T h e  C o l l e c t e d  W o r k s  O f

# THE BIOLOGICAL COMPUTER LABORATORY

1957 - 1976

Edited by Kenneth L. Wilson

ILLINOIS BLUEPRINT CORPORATION

Peoria, Illinois 1976

# INTRODUCTORY FICHE INDEX

# CREDITS AND ACKNOWLEDGMENTS

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| Editor | Kenneth L. Wilson |
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I would like to acknowledge the invaluable assistance of Professor Heinz Von Foerster, Director of the Biological Computer Laboratory, in all phases of this publication. Further, his continuous effort over the past twenty years to maintain an organized and efficient publication system at BCL has made the production of this collection much easier than it might have been. And without Dr. Von Foerster there would be no collection to collect.

I would like to thank Edwin Schlossberg for the origional idea which motovated this project. Ricardo Uribe lent his enthusiasm and support and with Shea Zellweger and John Hackmann helped to organize the BCL Library. David Grothe helped in the final printing of the Author index, and Paul Weston gave valuable criticisms and advice on microfiche formatting.

A large debt of gratitude is owed to the publishers, Bob Brem and Bill Clark, for their persistence in providing first rate reproductions and having the foresight to recognize new and interesting areas in micro publication.

Credit for the journal, periodical, or book of original publication together with the publisher is given on each reference in the Author Index and BCL Publications Index 74.1 as well as on the title page of each article.

# THE BCL MICROFILM COLLECTION

## SCOPE AND INTENT

This collection contains the complete publications of the Biological Computer Laboratory for the years 1957 to 1976. It is our desire that this collection be a resource and an invitation to the reader's needs, providing conceptual tools suitable for investigations in cybernetics, cognitive studies and other areas in which BCL has made contributions over the years. It is our hope that this collection will, by presenting papers in the intellectual context in which they arose, serve to explicate the process by which these conceptual tools came to be.

## USE OF THE COLLECTION

The collection is structured alphabetically, by author, on Fiche Cards 1 through 115 and chronologically on the remaining fiche cards, 116 through 146, which contain the yearly BCL Summaries. Each fiche card contains 7 rows of 14 squares each with papers beginning on any square of a row and continuing left to right and top to bottom until completion. Preceding each paper is a large arrow which indicates the break between papers. Access to the papers is provided through three indexes and the INTRODUCTION contained on Fiche cards 0 and 00.

## USE OF THE INDEXES

The Author Index provides a complete alphabetical listing by author of works done at BCL. The papers done by an author are presented in chronological order. When a paper was authored by more than one person, a reference to the paper will appear under each author with an asterisk * after the first author. Such papers are located in the section containing papers by the first author.

As shown below, references are given in a standardized form listing author, title, title of book or magazine in which

published if any, page numbers, and date of publication. When a paper was published in a journal or book the title of the paper is in quotes. When the paper was published by BCL the title appears in all capital letters without quotes. Journals are not given in capital letters where books are given in all capitals. When a paper was published in more than one form the reference includes all versions.

Amiot, L. W., H. Von Foerster*, & P. M. Mora: "Doomsday: Friday, 13 November, A. D. 2026",
Science, Vol. 132, 1291-1295 (1960).
also
DOOMSDAY, FRIDAY, NOVEMBER 13, 2026 A. D. + 2000 DAYS,
Biological Computer Laboratory, University of Illinois; Urbana, 15 pp. (1960).
BCL # 35
BCL TR # 2.2
Fiche # 87/6

After the reference follow one or several BCL numbers which will be explained in a subsequent paragraph. The last number which appears on each reference is the Fiche number identifying the location of the paper in the collection. This number gives the Fiche card number and the row on that fiche where the paper begins (Fiche # Card/Row). If the paper does not fit completely on that card the additional card numbers are given (for example, Fiche # 76/6 & 77 & 78 & 79).

The BCL Index is an index which was published by BCL every few years. The latest index, BCL 74.1, was published in 1974, and an updated version of that index is included on Fiche 00. This index lists publications according to a BCL numbering system which divides publications into categories: publications (papers published outside of BCL), BCL Technical Reports, BCL Reports, Theses, and BCL Summaries. For a more complete explanation of

this numbering system refer to the last paragraph of this introduction. The fiche card and row number are included after each reference. If any questions arise as to the correctness of a citation please refer to the Author Index, which is the last word in all cases.

The Brief Topical Index will give the reader an idea of the general topical area in which each of the major authors worked. This index is arranged by author with suggested papers in each area. This index is by no means complete and represents only a cursory selection and categorization which may lead the reader into areas of interest.

## THE BCL NUMBERING SYSTEM

During the course of operation of BCL many items were written, including articles and papers for books and journals, technical reports, occasional papers, theses, and summaries. Papers in each of these different categories were labeled with different numbering systems (reference should be made to the BCL Publications Index 74.1 indcluded on the bottom p tion of Fiche #00). Articles, papers, books, and theses which were published by an institution other than BCL are given BCL Publication Numbers 1 through 256 (listed in the Author Index as BCL # 1, BCL # 2, etc.). BCL Technical Reports are papers which were published by BCL under the sponsorship of various grants given to BCL by such agencies as the National Science Foundation. In 74.1 these grants are listed along with the various publications which were sponsored by them. Technical reports are numbered sequentially by grant (chronologically), and sequentially within the grant thus giving a two-part number (such as BCL TR #2.1 which would be the first paper in the second grant). Originally these were numbered by small roman numerals within the grant but this system has been simplified for the present collection. Ph.D. and M.Sc. Theses are numbered sequentially in a separate section of 74.1. However, all theses (with the exception of three which were done under Von Foerster or W. R. Ashby and not at BCL) are either BCL Publications or BCL Technical Reports or both and are therefore numbered

in the microfiche collection with only their Publication and Technical Report numbers. BCL Reports are papers which were published by BCL without the sponsorship of a grant. These papers are numbered according to topical categories which include: Tables, Combinatorics, Epistemology, Computation, Networks, Physiology, Psychology, Systems Analysis, Cognition, Motor Activity, and Miscellaneous. Within each Category the publications are numbered sequentially thus giving a two part number such as BCL Report # 9.3, which would be the 9th category (Cognition) and the 3rd paper in that category. BCL Summaries are volumes of shorter papers which were collected each year, along with a summary of activity at BCL for that year, and published by the Lab. It should be noted that these papers are individually indexed in the author index. The Summaries are numbered by year and followed by a second number which indicates the following: 1 = publication list, 2 = Accomplishment Summary, 3 = other collectively initiated publications. For access to the papers in all of these summaries the reader should refer to the Author Index or the table of contents for each summary (the summaries are sequentially included in the microfiche collection on cards 116 through 146 and have green tops).

EDITORIAL NOTES

I have attempted to provide the reader with a complete and easily readable collection. This has not been without problems. Inasmuch as such a task has not been attempted at this scale, the complete works of a single laboratory, We, the publisher and myself, have been exploring new ground. Many attempts have been made to help the reader easily handle this large volume of material. Some will succeed and some perhaps will not. Some mention must be made here of several of the Editorial decisions which were made and for which I take responsibility.

The medium of microfiche was studied to understand the reader's reading of material. It was noted that difficulties arise when

papers are broken up on several fiche cards especially when the paper is short and would have fit on one card or part of a card. For this reason many hours were spent arranging the material and making many small decisions in order to keep the breaks in material to a minimum. To do this some condensations of pages were made within papers. For instance, many papers contained blank pages or pages containing only chapter titles which were also present on the following page. Many of these pages were removed with the only result being that those page numbers are not to be found in the collection. Such pages do not possess the same function in the microfiche format that they do in a book format--and can thus be eliminated. In some cases when space on a particular microfiche card was particularly dear, a few lines of print at the end of a chapter or page were put on the previous page. In a like manner some condensation of preface, credits, etc. was done. In all cases I can assure the reader that no information was lost.

Some papers exist in more than one form, such as being published by BCL as a Report and also being later published in a journal or book. Whenever possible, the typeset journal version is included in the microfiche collection. Both references, of course, are given in the Author index.

A few papers which are listed as BCL publications in the Index are not included in the collection. Some of these are books written by people working at BCL and published by publishing firms. For reasons of copyright infringement these are not included. Other books were edited by people working at BCL and contain material by people who were not associated with BCL. These were not included though the papers in them authored by BCL members are included, in most cases. Some PhD and Ms.C. theses were not included in this collection. Most of these were done under Von Foerster or Ashby and were not associated with BCL. A very few papers were not published in this collection because proper releases were not obtainable or because the paper, after exhaustive search through libraries and old manuscripts, could not be found. I hope the reader will be satisfied, as I am, that these exclusions do not affect the completeness of this

microfiche collection.

This project was attempted with the sole purpose of making the entire output of the Biological Computer Laboratory available in a convenient form. It must also be said that the actual impetus for doing this was the desire of a small group of us who have been working at BCL for the past few years to have this collection available for ourselves. We welcomed the opportunity provided by the Illinois Blueprint Company to publish this collection making it available to a larger audience. As were many of the papers included in the collection, so this collection itself is a labor of love. It is my hope that the collection will become and remain the valuable tool which I perceive it to be.

Kenneth L. Wilson

Kenneth L. Wilson

Editor

# INTRODUCTION

## THE BIOLOGICAL COMPUTER LABORATORY

Living organisms perpetually compute on their sensory inputs complex abstractions, relations and decisions in order to determine the appropriate actions which will allow them to survive in a hostile and capricious environment called "Nature." They leave the naive task of computing sums, products, differences, fractions, square roots, log tables, Bessel functions, etc., to machines, for their nervous system is busy solving much more sophisticated computational problems, for instance how to identify quickly and reliably whether entities in their environment are desirable or dangerous, how to predict within a certain degree of confidence the future behavior of these entities once identified and, ultimately, how to react, interact and relate to these entities once identified and understood. Of course, from a philosophical point of view the problem of identification and of prediction have the same root, since identifying an object means essentially predicting the invariance of some of its properties over some period of time. However, identification and prediction are meaningful only if what is identified and predicted is significant for the maintenance of the integrity of the organism who interacts with these entities. Today, in our times of the "information explosion" in which we are ever more forced to process information generated and absorbed by man, a question arises: "How have living organisms solved this problem of gathering, processing and utilizing information which, when necessary, may be communicated via signs or symbols to other organisms of the same or different kind?"

The Biological Computer Laboratory (BCL) of the University of Illinois was founded in 1958 to address precisely this question. BCL's main lines of research have been to explore the principles of computation in living organisms, to establish the structural and functional organization of such "biological computers," and

to utilize this knowledge in the design and construction of cognitive systems, conversant systems, inductive inference machines, etc. Research has been conducted on almost all levels of inquiry, from studies in epistemology, logic, linguistics, mathematics, neurophysiology, etc., to computer simulations, speech recognition and other electronic information systems. The senior members of the group carried joint appointments with various departments of this University, and the graduate students who participated in these studies majored in fields that range from philosophy, psychology, linguistics to physics and electrical engineering.

The founding and guiding spirit of BCL was that of Heinz Von Foerster. The group which formed BCL included such people as W. Ross Ashby, Gotthard Gunther, Lars Lofgren, Humberto Maturana, Gordon Pask, Heinz Von Foerster and Paul Weston. The following paragraphs give a descriptive picture of the work done by each of these people. This list is not inclusive and we advise the uninformed reader to explore the Author Index and short Topical Index for a more complete picture of those who worked at BCL.

## W. R. Ashby

W. Ross Ashby was the originator of cybernetics as it is known today. He provided an interpretation of Shannon's information theory in terms of the theory of sets as developed by N. Bourbalse. Thus he was able to bring the entire and powerful apparatus of modern set theory to bear upon the definition and analysis of systems information transfer, and regulation (7/6) (9/3) (9/5). He provided an information theoretical interpretation of the concepts of model and modelling, and with Roger Conant proved the theorem that "every good regulator of a system must be a model of that system" (4/3) (20/7). Ashby showed that the propositions of information theory were equivalent to proportions concerning certain functions of particians of integers: if you can count, you can be a cyberneticist.

As a result and extension of this work in systems and information theory, Ashby contributed major papers in areas of System Stability (5/6) (28/4) and Many Dimensional Relations (7/5) (53/5). The importance of Ashby's early work in cybernetics is widely recognized. The importance of these later works is only now becoming well known.

## Gotthard Günther

Classical logic is based on a monothematic ontology which specifies what can be studied by science. Objects and thus materiality can be known while subjectivity, being the immaterial aspects of a system, must be objectified before it can be studied. Monothematic ontology must therefore stipulate the notion of the transcendental soul in a dichotomy between thought (soul) and being (matter). In light of Ashby's statement that Cybernetics is the study of the immaterial aspects of systems, classical logic presents a fundamental descriptive weakness for the study of Cybernetics. Gotthard Günther proposes an interpretation of transclassical logic using a polythematic ontology to give a structural basis for object qua object and subject qua subject as well as object qua subject (33/1) (36/3) (36/4) (37/5) (38/4). In a polythematic ontology there are no attributes of the object without the subject and no attributes of the subject without the object. The object is discontextual with regard to the subject and vice versa, where contextual refers to the non-reducibility of subject and object by an excluded third. A more than two-valued logic allows us in speaking about descriptions to grasp the indefinite recursion of self reflexivity.

## Lars Löfgren

Lars Löfgren approaches the problems associated with a theory of description (51/7) and of explanation (52/1) by the axiomatic systems of automata theory. There is a similarity between the concepts of reproduction and explanation which implies a similarity between the less well understood concepts of complete self-reproduction and complete self-explanation (49/6). Löfgren shows these

latter concepts to be independent from ordinary logical-mathematical-biological reasoning, and in a special form, complete self-reproduction is shown to be axiomatizable (52/1). Involved is the question, previously argued by Wittgenstein, of whether or not there exists a function that belongs to its own domain. Complete self-reproduction is primarily of interest in connection with formal theories of evolution. The importance of Löfgren's work also lies in the mathematical machinery necessary for modeling self-reflective and completely closed systems (118/2) (see also L. Peterson 65/7 & 66).

Humberto R. Maturana

Humberto Maturana of the University of Chile and BCL has written fundamental works on the implications of biology on cognition. Maturana, in Biology of Cognition (55/1) and Neurophysiology of Cognition (54/6), presents an epistemological theory of the observer as a living system and the living system as a closed network of interactions. This closed systems concept is in opposition to current biological thought and makes possible a concise theory of cognition and associated phenomena. Maturana clarifies this concept in a book on the organization of living things (85/1) (56/1 & 57). He shows that all the phenomenology associated with living organisms arises from a closed circular organization. Maturana also recognizes the sociological implications of these theories (145) (57/5). His work gives the biological basis for a unified philosophy of cognition and living systems.

Gordon Pask

Gordon Pask has taken the concepts of self-referential systems and system modeling to synthesize new system formulations (63/5 & 64) (65/1), and apply them in "teaching-learning machines" (145). More recently, Pask has developed a theory of conversation which can be modeled and used in conversational teaching systems (Conversation, Cognition and Learning: Elsevier, 570 pp. (1975)). The theory of conversation makes a distinction between "material

individuals" and "psychological individuals" in order to model the process of topic-concept-memory formation in a conversation between one or more subjects. The object language used to explain topics and concepts is distinguished from the meta-language used to discuss how the object language is being used. Conversation is treated as a self-organizing system with an arbitrary distinction between teacher and student. Pask has made use of the Günther type logic system to model dialog with a true "dialogic."

Heinz Von Foerster

Heinz Von Foerster came from Hapsburg, Vienna and the Wittgenstein family and upholds an intense sense of the interconnections of epistemology, language, and ethics. Indeed, Wittgenstein's remark that "ethics and aesthetics are one and the same" (where aesthetics comes from the writings of Kant as the branch of metaphysics concerned with the laws of perception) could well serve as a motto not only for Von Foerster's own work but for the work of BCL as well, thus accounting for the at first glance perhaps bewildering scope of its activities, from the analysis of "musical" tones, over the standard range of cybernetic topics, to the notation of human movement.

Heinz Von Foerster has combined the tools of physics and mathematics with a critical understanding of systems theory to help lay a formal groundwork for cybernetics. His paper "On Self-Organizing Systems and Their Environments" (88/1) establishes crucial connections between information theory and systems theory. This connection is extended into automata theory in his paper "Molecular Ethology: An Immodest Proposal for Semantic Clarification"(98/5), which has ramifications and implications for all of the cognitive and behavioral sciences. The consequences of these and other fundamentals of cybernetics are applied to the theory and study of memory in several important papers (93/3), (96/1) (95/1). A major part of Von Foerster's work has been to develop a philosophy of cognition based on the principles of cybernetics (89/5) (91/1) (94/3) (99/1) (103/6) (104/1) (10[illegible]3).

Paul Weston

Paul Weston has developed a new and powerful data structuring concept called "Cylinders" (118/3) (110/1). This structuring method makes possible very fast and efficient relational data bases necessary for dealing with the subtlties of language. Weston has also done fundamental work in the field of natural language computation which he and Von Foerster have aptly termed "Computing in the Semantic Domain" (124/5) (125/5) (110/7) (130/7). Additionally, Paul Weston has written several papers on the philosophical and practical aspects of machines which can understand (96/1) (123/6) (124/4) (109/4) (133/6) (109/6).

Kenneth L. Wilson
Richard H. Howe

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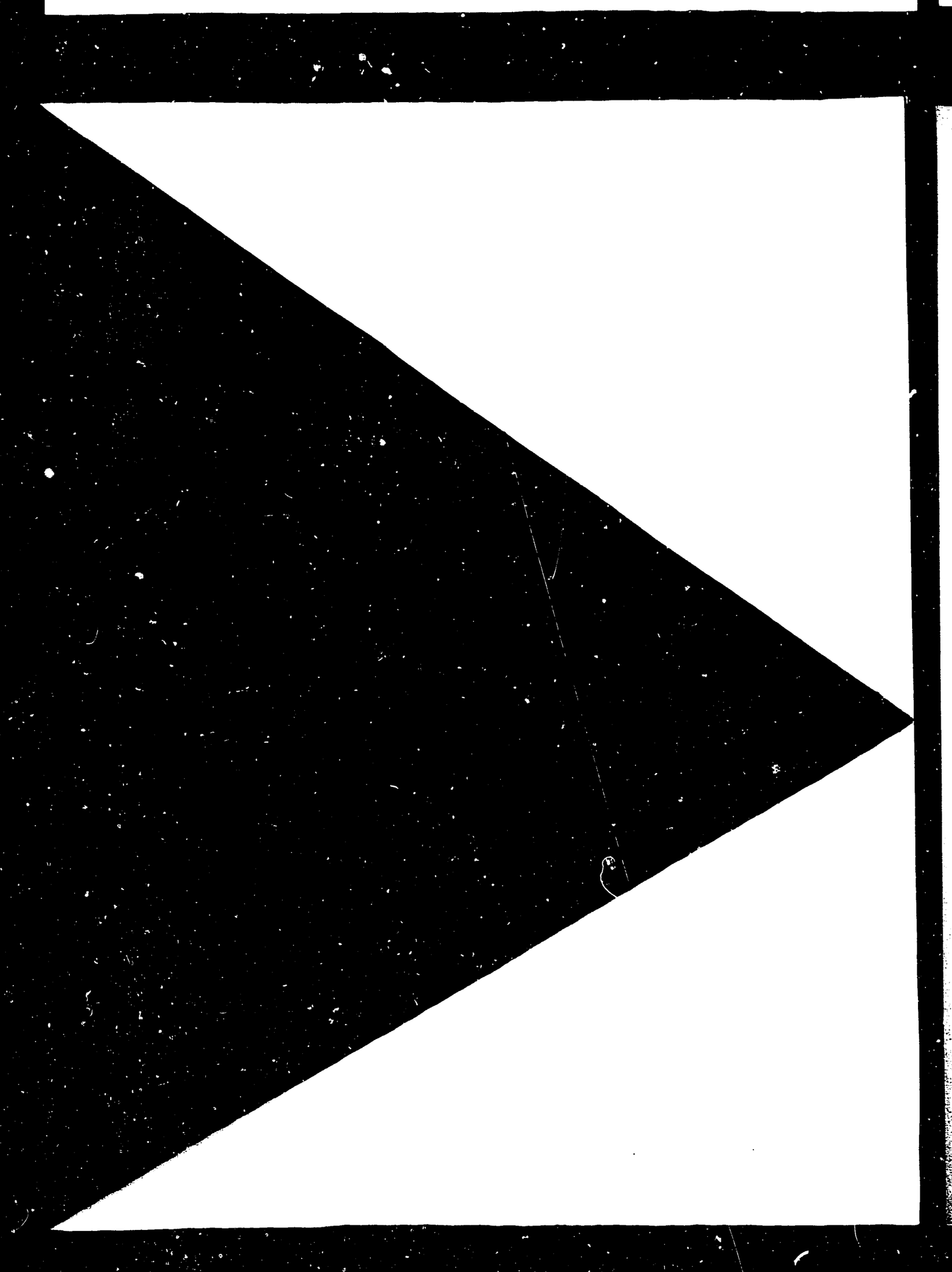

# BCL

| REPORT NO. | 7 | 4.1 |
|---|---|---|

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|---|---|
| TITLE: | B.C.L. PUBLICATIONS |
| AUTHOR: | B.C.L. Staff |
| DATE: | 31 December 1974 |
| SPONSOR: | See Chapter I. |

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RTMENT OF ELECTRICAL ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA, ILLINOIS

# PUBLICATIONS
# BY MEMBERS OF THE
# BIOLOGICAL COMPUTER LABORATORY
# UNIVERSITY OF ILLINOIS
# URBANA, ILLINOIS

B.C.L. Report No. 74.1

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Mr. and Mrs. H. Von Foerster
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# PREFACE

The following pages reflect the activity of the Biological Computer Laboratory of the University of Illinois by the books, articles, theses and reports that were published by its members since B.C.L. was established January 1, 1958 until December 31, 1974.

We shall be glad to supply interested colleagues with reprints of these publications in as much as they may be available.

H.V.F.
12/31/74

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## Editor's Note

This is an updated version of BCL Report 74.1. Several new papers have been included and a new and simplified Technical Report numbering system used. The microfiche location numbers appear after each reference in ink lettering using the two part (card #/ Row #) number as in the author index. The abbreviation "ni" is used when a paper is not included in the microfiche collection. Some reference mistakes still remain in this index such as first author or spelling. These have been corrected in the Author Index. Also, many papers appear twice or three times, as BCL Publications, Theses, and Technical Reports, and thus will appear only once in the Author index with all numbers listed.

KLW

# SPONSORS OF B.C.L.

1. Toward the Realization of Biological Computers. Contract NONR 1834(21), ONR Project No. NR 049-123; Sponsored by Information Systems Branch, Mathematical Science Division, Office of Naval Research. Period: 1 January 1958 to 31 July 1961. Principal Investigator: H. Von Foerster.

2. Mechanisms of White Cell Production and Turnover. United States Public Health Grant CA-04044; Sponsored by Department of Health, Education and Welfare, Public Health Service, National Institutes of Health. Period: 1 July 1958 to 21 October 1963. Principal Investigator: H. Von Foerster.

3. Analysis Principles in the Mammalian Auditory System. Contract No. AF 33(616)-6428, Project No. 60(8-7232), Task No. 71782; Sponsored by Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Period: 1 May 1959 to 30 September 1961. Principal Investigator: H. Von Foerster.

4. Theory and Circuitry of Property Detector Nets and Fields. NSF Grant 17414; Sponsored by the National Science Foundation, Washington, D.C. Period: 27 March 1961 to 30 June 1962. Principal Investigator: H. Von Foerster.

5. Theory and Circuitry of Property Detector Nets and Fields. NSF Grant 25148; Sponsored by the National Science Foundation, Washington, D.C. Period: 1 July 1962 to 31 December 1963. Principal Investigator: H. Von Foerster.

6. Theory and Circuitry of Systems with Mind-Like Behavior. AF-OSR Grant 7-63; Sponsored by Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 October 1962 to 31 October 1964. Principal Investigator: H. Von Foerster.

7. Semantic and Syntactic Properties of Many Valued Systems of Logic. AF-OSR Grant 8-63; Sponsored by Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 2 October 1962 to 31 March 1964. Principal Investigator: Gotthard Günther.

8. Principles of Information Transfer in Living Systems. United States Public Health Grant GM-10718; Sponsored by Department of Health, Education and Welfare, Public Health Service, National Institutes of Health. Period: 1 May 1963 to 30 April 1966. Principal Investigator: H. Von Foerster; Co-investigator: W. R. Ashby.

9. Information Processing Capabilities of the University of Illinois Dynamic Signal Analyzer. Contract No. AF 33(657)-10659; Sponsored by Aerospace Medical Research Laboratory, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio. Period: 1 February 1963 to 31 January 1964. Principal Investigator: M. L. Babcock.

10. Theory and Circuitry of Systems with Mind-Like Behavior. AF-OSR Grant 7-64; Sponsored by Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 November 1964 to 31 October 1965. Principal Investigator: H. Von Foerster.

11. Semantic and Syntactic Properties of Many-Valued and Morphogrammatic Systems of Logic. AF-OSR Grant 480-64; Sponsored by Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 October 1963 to 30 September 1967. Principal Investigator: G. Günther.

12. Information Processing Capabilities of the University of Illinois Dynamic Signal Analyzer. Contract No. AF 33(615)-2573; Sponsored by Aerospace Medical Research Laboratory, Air Force Systems Command, United States Aif Force, Wright-Patterson Air Force Base, Ohio. Period: 1 February 1965 to 31 January 1966. Principal Investigator: M. L. Babcock.

13. Cybernetics in Anthropology. Grant No. 1720; Sponsored by the Wenner-Gren Foundation for Anthropological Research, New York, New York. Period: 1 February 1965 to 30 September 1966. Principal Investigator: H. Von Foerster.

14. Integration of Theory and Experiment Into a Unified Concept of Visual Perception. AF 49(638)-1680: Sponsored by The Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 March 1966 to 30 April 1969. Principal Investigator: H. Von Foerster.

15. Theory and Application of Computational Principles in Intelligent, Complex Systems. AF-OSR Grants 7-66 and 7-67; Sponsored by the Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 November 1965 to 31 October 1967. Principal Investigator: H. Von Foerster.

16. Cybernetics Research. Contract AF 33(615)-3890; Sponsored by Air Force Systems Engineering Group, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio. Period: 1 April 1966 to 31 March 1969. Principal Investigator: H. Von Foerster.

17. Information, Communication, Multi-Valued Logic and Meaning. AF-OSR 68-1391; Sponsored by Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 October 1967 to 30 September 1969. Principal Investigator: H. Von Foerster.

18. Study Toward the Mechanization of Cognitive Processes. NASA NGR 14-005-111; Sponsored by the National Aeronautics and Space Administration, Electronics Research Center, Boston, Massachusetts. Period: 1 October 1967 to 30 September 1968. Principal Investigator: M. L. Babcock and H Von Foerster.

19. Theory and Application of Computational Principles in Complex, Intelligent Systems. AF-OSR Grant 7-67; Sponsored by the Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 September 1967 to 31 August 1969. Principal Investigator: H. Von Foerster.

20. Application of Cognitive Systems Theory to Man-Machine Systems. AF-OSR 70-1865. Sponsored by the Air Force Office of Scientific Research, United States Air Force, Washington, D.C. Period: 1 October 1969 to 31 September 1970. Principal Investigator: H. Von Foerster.

21. Notation of Movement. Grant DA-ARO-D-31-124-G998; Sponsored by the United States Army Research Office, Durham, North Carolina. Period: 1 March 1968 to 31 August 1969. Principal Investigator: H. Von Foerster.

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