York, N. Y., 1962).

4. N. J. Nilsson, Learning Machines (McGraw-Hill, New York, N. Y., 1965).

5. Y.-C. Ho and A. K. Agrawala, "On Pattern Classification Algorithms--Introduction and Survey," to be published in the IEEE Trans. on Automatic Control.

6. N. Lindgren, "Machine Recognition of Human Language--Parts I-III," IEEE Spectrum, pp. 114-136 (March, 1965), pp. 44-59 (April, 1965), pp. 104-116 (May, 1965).

7. N. J. Nilsson, "Adaptive Pattern Recognition: A Survey," Proc. 1966 Bionics Symposium.

8. N. J. Nilsson, "Survey of Pattern Recognition," a paper presented at the New York Academy of Sciences Conference on The Use of Data Mechanization and Computers in Clinical Medicine, New York (January, 1968).

9. G. Nagy, "State of the Art in Pattern Recognition," Proc. IEEE, pp. 836-862 (May, 1968).

10. A. Rosenfeld, "Picture Processing by Computer," University of Maryland Computer Science Center Report TR-71, Contract Nonr-5144(00) (June, 1968).

IV PERSONNEL

The proposed work will be conducted by Dr. Nils J. Nilsson and Dr. Richard O. Duda of the Artificial Intelligence Group, Information Science Laboratory. Their biographies follow.

Nilsson, Nils J. - Senior Research Engineer, Artificial Intelligence Group
Information Science Laboratory

Dr. Nilsson has been on the staff of Stanford Research Institute since August 1961 where he has participated in and led research in pattern recognition, learning machines, and artificial intelligence. He has taught courses on learning machines at Stanford University and at the University of California, Berkeley. McGraw-Hill published, in 1965, a monograph by Dr. Nilsson describing recent theoretical work in pattern recognition. He has written several papers on pattern recognition and artificial intelligence topics.

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 field of graduate study was the application of statistical techniques to radar and communication problems.

Before coming to SRI, Dr. Nilsson completed a three-year term of active duty 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.

Dr. Nilsson is a member of Sigma Xi, Tau Beta Pi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Duda, Richard O. - Research Engineer, Artificial Intelligence Group
Information Science Laboratory

Dr. Duda received a B.S. degree in 1958 and an M.S. degree in 1959, both in Electrical Engineering, from the University of California at Los Angeles. In 1962 he received a Ph.D. degree from the Massachusetts Institute of Technology, where he specialized in network theory and communication theory.

Between 1955 and 1958 he was engaged in electronic component and equipment testing and design at Lockheed and ITT Laboratories. From 1959 to 1961 he concentrated on control system analysis and analog simulation, including adaptive control studies for Titan II and Saturn C-1 boosters, at Space Technology Laboratories.

In September 1962, Dr. Duda joined the staff of Stanford Research Institute, where he has been working on pattern recognition and related topics in artificial intelligence. He has taught a course on learning machines for the University of California Extension and has been the author or coauthor of several papers in this field.

Dr. Duda is a member of Phi Beta Kappa, Tau Beta Pi, Sigma Xi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

V REPORTS

A final report (or reports) will be written giving the results of the survey.

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VI ESTIMATED TIME AND CHARGES

The time required to complete this continuation and report its results is 13 months. Work on the continuation would begin upon completion of the current project. A detailed cost estimate for the proposed work is attached.

VII CONTRACT FORM

It is requested that any contract resulting from this proposal be written as an extension to Contract N0014-68-C-0266.

VIII PATENT PROVISIONS - WITHHOLDING OF PAYMENT

In view of the Institute's nonendowed, nonprofit status, and because it is extremely unlikely that a patent disclosure and/or application will result from the work proposed herein, and in keeping with the spirit and intent of the applicable Patent Clause (ASPR 9-107.5(b)), it is requested that any contract resulting from this proposal include the following statement regarding patents:

"Interim and Final Inventions Reports - Pursuant to Subparagraphs (f)(2) and (f)(3) of the clause of this contract entitled PATENTS RIGHTS (LICENSE), there shall be withheld, when appropriate, fifty thousand dollars ($50,000.00), or five percent (5%) of the total amount of the contract as amended from time to time, whichever is less; provided, however, that such amount shall not be withheld from any interim payment voucher(s) except upon written instructions from the Contracting Officer."

IX ACCEPTANCE PERIOD

This proposal will remain in effect until 10 January 1969. If consideration of the proposal requires a longer period, the Institute will be glad to consider a request for an extension in time.

Respectfully submitted,

Nils J. Nilsson
Richard O. Duda

Nils J. Nilsson, Sr. Research Engineer
Richard O. Duda, Research Engineer
Artificial Intelligence Group

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Att.

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Approved:

David R. Brown

David R. Brown, Director
Information Science Laboratory

Torben Meisling

Torben Meisling, Executive Director
Information Science & Engineering

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Appendix A

TENTATIVE OUTLINE FOR ARTIFICIAL INTELLIGENCE SURVEY (EXCLUDING PATTERN RECOGNITION)

I INTRODUCTION

A. The Problem (Transforming Information Structures)

B. The Methodology (Representation, Search, Interpretation)

C. An Example--The Tower of Hanoi Puzzle

D. Static and Dynamic Problems

E. Some Example Problems

1. Puzzles
2. Distribution Problems
3. Control Problems
4. Syntax Analysis Problems
5. Proving Mathematical Theorems
6. Reasoning About Actions

F. Graph Notation (8-Puzzle Example)

II SEARCHING FOR PATHS IN A GRAPH

A. Blind Search

1. Finding Paths in a Graph
2. Breadth-First Methods
3. Depth-First Methods

B. Heuristic Search

1. Discussion of Heuristic Information
(evaluation functions, heuristic power)

2. Use of Evaluation Functions
(Statement of general Dynamic Search Algorithm, 8-puzzle example)

3. An Optimal Search Algorithm

   a. The Evaluation Function

   b. Admissibility

   c. Optimality

   d. Heuristic Power

4. Use of Other Heuristics

   a. Shallow Look-Ahead

   b. "Staged" Search

   c. Limitation of Successors
   (Use of heuristic information, "partial expansion" of nodes)

5. Measures of Performance
(penetrance, effective branching factor)

6. Improving the Evaluation Function while Searching
(learning)

III AND/OR GRAPHS FOR THEOREM PROVING, PROBLEM SOLVING, AND GAME PLAYING

A. Proofs in the Propositional Calculus

1. Deductions

2. Proofs

3. Derived Rules

4. Proving Deductions by Graph Searching

5. AND/OR Graphs

6. Examples of the Use of AND/OR Graphs in Proving Deductions

7. A Simple Automatic Proof System

8. "Fishtail" Proofs and the Completeness of the Simple Proof System

B. Problem Solving

1. Sequents

2. Examples

a. 8-Puzzle

b. Geometry theorem proving

c. Symbolic integration

3. Use of "Models" and Other Heuristics

4. Planning

C. Game Playing

IV SEARCH METHODS FOR REDUCTION GRAPHS

A. Blind Search

1. Solution Graphs

2. Breadth First and Depth First

3. Minimal Cost Solutions

B. Heuristic Search

1. "Arrow Method"

2. Other Dynamic Ordering Methods

3. Examples

C. Applications to Game Trees

1. α-β Procedure

2. Improving the Evaluation Function while Searching (learning)

3. Examples

V THEOREM PROVING

A. Theorem Proving in the Predicate Calculus

1. Summary of Predicate Calculus

2. Herbrand Methods

3. Resolution Method

B. Special Search Strategies
(set of support, unit preference, etc.)

C. Representation as a Graph-Searching Problem

1. Application of Dynamic Search Algorithm

2. Examples

D. Planning Proofs

VI REPRESENTATION

A. The Problems of Specifying Representations

B. Forms for Representations

1. Object-Operator Production Systems (Newell, Amarel)

2. Some Examples of Problems having Alternative Representations

3. Macro-Operators

4. Identification of "Narrows"

5. Predicate Calculus Representations

C. Some Important Representations Used in Machine Intelligence Programs

1. Objects and Operators of GPS

2. Syntax Analysis Representations

3. Predicate Calculus Representations

D. On Developing Programs to Produce Representations

1. Isolating the Role of Previous Knowledge

2. Producing Primitive Representations

3. Transforming Representations (Newell)

4. Transforming English Statements into Predicate Calculus

VII APPLICATIONS OF FORMAL THEOREM PROVING TO PROBLEM SOLVING

A. All Problems as Theorem-Proving Problems

B. Axiomatization of Informal Problem Domains

C. Examples

1. Question Answering

2. Puzzle Solving

3. Reasoning about Actions

4. Program Writing

VIII DYNAMIC PROBLEMS

A. Learning

B. Processing Sensory Information

C. Setting Up Sequences of Static Problems

D. Induction Problems (discovering grammars, etc.)

E. Advice Taker and Question-Answering Systems

IX MACHINE INTELLIGENCE SYSTEMS

Appendix B

TENTATIVE OUTLINE FOR PATTERN RECOGNITION SURVEY

I INTRODUCTION

II BAYESIAN CLASSIFICATION

- A. General Formulation
- B. Normal Distributions
- C. Multinomial Distributions

III BAYESIAN LEARNING

- A. Normal Distributions
- B. Exponential Family
- C. Reproducing Densities and Sufficient Statistics
- D. General Bayesian Learning

IV NONPARAMETRIC METHODS

- A. Estimation of Densities
- B. Nearest Neighbor Rules
- C. Discrinimant Analysis

V LEARNING ALGORITHMS

- A. Geometry of N-Space
- B. Error-Correction Rules
- C. Steepest-Descent Rules
- D. Stochastic Approximation
- E. Relation to Discriminant Analysis

VI UNSUPERVISED LEARNING

- A. Identifiability and Mixture Distributions

B. Factor Analysis

C. Clustering Algorithms

VII FEATURE EXTRACTION

A. Criterion Functions

B. Feature Selection

C. Dimensionality Reduction

VIII EXTENSIONS OF DECISION THEORY

A. Empirical Bayes Procedures

B. Compound Decision Theory and Context

C. Sequential Feature Selection

IX GEOMETRICAL PATTERN RECOGNITION

A. Integral Geometry

B. Local Properties

C. Perceptron Limitation Theorems

D. Automata on a Two-Dimensional Tape

E. Global Properties

F. Syntactic Methods

X PREPROCESSING PICTORIAL DATA

A. Fourier Methods

B. Local Averaging

C. Edge Enhancement

D. Texture and Color Operators

E. Optical Implementation

XI THREE-DIMENSIONAL PATTERNS

A. Perspective Transformations

B. Model Techniques

C. Occlusion and Scene Analysis

D. Relative Motion and Stereo

XII VISUAL PATTERN RECOGNITION SYSTEMS

A. Optical Character Recognition

B. Handprinted Character Recognition

C. Cursive Script Recognition

D. Graphical Data Processing

E. Fingerprint Identification

F. Biological Image Processing

G. Automatic Photointerpretation

H. Analysis of Bubble Chamber Tracks

I. Visual Systems for Automata

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REPRESENTATIVE REFERENCES ON PATTERN RECOGNITION

General

1. G. Sebestyen, Decision-Making Process in Pattern Recognition (Macmillan, New York, N. Y., 1962).

2. G. L. Fischer, D. K. Pollock, B. Raddack, and M. E. Stevens, eds., Optical Character Recognition (Spartan, Washington, D. C., 1962).

3. E. A. Feigenbaum and J. Feldman, eds., Computers and Thought (McGraw-Hill, New York, N. Y. 1962).

4. J. T. Tippett, D. A. Berkowitz, L. C. Clapp, C. J. Koester, and A. Vanderburgh, eds., Optical and Electro-Optical Information Processing (MIT Press, Cambridge, Mass., 1965).

5. N. J. Nilsson, Learning Machines (McGraw-Hill, New York, N. Y., 1965).

6. L. Uhr, ed., Pattern Recognition, (Wiley, New York, N. Y., 1966).

7. A. G. Arkadev and E. M. Braverman, Computers and Pattern Recognition (Thompson, Washington, D. C., 1966).

8. L. Kanal, ed., Pattern Recognition (Thompson, Washington, D. C., 1968).

9. P. A. Kilers and M. Eden, eds., Recognizing Patterns (MIT Press, Cambridge, Mass., 1968).

10. G. C. Cheng, R. S. Ledley, D. K. Pollock, and A. Rosenfeld, eds., Pictorial Pattern Recognition (Thompson, Washington, D. C., 1968).

11. K. S. Fu and J. Mendel, Adaptive and Learning Systems (Academic Press, New York, N. Y., to be published in 1969).

Chapter I

1. O. G. Selfridge and U. Neisser, "Pattern Recognition by Machine," Scientific American, Vol. 203, pp. 60-68 (August 1960).

2. M. Minsky, "Steps Toward Artificial Intelligence," Proc. IRE, Vol. 49, pp. 8-30 (January 1961). Also in Computers and Thought, Feigenbaum and Feldman, eds. (McGraw-Hill Book Co., New York, N. Y., 1963).

3. E. David and O. G. Selfridge, "Eyes and Ears for Computers," Proc. IRE, Vol. 50, pp. 1093-1101 (May 1962).

4. L. Uhr, "Pattern Recognition," in Pattern Recognition, pp. 365-381, Uhr, ed. (Wiley, New York, N. Y., 1966).

5. N. J. Nilsson, "Adaptive Pattern Recognition: A Survey," Proc. 1966 Bionics Symposium.

6. G. Nagy, "State of the Art in Pattern Recognition," Proc. IEEE, pp. 836-862 (May 1968).

Chapter II

1. H. Chernoff and L. E. Moses, Elementary Decision Theory (Wiley, New York, N. Y., 1959).

2. D. Blackwell and M. A. Girshick, Theory of Games and Statistical Decisions (Wiley, New York, N. Y., 1954).

3. T. W. Anderson, An Introduction to Multivariate Statistical Analysis (Wiley, New York, N. Y., 1958) (Chapter 6).

4. C. K. Chow, "An Optimum Character Recognition System Using Decision Functions," IRE Trans. on Electronic Computers, Vol. EC-6, pp. 247-253 (December 1957).

Chapter III

1. N. Abramson and D. Braverman, "Learning to Recognize Patterns in a Random Environment," IRE Trans. on Information Theory, Vol. IT-8, pp. S58-S63 (September 1962).

2. J. Spragins, "A Note on the Iterative Application of Bayes' Rule," IEEE Trans. on Information Theory, Vol. IT-11, pp. 544-549 (October 1965).

3. D. G. Keehn, "A Note on Learning for Gaussian Properties," IEEE Trans. on Information Theory, Vol. IT-11, pp. 126-132 (January 1965).

Chapter IV

1. E. Parzen, "On Estimation of a Probability Density Function and Mode," Ann. Math. Stat., Vol. 33, pp. 1067-1076 (1962).

2. D. O. Loftsgaarden and C. P. Quesenberry, "A Nonparametric Estimate of a Multivariate Density Function," Ann. Math. Stat., Vol. 36, pp. 1049-1051 (1965).

3. T. M. Cover and P. E. Hart, "Nearest Neighbor Pattern Classification," IEEE Trans. on Information Theory, Vol. IT-13, pp. 21-27 (January 1967).

4. R. M. Miller, "Statistical Prediction by Discriminant Analysis," Meteorological Monographs, Vol. 4, No. 25 (October 1962).

Chapter V

1. T. M. Cover, "Geometrical and Statistical Properties of System of Linear Inequalities With Applications in Pattern Recognition," IEEE Trans. on Electronic Computers, Vol. EC-14, pp. 326-334 (June 1956).

2. A. B. J. Novikoff, "On Convergence Proofs for Perceptrons," pp. 615-622, Proc. Symp. on Math. Thy. of Automata, Brooklyn, N. Y. (Polytechnic Press, 1963).

3. B. Widrow, "Generalization and Information Storage in Networks of Adaline 'Neurons'," in Self-Organizing Systems-1962, pp. 435-461, Yovits, Jocobi, and Goldstein, eds. (Spartan Books, Washington, D. C., 1962).

4. Y.-C. Ho and R. L. Kashyap, "An Algorithm for Linear Inequalities and Its Applications," IEEE Trans. on Electronic Computers, Vol. EC-14, pp. 683-688 (October 1965).

5. M. A. Aizerman, E. M. Braverman, and L. A. Rozonoer, "The Probability Problem of Pattern Recognition Learning and the Method of Potential Functions," Automation and Remote Control (English Translation), Vol. 25 (March 1965).

6. C. Balydon and Y.-C. Ho, "On the Abstraction Problem in Pattern Classification," Proc. NEC, Vol. 22, pp. 857-862 (1966).

7. J. S. Koford and G. F. Groner, "The Use of an Adaptive Threshold Element to Design a Linear Optimal Pattern Classifier," IEEE Trans. on Information Theory, Vol. IT-12, pp. 42-50 (January 1966).

Chapter VI

1. E. A. Patrick and J. C. Hancock, "Nonsupervised Sequential Classification and Recognition of Patterns," IEEE Trans. on Information Theory, Vol. IT-12, pp. 362-372 (July 1966).

2. J. Spragins, "Learning Without a Teacher," IEEE Trans. on Information Theory, Vol. IT-12, pp. 223-230 (April 1966).

3. G. H. Ball, "Data Analysis in the Social Sciences," Proc. FJCC, Las Vegas, Nevada, 1965 (Spartan, Washington, D. C., 1965).

4. G. Nagy and G. L. Shelton, "Self-Corrective Character Recognition System," IEEE Trans. on Information Theory, Vol. IT-12, pp. 215-222 (April 1966).

5. E. R. Ide and C. J. Tunis, "An Experimental Investigation of a Nonsupervised Adaptive Algorithm," IEEE Trans. on Electronic Computers, Vol. EC-16, pp. 860-864 (December 1967).

6. G. Ball, D. J. Hall, and D. A. Evans, "Implications of Interactive Graphic Computers for Pattern Recognition Methodology," a paper presented at the Int'l. Conf. on Methodologies of Pattern Recognition, Honolulu, Hawaii (January 1968).

Chapter VII

1. P. M. Lewis, "The Characteristic Selection Problem in Recognition Systems," IRE Trans. on Information Theory, Vol. IT-8, pp. 171-178 (February 1962).

2. T. Marill and D. M. Green, "On the Effectiveness of Receptors in Recognition Systems," IEEE Trans. on Information Theory, Vol. IT-9 pp. 11-17 (January 1963).

3. R. G. Casey, "Linear Reduction of Dimensionality in Pattern Recognition," Report No. RC-1431, IBM Research Division (March 1965).

4. P. E. Hart, "A Brief Survey of Preprocessing for Pattern Recognition," Technical Documentary Report, Contract AF 30(602)-3945, Stanford Research Institute, Menlo Park, California (December 1966).

5. C. N. Liu, "A Programmed Algorithm for Designing Multifont Character Recognition Logics," IEEE Trans. on Electronic Computers, Vol. EC-13, pp. 586-593 (October 1964).

6. L. Uhr and C. Vossler, "A Pattern Recognition Program that Generates, Evaluates, and Adjusts Its Own Operators," Proc. WJCC, pp. 555-569 (1961). Also in Pattern Recognition, pp. 349-364, Uhr, ed. (Wiley, New York, N. Y., 1966).

Chapter VIII

1. H. Robbins, "An Empirical Bayes Approach to Statistic," Proc. Third Berkeley Symp. on Math. Stat. and Prob., pp. 157-163 (UC Press, 1956).

2. M. V. Johns, "Non-Parametric Empirical Bayes Procedures," Ann. Math. Stat., Vol. 28, pp. 649-669 (1957).

3. E. Samuel, "An Empirical Bayes Approach to the Testing of Certain Parametric Hypotheses," Ann. Math. Stat., Vol. 34, pp. 1370-1385 (1963).

4. K. Abend, "Compound Decision Procedures for Pattern Recognition," Proc. NEC, Vol. 22, pp. 777-780 (1966).

5. J. Raviv, "Decision Making in Markov Chains Applied to the Problem of Pattern Recognition," IEEE Trans. on Information Theory, Vol. IT-13, pp. 536-551 (October 1967).

6. Y. T. Chien and K. S. Fu, "A Modified Sequential Recognition Machine Using Time-Varying Stopping Boundaries," IEEE Trans. on Information Theory, Vol. IT-12, pp. 206-214 (April 1966).

7. K. S. Fu, Y. T. Chien, and G. P. Cardillo, "A Dynamic Programming Approach to Sequential Pattern Recognition," IEEE Trans. on Electronic Computers, Vol. EC-16, pp. 790-803 (December 1967).

Chapter IX

1. A. B. J. Novikoff, "Integral Geometry as a Tool in Pattern Recognition," in Principles of Self-Organization, pp. 347-368, H. Von Foerster and G. W. Zopf, eds. (Pergamon, New York, N. Y., 1962).

2. G. P. Dineen, "Programming Pattern Recognition," Proc. WJCC, pp. 94-100 (March 1955).

3. M. Minsky and S. Papert, "Perceptrons and Pattern Recognition," MIT Project MAC, Artificial Intelligence Memo No. 140, MAC-M-358 (September 1967).

4. M. Blum and C. Hewitt, "Automata on a 2-Dimensional Tape," Proc. 1967 Eighth Annual Symposium on Switching and Automata Theory, pp. 155-160 (October 1967).

5. J. Feder, "The Linguistic Approach to Pattern Analysis: A Literature Survey," Technical Report 400-133, Dept. of Elec. Engr., New York University (February 1966).

6. R. Narasimhan, "Syntax-Directed Interpretation of Classes of Pictures," Comm. ACM, Vol. 9, pp. 166-173 (March 1966).

7. T. Marill, et al., "CYCLOPS-1: A Second-Generation Recognition System," Proc. FJCC, pp. 27-33 (1963).

Chapter X

1. J. T. Tippett, et al., eds., Optical and Electro-Optical Information Processing (MIT Press, Cambridge, Mass. 1965).

Chapter XI

1. L. G. Roberts, "Machine Perception of Three-Dimensional Solids," in Optical and Electro-Optical Information Processing, pp. 159-197, Tippett et al., eds. (MIT Press, Cambridge, Mass., 1965).

2. A. Guzman, "Decomposition of a Visual Scene Into Bodies," MIT Project MAC, Artificial Intelligence Memo No. 139, MAC-M-357 (September 1967).

Chapter XII

1. R. A. Wilson, Optical Page Reading Devices (Reinhold, New York, N. Y., 1966).

2. J. H. Munson, "Experiments in the Recognition of Hand-Printed Text: Part I--Character Recognition," Proc. FJCC, San Francisco, California, 1968.

3. L. S. Frishkopf and L. D. Harmon, "Machine Reading of Cursive Script," in Information Theory, pp. 300-316, C. Cherry, ed. (Butterworths, Washington, D. C., 1961).

4. W. J. Hankley and J. T. Tou, "Automatic Fingerprint Interpretation and Classification Via Contextual Analysis and Topological Coding," in Pictorial Pattern Recognition, pp. 411-456, G. C. Cheng, et al., eds. (Thompson, Washington, D. C., 1968).

5. R. Ledley, "High Speed Automatic Analysis of Biomedical Pictures, *Science*, Vol. 146, pp. 216-223 (9 October 1964).

6. W. S. Holmes, "Automatic Photointerpretation and Target Location," *Proc. IEEE*, pp. 1679-1686 (December 1966).

7. P. L. Bastien, et al., "Programming for the PEPR System," in *Methods of Computational Physics*, Vol. 5 (Academic Press, New York, N. Y. 1966).

8. G. E. Forsen, "Processing Visual Data with an Automaton Eye," in *Pictorial Pattern Recognition*, pp. 471-502, G. C. Cheng, et al., eds. (Thompson, Washington, D. C., 1968).