

THE UNIVERSITY OF MICHIGAN
COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS
Department of Communication Sciences

Final Report

AUTOMATON RESEARCH: DESIGN, CONSTRUCTION, COMPLEXITY, ADAPTATION

Logic of Computers Group

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RESEARCH PROGRESS REPORT

Title: "Automaton Research: Design, Construction, Complexity, Adaptation,"
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Contract No. Nonr-1224(21).

Background: The Logic of Computers Group of the Department of Communication Sciences of The University of Michigan is investigating the application of logic and mathematics to the design of computing automata.

Condensed Report Contents: The Office of Naval Research sponsored research program of the Logic of Computers Group of The University of Michigan is reviewed, and principal resulting reports and papers listed. The research first concentrated on showing the existence or non-existence of mechanical design procedures for computing automata. Later research included research on problems of automata which grow and reproduce, and problems of measuring the complexity of machines. Automaton composition de-composition problems were studied employing the methods of group and semi-group theory, category theory, and graph theory. Some problems of adaptation and learning in machines, as well as the relationship between probabilistic and deterministic machines were also examined.

For Further Information: The complete report is available in the major Navy technical libraries and can be obtained from the Defense Documentation Center. A few copies are available for distribution by the author.

INTRODUCTION

Research on Task NR 049-114 under Contract Nonr 1224 (21) began 1 January 1957 and continued to 31 December 1967. In the eleven years of the contract, 50 technical reports of research in the field of theory of automata and logical design of computer nets were submitted to the Office of Naval Research. This final report of research under Nonr 1224 (21) consists of three parts: I. A brief summary review of the research performed; II. A listing of the principal reports and publications resulting from the research; and III. A listing of the scientific personnel whose ONR supported research led to the obtaining of advanced degrees at The University of Michigan.

PART I

In the early years of this ONR sponsored research, attention was focussed on finding appropriate mathematical languages for the description of automaton structure and behavior, and then showing the existence or nonexistence of mechanical design procedures for classes of automata whose design specifications are expressed in the languages. Thus (of the list of Part II of this report) 1, 2, 4, 5, 6, 7, 8, 9, 11, 12, 13, and 32 all fall in this category.

This research on design algorithms led to several foundational mathematical studies especially Items 16, 17, 18, and 19.

In Item 20, several research areas were reviewed; these included problems of machines which grow and reproduce, and problems of the measuring of the complexity (and thus capabilities) of machines. Work on growing and cellular

machines is reported in Items 29 and 30, while research on automaton structural and behavioral complexity measures is presented in 21, 22, and 46.

The general problem of finding appropriate simple automaton sub-units from which all machines could be built and into which all machines could be decomposed, led to a program of research into the use of algebraic and graph theoretic techniques for describing machines. Work in this area is reported in Items 24, 26, 27, 31, 35, 36, 37, 40, 42, 43, 44, 45, and 48.

Problems of securing adaptive behavior in machines is discussed in Items 20, 41, and 47. Some practical issues in the design of the next generation of computers are discussed in Item 38, while in Items 34 and 39, the relationship between completely deterministic machines and machines which (like all physical machines) have some probability of incorrect behavior is analyzed.

PART II

A LIST OF THE PRINCIPAL REPORTS AND PUBLICATIONS

(The work listed here was supported in whole or in part by funds supplied through Nonr 1224 (21). Some of the work here listed was supported in part by the U.S. Army principally through the Army Signal Corps-Monmouth and the Army Research Office-Durham, and by the National Science Foundation and the National Institutes of Health.)

1. "Realization of Events by Logical Nets," I. M. Copi, C. C. Elgot and J. B. Wright, Journal of the Association for Computing Machinery 5 (1958) 181-196.
Also: in Sequential Machines ed. E. F. Moore Addison-Wesley, 1964, 175-192.
2. "Quantifier Elimination in a Problem of Logical Design," C. C. Elgot and J. B. Wright, Michigan Mathematical Journal 6 (1959) 65-69.

3. "Series-Parallel Graphs and Lattices," C. C. Elgot and J. B. Wright, Duke Mathematical Journal, 26 (1959) 325-338.
4. "The Non-Existence of Certain Algorithms of Finite Automata Theory," J. R. Buchi, C. C. Elgot, J. B. Wright, (Abstract) Notices American Mathematical Society 5, No. 1 (Feb. 1958), 98.
5. "Decision Problems of Weak Second-Order Arithmetics and Finite Automata. Part I," J. R. Buchi and C. C. Elgot (Abstract) Notices American Mathematical Society 5, 7 (Dec. 1958), 834.
6. "Weak Second-Order Arithmetic and Finite Automata," J. R. Buchi, Zeitschrift für Mathematische Logik und Grundlagen der Mathematik 6 (1960) 66-92.
7. "Decision Problems of Weak Second-Order Arithmetics and Finite Automata," Part II. C. C. Elgot (Abstract) Notices American Mathematical Society 6, 1 (Feb. 1959), 48.
8. "Decision Problems of Finite Automata Design and Related Arithmetics," C. C. Elgot, Transactions American Mathematical Society, 98 (1961) 21-51. Errata, ibid., 103 (1962) 558-559.
9. "Regular Canonical Systems and Finite Automata," J. R. Buchi, Technical Report, University of Michigan (December 1959).
Also: Archiv für Mathematische Logik und Grundlagenforschung 6, 5/4 (1962), 91-111.
10. "Computation, Structure and Behavior in Fixed and Growing Automata," A. W. Burks, Self-Organizing Systems, New York, Pergamon Press, 1960, 282-311.
Also: (Revised version): Behaviorial Science 6, 1 (1961) 5-22.
11. "On a Problem of Tarski," J. R. Buchi, Technical Note University of Michigan, July 1960.
12. "On a Problem of Tarski," J. R. Buchi, Abstract: Notices American Mathematical Society 7, 3, 381-382.
13. "On a Decision Method in Restricted Second Order Arithmetic," J. R. Buchi; Logic, Methodology and Philosophy of Science: Proceedings of the 1960 International Congress, ed. Nagel, Suppes. Tarski, Stanford U. Press, 1-11.
14. "Sequence Generators and Digital Computers," A. W. Burks and J. B. Wright, Recursive Function Theory: Proceedings of Symposia in Pure Mathematics, 5, 139-199, American Mathematical Society, 1962.
15. "Sequence Generators, Graphs, and Formal Languages," A. W. Burks and J. B. Wright, Information and Control 5 (1962) 204-212.

16. "Inseparable Sets and Reducibility," S. Tennenbaum, Technical Report University of Michigan, July 1961.
17. "Turing Machines and the Entscheidungsproblem," J. R. Buchi, Abstract: Notices American Mathematical Society 8, 4 (1961) 354.
18. "Turing Machines and the Entscheidungsproblem," J. R. Buchi, Mathematische Annalen, 148 (1962) 201-213.
19. "On Validity in Finite Domains," J. R. Buchi, Abstract: Notices American Mathematical Society 8, 4 (1961).
20. "Concerning Efficient Adaptive Systems," J. H. Holland, Self-Organizing Systems-1962, New York, Pergamon Press, 1962 (Manuscript preparation and publication: ONR supported).
21. "The Star-height of Regular Expressions," L. C. Eggen, Abstract: Notices American Mathematical Society, 9, 4 (1962) 298.
22. "The Star-height of Regular Expressions," L. C. Eggen, Michigan Mathematical Journal 10 (1963), 385-397.
23. "Commutative Machines," R. Laing and J. B. Wright, Technical Report, University of Michigan, December 1962.
24. "Normal Monoids and Factor Monoids of Commutative Monoids," Y. Give'on, Technical Report, University of Michigan, May 1963.
25. "Notes on Mathematical Automata Theory," J. W. Thatcher, Technical Note, University of Michigan, December 1963.
26. "The Theory of Algebraic Automata I: Morphisms and Regular Systems," Y. Give'on, Technical Note, University of Michigan, January 1964.
27. "Outline for an Algebraic Study of Event Automata," Y. Give'on, Technical Report, University of Michigan, June 1964.
28. "Lattice Matrices," Y. Give'on, Information and Control 1, 4, (1964), 477-484. (Revised and prepared for publication under Nonr 1224 (21)).
29. "Variants of Thatcher's Algorithm for Constructing Pulsers," S. Hedetniemi, University of Michigan Technical Report, August 1964.
30. "Universality in the Von Neumann Cellular Model," J. W. Thatcher, University of Michigan Technical Report, September 1964.

Also: To appear in Essays in Cellular Automata ed. A. W. Burks, University of Illinois Press.

31. "Toward a Homological Algebra of Automata," Y. Give'on (This work consists of 4 parts; these appeared as separate reports during 1965; the parts are as follows:
 I. 1. The Representation and Completeness Theorem for Categories of Automata
 II. 2. A Note on Some Well-Known Functors of Automata
 III. 3. Composition Series of Automata, 4. Extensions of Q-Automata
 IV. 5. The Characterization of Projective Automata)
32. "Decision Problems for Multiple Successor Arithmetics," J. W. Thatcher, University of Michigan Technical Report April 1965.

 Also: Journal of Symbolic Logic 31, 2 (1966), 182-190
33. "Tape Machine Realization of Commutative Regular Events," R. Laing, University of Michigan Technical Report, October 1965.
34. "Equivalences Between Probabilistic and Deterministic Sequential Machines," C. V. Page, University of Michigan Technical Report, April 1965.

 Also: Information and Control 4, 469-520 (1966)
35. "Transparent Categories and Categories of Transition Systems," Y. Give'on, University of Michigan Technical Report May 1965.

 Also: (Related paper) 1965 IEEE Conference Record on Switching Circuit Theory and Logical Design (Record of Sixth Annual Symposium) 235-241.

 Also: (Related paper) Proceedings of the Conference on Categorical Algebra: La Jolla 1965, eds. Eilenberg, Harrison, MacLane, and Rohrl, Springer Verlag 1966, 317-330.

 Also: (Related paper) Logic, Computability and Automata, ed. F. Cannonito, Thompson Book Co. Washington D.C.
36. "A Homomorphic Theory of Content-Free Languages and Its Generalizations," Y. Give'on, University of Michigan Technical Report, September 1965.
37. "Homomorphisms of Graphs," S. Hedetniemi, University of Michigan Technical Report, December 1965.
38. "Iterative Circuit Computers: Characterization and Resume of Advantages and Disadvantages," J. H. Holland, Microelectronics and Large Systems, eds. Mathis, Witey, Spandorfer. Spartan Press, 1965, 171-178.
39. "Equivalences Between Probabilistic Sequential Machines," C. V. Page, University of Michigan Technical Report, December 1965.
40. "On Some Categorical Algebra Aspects of Automata Theory: The Categorical Properties of Transition Systems, Y. Give'on University of Michigan Technical Report, February 1966.

41. "Non-Linear Environments Permitting Efficient Adaptation," J. H. Holland, Computers and Information Sciences-11, ed. J. T. Tou, Academic Press 1967, 147-164.
42. "Homomorphisms of Graphs and Automata," S. Hedetniemi, University of Michigan Technical Report, August 1966.
43. "Degenerate Automata: Some Relationships Involving Semi-Group Order and Regular Events," B. Zeigler, University of Michigan Technical Report, December 1966.
44. "On Hereditary Properties of Graphs," S. Hedetniemi, University of Michigan Technical Report, February 1967.
45. "Some Interpolation Theorems for Partitions of Graphs," S. Hedetniemi, University of Michigan Technical Report, March 1967.
46. "Realization and Complexity of Commutative Events," R. Laing, University of Michigan Technical Report, March 1967.
47. "A Class of Sequential Sampling Problems Arising in Certain Learning Situations," E. Bainbridge, University of Michigan Technical Report, December 1967.
48. "Decompositions of Automata Using Normal Submonoids," B. Zeigler, University of Michigan Technical Report, December, 1967.

PART III

ADVANCED DEGREES EARNED THROUGH ONR SPONSORED RESEARCH

1. Calvin Elgot obtained the Ph.D. in Mathematics from The University of Michigan; his dissertation is item 8 of the list of reports and publications.
2. James Thatcher obtained the Ph.D. in Communication Sciences from The University of Michigan; his dissertation is item 32 of the list of reports and publications.
3. Y. Give'on obtained the Ph.D. in Communications Sciences from The University of Michigan; his dissertation is item 40 of the list of reports and publications.
4. C. V. Page obtained the Ph.D. in Communication Sciences from The University of Michigan; his dissertation is item 39 of the list of reports and publications.

5. S. Hedetniemi obtained the Ph.D. in Communication Sciences from The University of Michigan; his dissertation is item 42 of the list of reports and publications.

In addition, at the conclusion of Nonr 1224 (21) five graduate students were pursuing research, with ONR contract support, which will lead to the Ph.D. in Communication Sciences at The University of Michigan.

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