# COMPUTERS and AUTOMATION

### DATA PROCESSING • CYBERNETICS • ROBOTS

Computers for the Highway Engineering Program

Could a Machine Make Probability Judgments?

JANUARY 1959 • VOL. 8 - NO. 1





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3

# COMPUTERS and AUTOMATION

### DATA PROCESSING • CYBERNETICS • ROBOTS

#### Volume 8 Number 1

### JANUARY, 1959

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FRONT COVER Testing an Air Defense Weapon	•	-
ARTICLES		

Computers for the Highway Engineering Program.	. 12
JACK BELZER	
Could a Machine Make Probability Judgments?	
(Part 1)	. 14
I. J. GOOD	
Symbolic Logic and Automatic Computers (Part 3-	

### READERS' AND EDITOR'S FORUM

Some Ideas from the Eastern Joint Computer Conference	6
Competition for Our Front Cover Pictures	8
Advanced Course in Analog Computing	8
Multilingual Terminology Project of the Provisional International Computation Centre, Rome	8
Interdisciplinary Conference on Self-Organizing Systems 1 SCOTT CAMERON	.0

#### **REFERENCE INFORMATION**

Computer Talks — Eastern Joint Con	nputer	Con	ferei	nce,
Philadelphia, Pa., Dec. 3 to 5, 1958	3	•		. 11
Annual Index to Computers and Aut	omatio	n.	•	. 23

### INDEX OF NOTICES

Advertising Index .			32	2
Back Copies		•	see Nov. issue, p. 13	3
Bulk Subscriptions .			see Oct. issue, p. 20	6
Manuscripts	•		see Oct. issue, p. 20	6
Who's Who Entry Form			see Nov. issue, p. 28	8

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Readers' and Editor's Forum

### FRONT COVER: TESTING AN AIR DEFENSE WEAPON

THE FRONT COVER shows a supersonic missile, a version of Lockheed Aircraft's "Kingfisher," which has been specially designed and instrumented for testing a "Talos" intercepting weapon for air defense. The Kingfisher pictured was "shot down" by a Talos, and, after a drop from high altitude, is being recovered for reuse, by virtue of a parachute and a long nose spike buried deep in the desert at White Sands Proving Grounds in New Mexico. This picture was taken shortly after a recovery crew had placed supports against the missile, preparatory to digging it out of the ground and taking it back to the base to be used again.

The interception of the Kingfisher by the Talos was registered by a Lockheed electronic computing device known as a firing error indicator.

None of the processes of launching, directing, intercepting, and recovering are possible without computers.

### SOME IDEAS FROM THE EASTERN JOINT COMPUTER CONFERENCE

THE EASTERN JOINT Computer Conference, Dec. 3 to 5, 1958, in Philadelphia, is naturally one of the important events in the computer field each year. It is worth while reflecting on a number of the ideas expressed at that conference. Here are some of them:

The effective use of the weapons of the United States Air Force in defense of the United States now depends almost entirely on the capacity of computers to make the necessary and difficult calculations within very narrow time limits, because they have to solve the problems of interception in real time.

> - "Role of Computers in Air Defense," W. H. Tetley, U.S.A.F.

The computer field has become accustomed to improvements of ten times the speed — why not reach for a reduction to one-fifth of the cost?

- "New Frontiers," J. W. Forrester, M.I.T.

Complete perfection in the detection and correction of errors is theoretically impossible — but a great deal of automatic detection and automatic correction of errors is possible and can be demonstrated with existing equipment.

> "Philosophy of Automatic Error Detection,"
>  R. M. Bloch, Datamatic Div. of Minneapolis-Honeywell

It is possible to make a random access memory using photographic means containing at least 135,000 machine words of 80 binary digits each, with a maximum time of 5 microseconds for random read-out.

--- "A High-Speed High-Capacity Photo Memory," C. A. Lovell, Bell Telephone Laboratories

By using new devices, it may be expected that at

least 10,000 logical elements for computers may be placed on one square inch of surface.

- "The Impending Revolution in Computer Technology - Introduction," Rex Rice, IBM Corp.

A major increase in the reliability of computers does in fact allow a different approach to the operation and maintenance of computers. This is confirmed by nearly two years of operating experience with the Univac Athena Computer, a large general purpose digital computer used for the ground-based guidance system for the intercontinental ballistic missile TITAN.

-- "Athena Computer: A Reliability Report," G. A. Raymond and L. W. Reid, Remington Rand

The idea of computer components which are simple enough to be made in large numbers has led to the study of processes for their construction which use photography or electron beams.

- "An Approach to Automatic System Fabrication," Dudley Buck, M.I.T.

Instead of having fixed quantities of reports of fixed nature for each time period in a business, which cover all the items that management may consider, why not have varying quantities of reports of varying nature, which present only those items that require management to take action?

- "Data Processing and Information Production," R. H. Gregory, and Martin Trust, M.I.T.

In exploring the design of a new computer, an existing computer can be used to simulate and evaluate the new computing system and ideas for its circuits. This results in greater insight into problems, and faster decisions in engineering.

- "Special Purpose Computer Design by Simulation," P. L. Phipps, Remington Rand Univac, St. Paul

At the present time it is hard to evaluate linguistic translation rules proposed for machine translation from Russian to English, because there exists no practical way to test these rules automatically on large bodies of text. But why not test translation rules automatically? An automatic programming system is proposed and described, which accepts as its inputs a set of experimental translation rules, and a large body of Russian technical text. The system applies the rules to the text (making use of an "automatic dictionary"), and produces as its output a readable "trial translation," which is the English text resulting from applying the given rules to the Russian text.

— "The Trial Translator — An Automatic Programming System for Experimental Machine Translation of Russian to English," V. E. Giuliano, Harvard Computation Laboratory

COMPUTERS and AUTOMATION for January, 1959



### COMPETITION FOR OUR FRONT COVER PICTURES

EVERY ISSUE OF Computers and Automation since June 1957 (except the Computer Directory issue in June 1958) has had on its front cover a selected picture related to the computer field. Here are some of the examples:

- --- visitors to an exhibition in Brussels playing bridge with a computer;
- a stack of 500 documents on a table, and a girl holding up a ten inch strip of magnetic tape on which the references to all 500 have been recorded;
- a helicopter hovering in the air showing the pilot holding both his hands out of an open window, the helicopter being controlled by a newly developed automatic computing mechanism;
- a tiny ceramic electronic tube the size of half a thumb nail being held in a girl's fingers, and being compared with a small transistor;
- a small electro-mechanical model of a simple hardware "animal," with interchangeable plugboard "brains" around it;
- some of the calculating frames of a giant automatic computer, which had just begun to work for a hospital plan subscription service, being inspected by a photogenic young lady age four.

What is the procedure we use for selecting our front cover picture each month?

We try to choose a picture which meets these requirements:

- (1) It has a significant relation to "computers and their applications and implications" — which is the field of Computers and Automation";
- (2) It is a fairly recent picture;
- (3) It is interesting, striking, and dramatic.

We try to avoid pictures which show only smooth featureless outside coverings, with or without persons, because we think that most computer people are not interested in the covers. It is hard enough to understand a computing machine without covering up and concealing its mechanisms.

If we could look into the crystal ball that shows the future (and also inaccessible parts of the present) — if we could summon the help of a genie or magician who was unrestricted by military classification or industrial secrecy — and so have any pictures that we desired, we should be interested in such pictures as the following:

- pictures of the operation of the computing mechanisms of the Nautilus as it navigated under the North Polar ice cap;
- views of the computing mechanisms of the first space vehicle to travel around the moon;
- a view of the memory of the first practical operating computer made out of cryotrons;
- views of the computing mechanisms that enabled the United States' four-ton Atlas get into orbit on December 18, 1957;
- pictures of the first computing system that guides and controls wisely the economy of a planned society.

In the meantime, here and now, we run a little competition in our office every month, about the tenth of each month, for choosing the front cover picture of the next issue. We are always glad to consider for this competition glossy photos from anywhere in the world.

### ADVANCED COURSE IN ANALOG COMPUTING Electronic Associates

Princeton Computation Center Princeton, N.J.

THE SEVENTH "Advanced Course in Analog Computation" at the Princeton Computation Center of Electronic Associates, Inc., will be held February 9 through Feb. 20, 1959, at the Center in Princeton, New Jersey.

This is a graduate level course; it is specifically designed to meet the needs of the practising engineer or scientist. Students will be given thorough instruction in the techniques of analog simulation and how to apply these techniques to a wide variety of industrial problems. These problems have been selected to acquaint engineers with some of the great number of possible applications of analog computation. Many improved techniques which have been developed at the EA Computation Centers, including methods for economizing on programming time and equipment requirements, are included in the course.

Previous classes have included representatives from leading industrial and government laboratories.

Classes are limited to a maximum of twenty in order to permit proper instruction and to allow an adequate number of laboratory sessions on the computers located at the Center.

Inquiries should be addressed to: Administrative Assistant, Electronic Associates, Inc., Princeton Center, P.O. Box 582, Princeton, N.J.

### MULTILINGUAL TERMINOLOGY PROJECT OF THE PROVISIONAL INTERNATIONAL COMPUTATION CENTRE, ROME

#### I. From Edwin Holmstrom Lausanne, Switzerland

WE SHOULD LIKE to count on your support for the Multilingual Terminology Project of the Provisional International Computation Centre, Rome. The following letter is going to collaborators in the various countries that use English, French, German, Russian, and Spanish.

Dear . . . ,

As soon as they are ready, I shall send you sets of 314 sheets each containing a term and definition copied by permission from the glossary of computer terms published in the American journal Computers and Automation of October 1956. Will you please acknowledge receipt of them, and in accordance with what you have kindly undertaken, arrange to process them through stage (......) of the work described in my previous circular letter, namely:

Stage (2). Add on each sheet an exact (name of language) translation of the definition (not the term) and return it to me. . .

Stage (3). Insert after the symbol (indicating the country) the term which in the opinion of yourself and your local colleagues best matches the definition . . . and return it to me.

Please do not change the sense of the present definitions, but if you do not like them, mark them to that

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effect. In any case, you are welcome to suggest other definitions of either the same or additional concepts in your own language. These should be sent to me either marked in a publication or copied out, with their sources identified.

I will then have them translated into other languages, and ask the experts in the appropriate countries to match them with the terms they recommend in those languages.

You will notice that some of these American definitions are divided into parts 1, 2, 3, . . . all covered by the same underlined U.S. term. If you consider that these are really different concepts, and that in your language each should be denoted by a different term, please mark them accordingly. I will then give them each of them its own PICC number in the future. . . .

Please send back to me in Lausanne the sheets which you have processed through Stage (2) or (3) as quickly as possible, as many as you can manage each week until the whole lot is completed. . . .

#### II. From the Editor

We should like to ask each one of our readers who is interested in computer terms and definitions please to send us terms and expressions in the computer field which (1) have come into use since October 1956, or (2) which have new or additional or revised meanings since publication of our October 1956 glossary. Please also send us your suggested definition if you have one, or a passage or citation showing how the term is used, or both. We shall then forward a copy of this to Dr. Holmstrom, and keep a copy for the next revision of our glossary.

If any reader is seriously interested in working on this glossary project, we shall be very glad to send him a complimentary reprint of our October, 1956, glossary.

### INTERDISCIPLINARY CONFERENCE ON SELF-ORGANIZING SYSTEMS

AN INTERDISCIPLINARY CONFERENCE on Self-Organizing Systems will be held on May 5th and 6th, 1959, at the Museum of Science and Industry, Chicago, Ill. The conference is to be co-sponsored by the Information Systems Branch of the Office of Naval Research and the Armour Research Foundation.

The purpose of this conference is to bring together research workers in all fields of science who are concerned either with the development of self-adaptive information systems or with the conduct of research which may contribute to an improved understanding of cognitive, learning, and growth processes. Particular emphasis will be placed on theoretical models of systems which are capable of spontaneous classification, identification, and symbolization of their inputs.

Interested individuals may receive further information and a preliminary conference program when available by writing to:

> Mr. Scott Cameron ICSOS Conference Secretary Armour Research Foundation 10 West 35 St. Chicago 16, Ill.

COMPUTERS and AUTOMATION for January, 1959

## COMPUTER TALKS

### Eastern Joint Computer Conference (Eighth Annual) Philadelphia, Pa., December 3 to 5, 1958

- Data Processing in Banking and Other Service Industries / B. W. Taunton, Asst. Comptroller First National Bank of Boston
- Role of Computers in Air Defense / W. H. Tetley, Colonel, USAF, Hdqrs. ADSID, Hanscombe Field, Lexington
- New Frontiers / Prof. J. W. Forrester, M.I.T. School of Industrial Management
- Athena Computer: A Reliability Report / G. A. Raymond and L. W. Reid, Remington Rand
- Philosophy of Automatic Error Correction / R. M. Bloch, Datamatic Division of Minneapolis-Honeywell
- The Systems Approach to Reliability / H. D. Ross, International Business Machines Corp.
- Impulse Switching of Magnetic Elements / Robert E. McMahon, Mass. Inst. of Technology, Lincoln Laboratory
- A High Speed, High Capacity Photo Memory / C. A. Lovell, Bell Telephone Laboratories
- An Experimental Modulation-Demodulation Scheme for High-Speed Data Transmission / E. Hopner, IBM Corp.
- The Impending Revolution in Computer Technology Status of Present Research — Introduction / Rex Rice, IBM Research Center, Poughkeepsie, N.Y.
- Computer Design From the Programmer's Viewpoint / Walter F. Bauer, Space Technology Lab., Ramo-Wooldridge Corp.
- An Approach to Automatic System Fabrication / Dudley Buck, Mass. Inst. of Techn.
- New Logical and Systems Concepts / R. K. Richards, Consulting Engineer
- Speculation on Programming Perspectives / W. F. Bauer
- Speculation on System Design Viewpoint / R. K. Richards
- Speculation on Self Organizing Systems of Components / Dudley Buck
- An Information Filing and Retrieval System for the Engineering and Management Records of a Large-Scale Computer Development Project / G. A. Bernard, III, and Louis Fein, Ampex Corp.
- File Problems Connected with a National Menu Study / Phil M. Thompson, Market Research Corp. of America
- Data Processing and Information Production / Robert H. Gregory and Martin Trust, Mass. Inst. of Techn.
- National Bureau of Standards' Multi-Computer System / A. L. Leiner, W. A. Notz, J. L. Smith and A. Weinberger, National Bureau of Standards
- Data Handling by Control Word Techniques / G. A. Blaauw, IBM Corp.
- COMPUTERS and AUTOMATION for January, 1959

- An Electronic Directory for Sorting Mail / A. W. Holt, Rabinow Engineering Co.
- Special Purpose Computer Design by Simulation / P. L. Phipps, Remington Rand Univac, St. Paul
- The Logical Design of CG 24 / G. P. Dineen, I. L. Lebow, and I. S. Reed, Mass. Inst. of Techn., Lincoln Laboratory
- Design Criteria for Autosynchronous Circuits / J. C. Sims, Jr., Sylvania Electric Products, Inc., and H. J. Gray, Univ. of Pennsylvania
- Analysis of TRL Circuit Propagation Delay / W. J. Dunnet, E. P. Auger, and A. C. Scott, Sylvania Electric Products, Inc.
- The Recording, Checking, and Automatic Printing of Transistor Logic Diagrams / M. Kloomok, P. W. Case, and H. H. Graff, IBM Corp.
- State-Logic Relations in Autonomous Sequential Networks / William H. Kautz, Stanford Research Inst.
- System Evaluation and Instrumentation of a Special Purpose Data Processing System Using Simulation Equipment / A. J. Strassman and L. H. Kurkjian, Hughes Aircraft Co.
- APAR Automatic Programming and Recording / G. R. Bachand, J. L. Rogers, and T. F. Marker, Sandia Corp.
- A High-Speed Transistorized Analog-to-Digital Converter / R. C. Baron and T. P. Bothwell, Epsco, Inc.
- The Trial Translator An Automatic Programming System for Experimental Machine Translation of Russian to English / V. E. Giuliano, Harvard Computation Lab.
- DYANA: Dynamics Analyzer-Programmer / T. J. Theodoroff and J. Olsztyn, General Motors Corp.
- Univac Air Lines Reservations Systems / C. W. Fritze, V. E. Herzfeld, and D. K. Sampson, Remington Rand Univac
- The Siemens Digital Computer 2002 / Dr. Heinz Gumin, Siemens & Halske A. G., Munich, Germany
- Design of the RCA 501 System / T. M. Hurewitz and J. G. Smith, Radio Corp. of America
- The IBM 7070 Data Processing System / R. W. Avery, S. H. Blackford and J. McDonnell IBM Corp.
- Performance Advances in a Transistorized Computer System — The Transac S-2000 / R. J. Segal, J. L. Maddox and P. Plano, Philco Corp.
- Programming Design Features of the Gamma 60 Computer / Philippe Dreyfus, Cie. Des Machines Bull, Paris
- The G.E. Model 100 System / R. Hagopian, H. Herold, J. Levinthal, and J. Weizenbaum, General Electric Co.

### Computers for the Highway Engineering Program

Jack Belzer Systems Engineering Division Battelle Memorial Inst. Columbus, Ohio

THE FEDERAL AID Highway Act of 1956 has embarked the 48 states on one of the largest public works programs ever undertaken anywhere in the world. Over \$100 billion will be spent in the next 10 to 15 years to construct greatly needed streets and highways. Such an effort will place great demands upon our nation's resources in materials, manpower, administrative capabilities, and technical know-how, as well as finance.

The rate of effort required by this program will be much greater than the capabilities of the highway construction industry. To meet this challenge, the engineers and scientists engaged in research and development will be called upon to help lift the rate of effort in order to achieve what has been planned. The technologists will do this by developing better materials to be used on the highways and better equipment with which to build them. Improved equipment has already enabled the highway construction industry to increase its ability to build roads with comparatively much smaller increase in manpower.

The spending of the \$100 billion on this program will not, of course, produce \$100 billion worth of roads in place. In fact, a large share of this money will be spent on the purchase of right of way. Moreover other large expenditures must be made prior to the actual construction of highways. Among these are, surveying the land, making preliminary designs of roads which eventually lead to final designs, determining the number and types of bridges and overpasses needed, designing these bridges, and so on and on and on. The latter costs represent the effort to be expended by the civil engineers in the design of the highways. The modern superroads require tremendous engineering work to meet the many stringent conditions imposed on them by the anticipated traffic load such roads will have to bear.

The greatest shortage of personnel will be felt among the engineers who survey and design the highways and bridges. Engineers today are in great demand and the highway industry is now competing for their services. The industry will have difficulty in meeting its needs, but to attempt to get by with substandard engineering would be false economy. To overcome this shortage, highway engineers will have to be relieved of nonengineering duties, and duplication of effort will have to be eliminated. To this end, H. A. Radzikowski, Chief, Division of Development, Office of Operations, Bureau of Public Roads has been instrumental in encouraging increased highway engineering productivity through the use of electronic computers. This has been the most important step towards meeting the time schedule of the entire "Grand Plan" of the Federal Highway Program. There is evidence that the application of electronic computers to highway engineering problems is one of the most important means of rescuing this program. The shortage of trained highway engineers with which we are now faced will continue to exist, and electronic computers are capable of relieving the engineers of tedious computations and nonengineering responsibilities which are very time-consuming and costly.

Before the program for the construction of highways can begin, land must be surveyed by aerial or ground methods and route locations selected. Based on this information the right of way purchases are made. The highway engineers design the roads, determine the cut and fill, and then redesign it for optimization. Modern highways cannot follow the terrain as they did in the past. They have to be wider, more level, and straighter. This means that more bridges across railroads, rivers, and other highways will be built. To keep construction costs down, the mass diagrams of the cut and fill have to be better balanced. In bridge designing, stress analyses have to be performed to assure that the structures will meet the desired specifications at minimum cost. The completed designs have to supply a bill of materials for every item that goes into the construction of bridges. The determination of the number of beams required, their size and weight, and the exact points where they fit, has to be made. These are only some of the engineering problems requiring the tremendous amounts of calculation which electronic computers can do.

Many consulting engineering companies have become aware of the capabilities of electronic computers and are anxious to profit from them. However, it is not quite clear to many companies how this can be accomplished. Because the industry as a whole does not have a coordinated plan, a large amount of effort is wasted in preparing individual programs for automatic computers to perform these tasks. By the old standards, this is progress, and saves time and highway engineering effort. In too many instances, however, these programs become the private property of the company which developed them, and other companies must duplicate this effort for their own use. One serious problem is that the programs developed are often not sufficiently flexible to be of general use and cannot handle variations which exist from problem to problem. A coordinated and well-planned effort could create the means with which all highway engineers could readily solve their problems utilizing automatic electronic calculations.

The State Highway Departments and the highway engineering consulting companies who could profit from such an effort must realize its potentialities. They must know exactly in what way electronic computers can contribute to their total effort in designing highways and bridges. To help in this effort, Battelle conducted two workshops on Highway Engineering Applications of Automatic Computers, the first in September, 1956, and the second during February, 1957. The manner in which the workshops were received is most revealing. Engineers from New Hampshire to California, representing both the State Highway Departments and consulting engineers, attended the workshops. Their interests covered many phases of high-



Bridges like the one illustrated are being designed completely with the aid of electronic computers. The bridge above was designed by Burgess and Niple, Consulting Engineers, Columbus, Ohio. The computer time required to design the girder on an IBM type 650 computer is approximately one hour.

way engineering including photogrammetry, cut and fill calculations, road designs, stress analysis, and geometrics for bridge design, and traffic studies. At these workshops the engineers learned, among other things, the types of problems which are best suited for computers and the techniques that may be employed in obtaining their solutions. They also learned one of the most fundamental concepts of computers — once a problem or any part of a problem has been programmed, it does not have to be programmed again. This one fact about computers can reduce duplication of effort and help speed up the entire program. It appears that this concept offers the most fruitful area of research.

The initiation of a coordinated research program could realize the benefits of this principle and thereby advance the state of the art of computer utilization in highway engineering. Such a program could begin by examining thoroughly all problems confronting highway engineers. These problems could then be defined in terms of sound engineering principles, mathematical representations, and state practices and requirements. From these, only problems that can be solved by computers would be selected for further study. At this stage the research would take on a different appearance. A detailed review of the mathematics involved would be made, and numerical methods and techniques for their solutions could be set up. Once this is accomplished, a language to express the analytical methods for obtaining solutions to these problems could be developed. This language would employ the nomenclature familiar to highway engineers. To translate the various statements of such a language into computer terms would require the writing of computer routines and subroutines. These would express in computer language the operations required for the highway engineering tasks. The routines would be such that a simple statement in the new language would correspond to a computer run which would yield a program encompassing all the implications of that statement.

For example, in continuous beam analysis, the civil engineer frequently resorts to the moment-distribution technique for obtaining the magnitudes of the support moments. Professor Hardy Cross developed a method of moment distributions by successive approximations. It assumes zero slopes at all supports and determines fixed-end moments. This does not necessarily satisfy the principles of equilibrium. There can exist unbalanced moments at various supports, and balancing the beam constitutes distributing the unbalanced moments according to distribution factors. This process is repeated until a balance is obtained. The entire Hardy Cross method for moment distribution could be programmed in such a manner as to define all parameters by the problem input. Having established this, a programmer would merely refer to the Hardy Cross method stating the parameters of his specific problem, and the entire program for this phase of the problem would be automatically written by the computer step by step.

If subprograms were written for all fundamentally different sequences of arithmetic operations which are used frequently in highway engineering computations, then programming would constitute only the linkage statement which call for these subprograms. These linkage statements constitute a "compiler" language, and could be made in the language familiar to highway engineers. This technique would solve the major effort to programming highway engineering problems for computers.

Once a compiler for highway engineering work has been established, all programs could be written in this language. They would be written easily, rapidly, and accurately. With a plan such as this the federal highway program could make efficient use of electronic computers. Under the lead of the Bureau of Public Roads the establishment of such a plan would be entirely possible and desirable. The state highway departments in the 48 states as well as the consulting engineers engaged in this program could then utilize the plan in their own areas.

### Could a Machine Make Probability Judgments?

I. J. Good

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MANY THEORIES OF probability are concerned with degrees or intensities of belief or of rational belief. The notion of a machine that has degrees of belief may sound paradoxical, and this is why I find it interesting to ask whether a machine could make probability judgments. In attempting to answer such a question we may clarify the expression "degree of belief." All the same I shall be deliberately speculative and I am unable to place a machine on the table that actually makes probability judgments. My aim is simply to try to answer the question asked as best I can in a reasonable time.

Our discussion will touch on the topics of learning machines, chess-playing machines, and machines consisting largely of random networks. A certain amount of work has already been done on these topics but I shall not attempt to list all the relevant literature here.<sup>2</sup>

One further warning is necessary. Some of the discussion of machines will seem to be anthropomorphic and teleological. If so, it is because the words "as if" will be frequently taken for granted. If an argument is expressed too rigorously, it is liable to become uninteresting. A completely rigorous argument may go on forever and would be understood by no one.

If I gave ten different definitions of "machine," ten meanings to "probability" and ten definitions of "judgment," I should have 1000 different questions to answer. If I were to talk for fifty minutes, and few people should be allowed to talk for longer, I should have an average of three seconds to deal with each question. Actually I shall of course severely restrict the meaning of the question.

I recall a science fiction story in which the only observable distinction between a human being and an android was that the androids were stamped, inaccessibly, "made in Birmingham" or "fabriquée en Paris." If androids could be manufactured, the question whether they could feel pain would be interesting legally, morally and philosophically, but the question whether they could make probability judgments would reduce to whether human beings could do so. Moreover I find it too speculative to consider whether androids could be constructed. I am more interested in the practical question of whether machines will be making probability judgments in the near future.

The sort of machines I have in mind are generalpurpose computers of the types that are likely to be constructed during the next twenty years, and machines consisting largely of random electrical networks,<sup>3</sup> functionally resembling the brain more than most generalpurpose computers do. A partially random electrical network is one whose design is left to chance to some extent. Once the design is fixed the behaviour may or may not be deterministic.

It seems likely that the brain consists largely of random neural networks. (Identical twins have different finger-prints so that the development of finger-prints is presumably partially random. The same is likely to be true of the brain since it contains far more components than a finger-print.) Machines consisting largely of random networks would have the advantage of greater speed over brains, but the disadvantage of far less elementary components, if existing techniques are used. It is true that in principle a general-purpose computer can do any logical operation that can be done by a partially random network, but in practice a partially random network may be far more efficient at various classes of jobs. For one thing it may be capable of more parallel working than are most general-purpose computers.

In an article in *Mind*,<sup>4</sup> entitled "Computing machinery and intelligence," Turing argued that a general-purpose computer may be programmed to "think" within the next fifty years. He said that a machine could be said to think if it could fool you into supposing that it was a woman just as well as a man could do so, in five minutes' conversation, the conversation being carried on by teleprinter. Turing's arguments were mainly concerned with the disposal of counter-arguments and he was not constructive in this article. I do not know whether he ever attempted to work out how the program could be organised.

There have also been short published discussions by Popper<sup>5</sup> and by Somenzi<sup>6</sup> on whether scientific induction could be mechanised. If a machine could think or if it could perform scientific induction, than *a fortiori* it could make probability judgments, at any rate if people can. Likewise, if a machine could carry out perfect translation, in the style of a human translator, then it would need to make probability judgments, since most linguistic texts are ambiguous. (But a machine might list all the meanings of an ambiguity instead of selecting the most probable meaning.)

Our question then is relevant to the answers to these other questions, and is also less ambitious. If we can think of examples of a practicable machine that can make probability judgments within a limited field, then our question is answered affirmatively and constructively. It is not necessary that the machine should be able to make probability judgments about everything.

It is worth saying that in principle a machine could certainly think, in Turing's sense, because it could store suitable answers to every possible question. The main trouble with this strategy is that it would be impracticable. Also, thinking is presumably more than the mere use of memory. We see that the only point in asking whether machines could think is if we are interested in whether such machines are practicable, and the same applies to the question of whether machines could make probability judgments.

### Probability Judgments

It is now time to discuss what is meant by a "probability judgment." The meaning naturally depends on our theory of probability. I shall therefore describe briefly the theory of probability that I adopt.<sup>7, 8, 9</sup>

Up to a point the theory has the form of any other scientific theory that has reached a polished form. Judgments are fed into a "black box" and "discernments" are fed out.

Judgments  $\longrightarrow$   $\xrightarrow{}$   $\xrightarrow{}$   $\xrightarrow{}$  Black  $\longrightarrow$  "Discernments"

The black box is the formal apparatus (i.e., the abstract theory or mathematical theory) which depends on the axioms (i.e., the formal postulates) of the theory. Within the black box the word "probability" is not given any particular meaning. There are six or seven axioms, of which the following are typical:

A1. P(E|F) (pronounced "the probability of E given F") is a non-negative number, where E and F are propositions.

A3. P(E.F|H) = P(E|H)P(F|E.H), where E.F means "E and F."

- A4. If E and F are logically equivalent, then P(E|G) = P(F|G), and P(G|E) = P(G|F) for any G.
- There is the possible modification of A4:
- A4'. If "you" have proved that E and F are logically equivalent, then P(E | G) = P(F | G), etc.

In order to use the black box we need rules of application. Let P'(E | F) > P'(G | H) be a probability judgment, i.e. a statement that your degree (or intensity) of belief in E given F (i.e., if F is assumed) would exceed your degree of belief in G given H. (Note that the possibility of making such judgments does not depend on the existence of numerical degrees of belief.) Then the main rule of application is that the primes (dashes) can be erased, i.e., in the black box you can write P(E | F) >P(G | H), and conversely. To plug in a judgment is to erase primes; to make a discernment is to insert primes.

The set of judgments is the input body of beliefs. The purpose of the theory of probability is to enlarge your body of beliefs and to detect inconsistencies in it. These may often be patched up by means of more mature consideration.

#### Theory of Rational Behavior

The theory can be extended into a "theory of rational behaviour" by introducing "utilities," combined with the "principle of rational behaviour." This principle is the recommendation to maximise the mathematical expectation of utility, integrated over the whole future, with a suitable decreasing weighting function.

In addition to the axioms and rules there are "suggestions." These are imprecise, because a precise suggestion would become a rule of application or an axiom. For example:

(i) Numerical probabilities can be introduced by imagining perfect packs of cards perfectly shuffled, or infinite sequences of trials under essentially similar conditions. Both methods are idealizations, and there is very little to choose between them. It is a matter of taste: that is why there is so much argument about it.

- (ii) Any theorem of probability theory and anybody's methods of statistical inference may be used to help you to make probability judgments.
- (iii) If a body of beliefs is found to be unreasonable after applying the theory, then a good method of patching it up is by being honest (using unemotional judgment). (This suggestion is more difficult to apply to utility judgments because it is more difficult to be unemotional about them.)
- (iv) Bayes' postulate, or the principle of indifference, is an example of a suggestion. It would be a rule but it cannot be made quite precise enough.

Justifications of the theory of rational behaviour have been given by F. P. Ramsey,<sup>10</sup> von Neumann and Morgenstern,<sup>11</sup> and by L. J. Savage.<sup>12</sup>

Some people prefer to apply the theory of probability to rational degrees of belief, supposed to be unique and independent of people. They are called "credibilities" by Edgeworth <sup>13</sup> and by Bertrand Russell.<sup>14</sup> Such theories are supported by Jeffreys <sup>15</sup> and by Carnap.<sup>16</sup> A credibility is supposed to exist independently of the existence of human beings, animals, or robots.

Note that the following two statements are equivalent: "I judge that the credibility of E given F exceeds that of G given H," and

"P'(E|F) > P'(G|H)," although the second statement concerns degrees of belief instead of credibilities. If you believe that credibilities exist, then you can have degrees of belief concerning the magnitude of credibilities.

Apart from degrees of belief and credibilities there are also "physical probabilities," which Popper calls "propensities." <sup>17</sup> These are the limits towards which (with credibility 1) a credibility will tend in an infinite sequence of experiments performed under "essentially the same conditions." Sometimes it is extremely difficult to perform an experiment more than once, as with the throwing of a die composed of a heterogeneous mixture of unbaked clay and mud. Nevertheless the propensity may be assumed to exist. In all cases one can imagine the experiment to be repeated, especially if the universe is assumed to be of infinite extent.

If you are interested in the probability of rain tomorrow, you would like to estimate the physical probability, but in practice you certainly cannot do better than estimate the credibility, and your estimate of the credibility is your degree of belief.

### Making Probability Judgments

Now if we fed a body of beliefs into a general-purpose computer, it may very well perform the operations of the black box for us. It does not seem reasonable to say of such a machine that it makes probability judgments (except perhaps where these may be used within pure mathematics): at most it merely deduces "discernments" (in the above technical sense). In fact I should say that the machine made probability judgments only if these were not deducible from the ones fed in by the operator. Also the machine would not be much good if it merely denied what was said by the operator. What seems to be wanted is that the machine should be capable of producing a *consistent* body of beliefs, at least after adequate training and mature consideration.

I shall assume that our machine could make use of the theory of probability, as described; the question that remains is how it is to make its own probability judgments. On the face of it there is a logical difficulty, because if we specified precisely how the judgments were to be made, then we should not call them judgments, but rather rules of application of the theory of probability. Therefore the specification must be imprecise. The question arises how imprecise specifications can be made for a machine or for a machine program.

Of course a machine could print out probability judgments at random, but then it would soon run into inconsistencies. There must be some principle that tends to make the machine reasonably rational. This principle can perhaps be found in the theory of rational behaviour.

In order to apply this theory the machine must behave as if it could make value (utility) judgments. Any targetseeking machine can be said to behave as if it could estimate utilities. Here again, the utilities may have been entirely determined by human beings. For example, a good chess-playing machine will behave as if it preferred winning to losing. In fact a certain type of chess-playing machine will serve as an adequate example for our main question. Machines that made bets with the operator, or with other machines, would provide another class of examples.

### Instructing a Machine to Make Probability Judgments

When we are teaching a machine to play chess it would be inefficient to wait until the end of the game for the post-mortem. It is better to carry out the instruction move by move, or, better still, judgment by judgment. (As I shall indicate later, the play can be largely expressed in terms of probability judgments.)

The instruction can take various forms, of which I shall consider only the following two:

- (a) "Telling" the machine that the last judgment was right or wrong; or, almost equivalently, but more efficiently, telling it our own judgments;
- (b) "Rewarding" or "punishing" the machine according to its last judgment.

This second form of instruction seems to be more appropriate for a machine constructed largely of partially random networks (a "P.R.N." machine, say). I shall suppose that the P.R.N. machine will consist largely of models of neurons, having synaptic connections between the neurons. Each neuron has a threshold such that when the input voltage is above the threshold then the neuron fires.

The point of using partially random networks is that a systematic arrangement may introduce prejudiced modes of operation not easily overcome by instruction. One of the main problems in the design of a P.R.N. machine would be to decide in what ways it should be systematic and in what ways random. Needless to say the machine must have input and output organs, and it may well be a hybrid machine consisting of a general-purpose computer combined with partially random networks.

When a P.R.N. machine makes a correct judgment it can be rewarded say by pouring some chemical over it, which will permanently lower the thresholds of all the neurons last used, at any rate until the next soaking.<sup>18</sup> Punishment consists in using an antidote that increases the thresholds. Degrees of reward and of punishment would also be possible and could correspond to the amount won or lost in a bet. This type of treatment is especially appropriate for juvenile P.R.N. machines. It should be applied in "hot blood," i.e. before the machine has forgotten what it is being rewarded or punished for. (Otherwise it may need reminding somehow.) The situations presented to the machine should at first be simple ones. The treatment is rather crude and may lead to traumas and to repression, especially if punishment has been given when reward was deserved. If the treatment failed over a long period, and after restarting from scratch a few times, then the machine would be classified as delinquent and it would be redesigned. It is also interesting to speculate on the possibility of treating it by some method analogous to psychoanalysis. Perhaps areas of irrationality could be located by a form of free association. Research along these lines may eventually benefit the study of human psychology as well as robot psychology. (Compare W. R. Ashby.<sup>19</sup>)

In the redesigning just mentioned there are a great many parameters that could be changed, such as

- (a) the total number of neurons,
- (b) the average number of connections to other neurons, and the standard deviation,
- (c) the proportion of inhibiting connections,
- (d) the time for which each synaptic joint is active if not renewed.

If we hit upon a non-delinquent machine, and if it were very complicated, we could fairly say that it was making its own judgments because we should not know how they were made. It is true that we should have brought up the machine ourselves and its judgments would therefore be liable to resemble our own. On the other hand if we were very careful in our instruction and did not instruct when tired or drunk, then the machine's judgment may be as good as ours at its best and much quicker. If we wish the machine really to develop a "mind of its own" then we should at some stage. let the machine begin to learn directly from its own experiences of success and failure, instead of continuing indefinitely to insist that our own judgments are better.

These remarks about P.R.N. machines are intentionally speculative. My own guess, however, is that some very striking successes will be obtained with P.R.N. machines during the next twenty years.

### Instructing a Machine to Play Chess

I should like to discuss method (a) of instructing the machine, namely by telling it whether its last judgment was right or wrong (without making use of "chemicals"), or by telling it our own judgments. This method would work with a sufficiently adult P.R.N. machine or with an android, if such machines could be constructed, but I should like to indicate that it would be quite practicable as a method of instructing a general-purpose computer to play chess.

Chess exhibits several of the features of theoretical scientific research and at the same time is simple enough to be discussed conveniently. This is presumably a reason why Turing, Shannon, and others have been interested in programming a machine to play chess. It may turn out that chess does not provide a practicable example. But it would be possible to invent some game for which the following general ideas would be effective. Whether a really good chess-playing machine will be constructed within the next twenty years is an open question. (The automatic solution of two-move chess problems, as programmed at Manchester, barely touches the fringe of the problem of chess-playing machines.)

### [To Be Continued]

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Dr. Adolf H. Knothe of Dr. Wernher von Braun's staff discusses a problem with Dr. Helmut Sassenfeld and Mr. William D. Smythe of the Huntsville Computer Center, operated by General Electric for the Computation Laboratory, Army Ballistic Missile Agency.

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### Symbolic Logic and Automatic Computers

Part 3—Concluding Part

Edmund C. Berkeley

(continued from the December 1958 issue, vol. 7, no. 12, p. 29)

#### 13. The Connectives of Statements

We can easily make new statements from given statements by means of logical connectives (or conjunctions or operators). For example, we can combine two statements with "or" in the sense "and/or." We can also turn a statement into its negative.

 $S \cdot S' = S$  and S; both S and S'

S v S' = S and S' or both; S and/or S

 $S \rightarrow S' = if S$ , then S'; S implies S

 $S \longleftrightarrow S' = S$  if and only if S'; if S, then S', and if S', then S

In this collection we also need to put "not," expressing the denial of a whole statement:

 $\sim$  S = not-S; it is not true that S

There are connectives between statements which are not in the territory of symbolic logic: for example, "S because S'," because cause and effect is in the realm of science; "S while S'," because the idea of time is outside of the field of symbolic logic.

These five operators AND, OR, IF . . . THEN, IF AND ONLY IF, NOT all have a very important property: the truth value of a combination statement using them can be calculated from the truth values of the constituent statements. For example, the truth value of S and

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8500 Culebra Road San Antonio 6, Texas S' is specified in the inventory of the four possible cases shown in the following table:

One Statement	Another Statement	Statement Resulting from Combining Them with AND
S	S'	S • S'
0	0	0
0	1	, <b>0</b>
1	0	0
1	1	1

Many connectives are equivalent to combinations of these five connectives. For example, "S unless S'" is the same as "if not-S', then S." For example, "John will come unless it rains" is the same as "if it does not rain, John will come."

Another connective between statements which is in symbolic logic is equality or interchangeability, S = S'. This is true if and only if each statement makes the same assertion, as for example, "two plus three make five" and "deux et trois font cinq" — both make the same assertion. But we cannot calculate the truth value of S = S' from knowing the truth value of S and the truth value of S'.

14. The All Operator and the Existence Operator

If we have a statement "x has the property K," we can construct another statement:

every x has the property K

This statement is translated into symbolic logic using what is called an "all-operator," and the form in which the statement is then written is:

(A x) (x K)

which is read, "for every x, x has the property K," or "for all x's, x has the property K."

From the statement "x has the property K," we can also construct the statement:

some x has the property K.

This statement has the same meaning as "there exists an x such that x has the property K." These statements are translated into symbolic logic using what is called the "existence-operator," and the form in which they are written is:

which is read "there exists an x such that x has the property K".

Different conventions are used by different authors writing in the field of symbolic logic for designating these operators. For example the A of the all operator may be omitted, so that the expression appears as (x) (x K). Or the existence operator may be written with a capital E backwards, a mirror image of the usual capital E. The meaning however is the same even though different symbolic conventions are used.

15. The Three Answer Statements Rewritten in the Symbolic Language of Symbolic Logic

Let us return now to the three statements which were the answers to the three problems given above. How do they look with the new symbols which we have defined?

Statement 1: A thing is the F of another thing if and only if it is M and is a P of that other thing.

<sup>(</sup>E x) (x K)

 $x F x' \leftrightarrow x M \cdot x P x'$ 

Statement 2: A thing is a B of another thing if and only if it is M and there exists something which is a P of both of them.

 $x B x' \longleftrightarrow [x M \cdot (E x'') (x'' P x \cdot x'' P x')]$ Statement 3: A thing is a U of another thing if and only if it is a B of a P of that other thing.

 $x U x' \longleftrightarrow [(Ex'') (x B x'' \cdot x'' P x')]$ 

We have now stripped away the English language for these statements, and expressed the exact skeleton of the relationship in the symbols of symbolic logic, which calculate. This is a worthwhile achievement, because we have escaped the various paraphrases of language, we have crystallized out the ideas, we have prepared ourselves for calculation and exact reasoning. Over and over again, in the progress of a mathematical science or art, the capacity to free oneself from the accidental or irrelevant, and concentrate on the fundamental and relevant, has been the gateway to progress.

16. The "Class of . . ." Operator

If we have the statement "x has the property K," we can talk of:

the class of all x's that have the property K

This class is designated as:

(C x) (x K)

read "the class of all x's such that x has the property K." This class is equal to K, in the sense of class rather than property.

17. The Relative Product

If:

x is an R of an R' of x'

or, in other words:

x has the relation R to something which has the relation R' to x'

we write:

 $\mathbf{x} \mathbf{R} \mid \mathbf{R'} \mathbf{x'}$ 

The exact meaning of this is:

 $\mathbf{x} \mathbf{R} \mid \mathbf{R'} \mathbf{x'} = (\mathbf{E}\mathbf{x''}) (\mathbf{x} \mathbf{R} \mathbf{x''} \cdot \mathbf{x''} \mathbf{R'} \mathbf{x'})$ 

 $R \mid R'$  is spoken of as the *relative product* of R and R'.

With these definitions, we are now ready for a tougher problem.

18. Definitions of Family Relationships

Problem 4: In describing the relationships of human beings, the following ideas may be used:

1.	mother	7.	grandparent	13.	half-brother
2.	child	8.	husband	14.	great-aunt
3.	sister	9.	wives	15.	nephew
4.	son	10.	spouse	16.	mother-in-law
5.	daughter	11.	siblings	17.	illegitimate child

6. aunt 12. first cousin 18. ancestor

(a) What is a list of three basic terms in the field of family relationships, which, together with the ideas of symbolic logic, will express every one of these ideas?

(b) What is their expression?

(c) How can a man be his own grandfather-in-law?

Solution: (a) A list of three basic terms is "Male. Parent, Wedded." (Other lists of three basic terms may be used instead, such as "Female, Child, Wedded.") Let:

xM = x is Male

xPx' = x is a Parent of x'

xWx' = x is Wedded to x'

(b) Using the symbols of symbolic logic, we can express all 18 ideas given in the problem with compact and precise definitions as follows:

1. x Mother  $x' = xPx' \cdot xM$ 



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- In words: "x is the mother of x'" is the same as
  - "x is a parent of x prime, and x is not male." 2. x Child x' = x'Px

In words: "x is a child of x'" is the same as

"x prime is a parent of x"

3. x Sister  $\mathbf{x}' = \mathbf{x}\mathbf{M} \cdot (\mathbf{E}\mathbf{x}'') (\mathbf{x}''\mathbf{P}\mathbf{x} \cdot \mathbf{x}''\mathbf{P}\mathbf{x}')$ 

In words: x is not male, and there exists another person x second such that x second is a parent of x, and x second is a parent of x prime.

- 4.  $x \text{ Son } x' = x'Px \cdot xM$ 
  - x prime is a parent of x, and x is male.
- 5. x Daughter x' == x'Px xM x prime is a parent of x, and x is not male.
  6. x Aunt x' == x Sister | Parent x'
- x is a sister of a parent of x prime.
- 7. x Grandparent x' == x Parent | Parent x' x is a parent of a parent of x prime.
- x Husband x' = xWx' xM x is wedded to x prime, and x is male.
- 9. Wives  $\mathbf{x}' = (C\mathbf{x}) (\mathbf{x}W\mathbf{x}' \cdot \sim \mathbf{x}M)$ )

In words: the class of all x's such that x is wedded to x prime, and x is not male.

- 10. x Spouse x' = xWx'
- x is wedded to x prime.
- 11. Siblings x' = (Cx) (x(Brother v Sister)x')the class of all x's such that x is a brother or a sister of x prime.
- 12. x First Cousin x' == x Child | (Brother v Sister)
  | Parent x'

x is a child of a brother or a sister of a parent of x prime.

- 13. x Half-Brother  $\mathbf{x}' = \mathbf{x}\mathbf{M} \cdot \mathbf{E}(\mathbf{x}_2, \mathbf{x}_3) \ (\mathbf{x}_2 \neq \mathbf{x}_3 + \mathbf{x}_2\mathbf{P}\mathbf{x} \cdot \mathbf{x}_2\mathbf{P}\mathbf{x}' \cdot \mathbf{x}_3\mathbf{P}\mathbf{x} \cdot \mathbf{x}_3\mathbf{P}\mathbf{x}')$ 
  - x is male, and there exist two different persons x two and x three such that x two is a parent of x, and x two is a parent of x prime, and x three is a parent of x, but x three is not a parent of x prime.
- 14. x Great-Aunt x' = x Sister | Grandparent x'x is a sister of a grandparent of x prime.
- 15. x Nephew x' == x Son | (Brother v Sister) x'
   x is a son of a brother or a sister of x prime
- x Mother-in-Law x' == x Mother | Spouse x' x is mother of a spouse of x prime.
- 17. x Illegitimate Child x' = x'Px [(Ex")(x" ≠ x' x"Px ~ x"Wx')]
  x prime is a parent of x, and there exists an x second such that x second is different from x prime, and x second is a parent of x, and x second is not wedded to x prime.
- 18. x Ancestor  $\mathbf{x}' = (\mathbf{E}\mathbf{K}) [(\mathbf{x} \in \mathbf{K} \cdot \mathbf{x}' \in \mathbf{K}) \cdot (\mathbf{A}\mathbf{x}_2) [(\mathbf{x}_2 \in \mathbf{K} \cdot \mathbf{x}_2 \neq \mathbf{x}) \rightarrow (\mathbf{E}\mathbf{x}_3) (\mathbf{x}_3 \mathbf{P}\mathbf{x}_2 \cdot \mathbf{x}_3 \in \mathbf{K})]]$

In words: x is an ancestor of x' if and only if there exists a class of persons K (including x and x') which has this property: for every person  $x_2$  in K (except for x) there exists some person  $x_3$  in K such that  $x_3$  is the Parent of  $x_2$ .

(c) A man a marries the mother m of a girl g who marries the man's father f.

That is: a Spouse  $m \cdot m$  Parent  $g \cdot g$  Spouse  $f \cdot f$  Parent a. Therefore:

a Spouse | Parent | Spouse | Parent a and so a is his own grandfather-in-law.

### THE IMPORTANT IDEAS OF SYMBOLIC LOGIC

Symbol	Meaning	Definition
x, x', x'',	things, individuals, (read "x, x prime, x second, " standing for "x, another x, still another x,")	primitive
K, K', K'',	classes, groups, sets (K, first letter of German "Klasse" meaning "class")	primitive
$R, R', R'', \ldots$	relations (R, first letter of "relation") Note: These are nearly always two-termed relations	primitive
S, S', S",	statements, propositions (S, first letter of "state- ment")	primitive
~ S	not-S	primitive
S v S'	S or S' or both	$\sim (\sim S \cdot \sim S')$
S • S'	S and S'	primitive
$S \rightarrow S'$	If S, then S'; S implies S'	$\sim (S : \sim S')$
$S \longleftrightarrow S'$	S if and only if S'	$(S \rightarrow S') \cdot (S' \rightarrow S)$
ε	is an element of, is a member of, is in (epsilon, the first letter of Greek "esti," meaning "is")	primitive
x e K	The thing x is in the class K	primitive
хK	The thing x has the property K (Note: This form is less often used)	equivalent in meaning to x  ext{ K}
xRx'	x has the relation R to x'	primitive
x,x' ¢ R	The ordered pair of things x,x' is in the relation R (Note: This form is seldom used)	equivalent in meaning to xRx'
(Ax) (x $\epsilon$ K)	For every x, x is in K. Every x is a K. (applies for a range of admissible values of x) (A, first letter of "all")	$\sim$ (Ex) ( $\sim$ x $\epsilon$ K)
(Ex) $(x \in K)$	There exists an x such that x is in K. Some x is in K. (E, first letter of "exists")	primitive
$\mathbf{x} = \mathbf{x'}$	x equals x'	$(AK) (x \epsilon K \longleftrightarrow x' \epsilon K)$
20		COMPUTERS and AUTOMATION for January, 1959

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Symbol	Meaning	Definition
(Cx) (x	the class of all x's such that x is in K (applies for a range of admissible values of x) (C, first letter of	primitive
(tx) (x  ext{ K})	"class") the x such that x is in K (t, the first letter of "the")	primitive, but it is necessary that $(Ex) [(Ax')]$
17		$(\mathbf{x} \in \mathbf{K} \to \mathbf{x} = \mathbf{x})]$
K K C V(	the class K; the class of all x s such that x is in K	$(\mathbf{X})$ $(\mathbf{X} \in \mathbf{K})$
$K \subset K$	K lies in K	$(Ax) (x \in K \rightarrow x \in K')$
K = K	K equals K	$(Ax)$ $(x \in K \cup x \in K')$
	K of K of Doin	(Cx) (xeK v xeK)
		(Cx) (xex $(xex)$ )
		$(Cx) (\sim x \in K)$
•		$(Cx) (x \in K \lor \sim x \in K)$
$\Lambda$	null class	$(\mathbf{C}\mathbf{x})  (\mathbf{x} \in \mathbf{K} \cdot \sim \mathbf{x} \in \mathbf{K})$
$\mathbf{K} \neq \mathbf{K}$	K and K are distinct	$(\mathbf{E}\mathbf{X}) \left[ (\mathbf{X} \in \mathbf{K} \cdot \mathbf{v} \times \mathbf{X} \in \mathbf{K}) \right]$ $(\mathbf{X} \in \mathbf{K}' \cdot \mathbf{v} \times \mathbf{X} \in \mathbf{K}) \right]$
R	the relation R; the class of all ordered pairs x, x' such that xRx'	(Cx,x') (xRx')
$R \subset R'$	R lies in R'	$(Ax,x') (xRx' \to xR'x')$
R = R'	R equals R'	$(Ax,x')  (xRx' \longleftrightarrow xR'x')$
R • R'	the logical product of the two relations R and R'	$(Cx,x')$ $(xRx' \cdot xR'x')$
R v R'	the logical sum of the two relations R and R'	(Cx,x') $(xRx' v xR'x')$
~ R	the negative of the relation R; the class of all pairs x,x' such that xRx' is false	$(Cx,x') (\sim xRx')$
R'x′	the R of x'; the x such that xRx'	(tx) $(xRx')$
R1'x'	the R's of x'; the class of all x such that xRx'	(Cx) $(xRx')$
R <sub>2</sub> 'x	the class of all x' such that xRx'	(Cx') $(xRx')$
R"K	the R's of K's	(Cx) $[(Ex') (x' \in K \cdot xRx')]$
D'R	the domain of R	(Cx) [(Ex') (xRx')]
CnvD'R	the converse domain of R	(Cx') [(Ex) (xRx')]
F'R	the field of R	(Cx) (Ex') (xRx' v x'Rx), which reduces to D'R v CnvD'R
CnvR	the converse of a relation R; the class of ordered pairs x',x such that xRx'	(Cx',x) (xRx')
R R'	the relative product of R and R'	(Cx,x'') [(Ex') (xRx' · x'R'x'')]
R <sup>2</sup>	the square of a relation R	R
R <sup>3</sup>	the cube of a relation R	$\mathbf{R}^2   \mathbf{R}$
sym	the class of symmetric relations	$(CR)$ $(Ax,x')$ $(xRx' \rightarrow x'Rx)$
asm	the class of asymmetric relations	(CR) (Ax,x') (xRx' $\rightarrow \sim x'Rx$ )
refl	the class of reflexive relations	(CR) (Ax) $(x \in F'R \to xRx)$
irr	the class of irreflexive relations	(CR) (Ax,x') (xRx' $\rightarrow$ x $\neq$ x')
trans	the class of transitive relations	(CR) $(Ax,x'x'')$ $(xRx' \cdot x'Rx'' \rightarrow x'Rx'')$
connex	the class of connected relations	(CR) $(Ax,x')$ $(x,x' \in F'R \rightarrow (xRx' v x'Rx v x = x')$
intr	the class of intransitive relations	(CR) $(Ax,x',x'')$ $(xRx' \cdot x'Rx'' \rightarrow \sim xRx'')$
onma	the class of one-many relations	(CR) $(Ax,x',x'')$ $(xRx' \cdot x'Rx'' \rightarrow x = x')$
maon	the class of many-one relations	(CR) $(Ax,x,'x'')$ $(xRx' \cdot xRx'' \rightarrow x' = x'')$
onon	the class of one-one relations	onma • maon
K Sim K'	the class K is similar to the class K'	(ER) (R $\epsilon$ onon $\cdot$ D'R = K $\cdot$ CnvD'R = K')
Nc'K	the cardinal number of K	(CK') (K' Sim K)
ser	class of serial relations	asm • trans • connex

#### 19. The Main Concepts of Symbolic Logic

Exactly what are the important ideas in the mean stream of symbolic logic, and what are the symbols used for them?

Many of the main ideas of symbolic logic are defined and explained in "Principia Mathematica" mentioned above, although in that work they are very hard to understand, because of the effort made to escape preconceived ideas by using solely a symbolic language. A second good source to find these ideas is in Chapter 2 of 'The Axiomatic Method in Biology" by J. H. Woodger, University Press, Cambridge, Eng., 1937.

Most of the concepts from this main stream of symbolic logic, with some modifications due to later investigators, are given in the adjacent brief, condensed summary. In this summary, difficult typographic symbols have been replaced by simpler ones. The summary leads up to the

ANNUAL INDEX TO "COMPUTERS AND AUTOMATION"

This index covers information published in the thirteen issues of Computers and Automation, vol. 6, no. 12, Dec. 1957, to vol. 7, no. 12, Dec. 1958, inclusive. The last part of each entry gives: volume/number (month of issue), page number. Items have been indexed by author, title, and, if necessary, topic or topics. There are more than 360 entries.

- A: Abstracting, "Scientific Abstracting by Computer," by H. T. Rowe (in Novel Applications of Computers), 7/3 (Mar.), 12
- Abstracts, Association for Computing Machinery, Meeting, Urbana, Ill., June 11 to 13, 1958: Part 1, 7/7 (July), 18; Part 2, 7/8 (Aug.), 16; Part 3, 7/9 (Sept.), 28
- "Against All Enemies, Foreign and Do-mestic," by Hanson W. Baldwin (in Social Responsibility of Computer Scientists --- Oct. 1958 Round-up), 7/10 (Oct.), 25
- "Air Flight and Combat by Computer" (in Novel Applications of Computers), 7/3 (Mar.), 10
- "Air Traffic Control by Digital Computer," by Walter L. Anderson (in Novel Applications of Computers), 7/3 (Mar.), 9
- Amber, George H., and Paul S. Amber, "Automatic Quality Control Computers and Other Machine Control Computers," 7/4 (Apr.), 14
- "Analysis of Investments by Automatic Computer" (in Novel Applications of Computers), 7/3 (Mar.), 13
- Anderson, V. L., and L. D. Pyle, "Standard Routines Available for the Datatron Computer at Purdue Statistical and Computing Laboratory," 7/7 (July), 13 Anderson, Walter L., "Air Traffic Con-
- trol by Digital Computers" (in Novel Applications of Computers), 7/3 (Mar.), 9 Animals, "An Electro-Mechanical Model
- of Simple Animals," by William R.

Sutherland, Malcolm G. Mugglin, and Ivan Sutherland, 7/2 (Feb.), 1, 3, 6; 7/2B (Feb. 28, 1959), 1, 4, 5

- "Annual Computer Census," by John Diebold and Associates, Inc., 7/5 (May), 8
- "Annual Index in January" (in Readers' and Editor's Forum), 7/12 (Dec., 1958), 6
- "The Application of Digital Control Systems in the Process Industries," by M. Phister, Jr., 7/8 (Aug.), 14
- Applications of computers, "Some Important Applications of Computers, 7/10 (Oct.), 8
- "Applications of Computers to a Teacher's Paper Work," by L. Wayne Johnson (in Readers' and Editor's Forum), 7/12 (Dec., 1958), 6
- Aronson, Milton H., "Round-Up on Social Responsibility of Computer Scientists," III, (in Readers' and Editor's Forum), 7/7 (July), 6;
- "There is Indeed a Horror Point" (in Social Responsibility of Computer Scientists — Oct. 1958 Round-up), 7/10 (Oct.), 25
- "Association for Computing Machinery Committee on Social Responsibility' (in Social Responsibility of Computer Scientists - Oct. 1958 Round-up), 7/10 (Oct.), 25
- "Association for Computing Machinery, Los Angeles Chapter Symposium, May 9, 1958 — Program," by Fred Gruen-berger (in Readers' and Editor's Forum), 7/4 (Apr.), 26
- Association for Computing Machinery Meeting, Urbana, Ill., June 11-13, 1958 (in Readers' and Editor's Forum), 7/4 (Apr.), 26; Program, Titles, and Abstracts, Part 1, 7/7 (July), 18; Part 2, 7/8 (Aug.), 16; Part 3, 7/9 (Sept.), 28
- Astrahan, Morton M., "Horror and Freedom" (in Social Responsibility of Computer Scientists - Oct. 1958 Roundup), 7/10 (Oct.), 25
- "An Attempt to Apply Logic and Common Sense to the Social Responsibility of Computer Scientists," by Neil Macdonald, 7/5 (May), 22
- "An Automatic Analyzer of Infrared Spectrum to Identify Chemicals" (in Some Important Applications of Computers), 7/10 (Oct.), 12

definitions of cardinal number, the whole number that counts the number of elements in a class, and series, the mathematical concept of a set of elements having a serial order, that can be arranged in a single sequence.

It is not easy nor desirable to try to understand these ideas by just reading them over one after another. One needs to get used to them over a long time, and by reading and studying books on symbolic logic.

Also, many of these ideas are not yet necessary for the present-day applications of symbolic logic to automatic computers. For such applications have so far made use of only Boolean algebra. But nevertheless Boolean algebra is only a small part of symbolic logic, and probably much more of symbolic logic will eventually come out of the realm of pure and unapplied disciplines, and be applied in the analysis and programming of automatic computers.

- "Automatic Computing Machinery --- List of Types" (Edition 4, cumulative), 7/11 (Nov.), 20
- 'Automatic Digital Recording and Translating on Photographs," by Thomas C. Flynn (in Some Important Applications of Computers), 7/10 (Oct.), 10
- "Automatic Flight Control System for Helicopters" (in Industry News Notes), 7/7 (July), 1, 6, 22
- "Automatic Programming for Business Applications," by Grace M. Hopper, 7/2 (Feb.), 14; 7/2B (Feb. 28, 1958), 12
- "Automatic Quality Control Computers and Other Machine Control Computers," by George H. Amber and Paul S. Amber, 7/4 (Apr.), 14
- "Automatic Reading of the Shape of Characters by Electronic Means" (in Some Important Applications of Computers), 7/10 (Oct.), 12
- "Automatika I Telemechanika": Feb. to Nov. 1957, 7/2 (Feb.), 28; 7/2B (Feb. 28, 1958), 24; of December, 1957, 7/3 (Mar.), 31; of January, 1958, 7/4 (Apr.), 32
- "Automation Comes to the Bible," by Clair M. Cook, 7/3 (Mar.), 16
- B: Baldwin, Hanson W., "Against All Enemies, Foreign and Domestic" (in Social Responsibility of Computer Scientists - Oct. 1958 Round-up), 7/10 (Oct.), 25
- "Ballot on Discussion of Social Responsibility of Computer Scientists" (in Readers' and Editor's Forum), 7/5 (May), 6
- "A Ball-Point Pencil Is a Computer?" by Ted F. Silvey, 7/2 (Feb.), 19; 7/2B (Feb. 28, 1958), 17
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- Bengston, Richard J., and Joseph E. Smith, Jr., "A Component Case History: Information Storage Devices: A Key to Automation": Part 1, 7/4 (Apr.), 11; Part 2, 7/5 (May), 14
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COMPUTERS and AUTOMATION for January, 1959

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  - "Editorial Policy of 50 Technical Magazines on Publishing Discussion and Argument on the Social Responsibility of Scientists and Engineers," 7/12 (Dec., 1958), 21;
  - "Symbolic Logic and Automatic Computers": Part 1, 7/11 (Nov.), 18; Part 2, 7/12 (Dec., 1958), 28
- "The Best Corn Hybrids Calculated by Electronic Computer," by W. E. Clark (in Novel Applications of Computers), 7/3 (Mar.), 11
- "Better Education," by Edmund C. Berkeley (in Readers' and Editor's Forum), 7/4 (Apr.), 28 Bible, "Automation Comes to the Bible,"
- Bible, "Automation Comes to the Bible," by Clair M. Cook, 7/3 (Mar.), 16
- "Books and Other Publications": 7/2 (Feb.), 26; 7/2B (Feb. 28, 1958), 23; 7/3 (Mar.), 21; 7/4 (Apr.), 23; 7/7 (July), 23; 7/8 (Aug.), 27; 7/10 (Oct.), 27
- "Bridge-Playing by Computer," by Phyllis Huggins (in Novel Applications of Computers), 7/3 (Mar.), 13
- Bridge playing, "International Bridge-Playing by Computer" (in Readers' and Editor's Forum), 7/11 (Nov.), 1, 6
- Brigham, Ken, and E. F. von Arx, "Inertial Navigation," 7/1 (Jan.), 6; 7/1B (Jan. 31, 1958), 3
- Building, "A Reinforced Concrete Building Designed by an Automatic Computer," by Eve Peasner (in Some Important Applications of Computers), 7/10 (Oct.), 12
- Burke, Admiral Arleigh A., Dr. W. H. Pickering, and the Editor, "Destruction of Civilized Existence by Automatic Computing Controls," 7/3 (Mar.), 13
- Business education, "Implications of Electronic Data Processing for Business Education in High School," by Enoch J. Haga, 7/9 (Sept.), 24
- "Butcher Knives and Dynamite," by Tom Garnett (in Social Responsibility of Computer Scientists—Oct. 1958 Roundup), 7/10 (Oct.), 24
- "Buyers' Guide for the Computer Field: Products and Services for Sale or Rent" (cumulative), 7/6 (June), 57; List of Headings, 7/6 (June), 58
- C: Cammer, Mrs. P., "Curse or Blessing?", I, (in Readers' and Editor's Forum), 7/1 (Jan.), 9; 7/1B (Jan. 31, 1958), 5
- Cams, "A Computer Case History: Miniature Complex Cams," by Phyllis Huggins, 7/4 (Apr.), 10
- Carlson, Mel, "The Ultimate Copy" (in Readers' and Editor's Forum), 7/8 (Aug.), 24
- Carr, John W., III, "Languages, Logic, Learning, and Computers," 7/4 (Apr.), 21;
- "Prediction of Translation by Computers from Other Languages to Russian" (in Novel Applications of Computers), 7/3 (Mar.), 12
- Census, "Annual Computer Census," by John Diebold and Associates, Inc., 7/5 (May), 8

- "Central Ohio Association for Computing Machinery — Second Annual Symposium — Columbus, Ohio, March 29, 1958," 7/3 (Mar.), 27
- Checking accounts, "The Special Purpose Computer ERMA for Handling Commercial Bank Checking Accounts," by Staff of the Stanford Research Institute Journal: Part 1, 7/5 (May), 20; Part 2, 7/7 (July), 16
- Chemical identification, "An Automatic Analyzer of Infrared Spectrum to Identify Chemicals" (in Some Important Applications of Computers), 7/10 (Oct.), 12
- "Chemical Structure Searching With Automatic Computers," by National Bureau of Standards, 7/11 (Nov.), 16
- Clark, W. E., "The Best Corn Hybrids Calculated by Electronic Computer" (in Novel Applications of Computers), 7/3 (Mar.), 11
- Cohn, Stanley, "Films for Instruction in Electronic Data Processing" (in Readers' and Editor's Forum), 7/3 (Mar.), 6
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- and Editor's Forum), 7/5 (May), 6 Commercial computers, "Survey of Commercial Computers," by Neil Macdonald, 7/11 (Nov.), 8
- "Communicating With Computers," by George H. Jenkinson, 7/9 (Sept.), 18
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- "Comparing Digital Computing Systems: An Increasing Problem," by John A. McGann, 7/2 (Feb.), 10; 7/2B (Feb. 28, 1958), 8
- "A Component Case History: Information Storage Devices: A Key to Automation," by Richard J. Bengston and Joseph E. Smith, Jr.: Part 1, 7/4 (Apr.), 11; Part 2, 7/5 (May), 14
- Components, "Impetus of Data Processing on Component Manufacturers," by W. W. Stifler (in Industry News Notes), 7/3 (Mar.), 22
- "Components of Automatic Computing Machinery — List of Types" (Edition 4, cumulative), 7/11 (Nov.), 22
- Computer as Musician'' (in Readers' and Editor's Forum), 7/3 (Mar.), 1, 6
- "A Computer as a Space Traffic Policeman" (in Some Important Applications of Computers), 7/10 (Oct.), 18
- "A Computer Case History: Miniature Complex Cams," by Phyllis Huggins, 7/4 (Apr.), 10
- "The Computer Directory and Buyers' Guide, 1958," 7/6 (June), 6; "List of Headings," 7/3 (Mar.), 28; Samples of Entries and Entry Forms, 7/3 (Mar.), 24
- Computer field, "Is the Computer Field Staying Together or Separating?" (in the Editor's Notes), 7/6 (June), 6 "Computer Glamour" (in Readers' and
- "Computer Glamour" (in Readers' and Editor's Forum), 7/10 (Oct.), 6
- "Computer Industry Notified of Infringement of Magnetic Core Patent," by Paul Steen (in Industry News Notes), 7/3 (Mar.), 22

- Computer society meetings, "Interesting Computer Society Meetings," by Jackson W. Granholm and the Editor (in Readers' and Editor's Forum), 7/8 (Aug.), 6
- "Computers and Data Processing Current Talks," 7/10 (Oct.), 22
- "Computing Services Survey," by Neil Macdonald, 7/7 (July), 9;
- Supplement, 7/10 (Oct.), 26; Supplement, 7/12 (Dec., 1958), 30
- Conferences SEE: Association for Computing Machinery;
  - Association for Computing Machinery, Los Angeles Chapter Symposium;
  - Central Ohio Association for Computing Machinery;
  - Eastern Joint Computer Conference;
  - International Conference on Information Processing;
  - International Conference on Scientific Information;
  - IRE 7th Regional Conference and Trade Show;
  - Symposium: Thinking Machines of the Future;
  - Western Joint Computer Conference
- Conventions SEE: IRE National Convention
- Cook, Clair M., "Automation Comes to the Bible," 7/3 (Mar.), 16
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- Corn hybrids, "The Best Corn Hybrids Calculated by Electronic Computer," by W. E. Clark (in Novel Applications of Computers), 7/3 (Mar.), 11
- Corrections of December 1957 issue, 7/3 (Mar.), 34
- "Current Application of Computers at Southwestern Computing Service," by J. H. Van der Weide, 7/7 (July), 12
- Current talks, "Computers and Data Processing — Current Talks," 7/10 (Oct.), 22
- "Curse or Blessing?" (in Readers' and Editor's Forum), 7/1 (Jan.), 9; 7/1B (Jan. 31, 1958), 5
- "Cybernetic Scheduler," by Edd Doerr, 7/11 (Nov.), 24
- D: "Data Processing Concepts An Elective Course for High School Seniors" (in Readers' and Editor's Forum), 7/11 (Nov.), 6
- "Data Reduction Notes from Telecomputing Corporation," by Richard Mickelson, 7/7 (July), 13 Data reduction, "Semi-Automatic Data
- Data reduction, "Semi-Automatic Data Reduction" (in Readers' and Editor's Forum), 7/8 (Aug.), 1, 6 Datatron Computer, "Standard Routines
- Datatron Computer, "Standard Routines Available for the Datatron Computer at Purdue Statistical and Computing Laboratory," by V. L. Anderson and L. D. Pyle, 7/7 (July), 13
- Davenport, John H., "'Peace Games' to be Analyzed by Computer" (in Social Responsibility of Computer Scientists — Oct. 1958 Round-up), 7/10 (Oct.), 24
- Dennis, Bernard K., "Rapid Retrieval of Information" (in Some Important Applications of Computers), 7/10 (Oct.), 1, 6, 8
- Destruction, "Comments on 'Destruction of Civilized Existence by Automatic Computing Controls," by Louis Sutro

(in Readers' and Editor's Forum), 7/5 (May), 6

- "Destruction of Civilized Existence by Automatic Computing Controls," by Admiral Arleigh A. Burke, Dr. W. H. Pickering, and the Editor, 7/3 (Mar.), 13
- "Deviation from a Pattern of Normal Common Sense and the Common Laws Governing the Community Climate,' by L. J. Rogers (in Social Responsibility of Computer Scientists - Oct. 1958 Round-up), 7/10 (Oct.), 24
- Diebold, John, and Associates, Inc., "Annual Computer Census," 7/5 (May), 8
- "Digital Computer Controlling Oil Process" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
- Digital control systems, "The Applica-tion of Digital Control Systems in the Process Industries," by M. Phister, Jr., 7/8 (Aug.), 14
- "Digital Tape System: 90,000 Characters Per Second" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
- Doerr, Edd, "Cybernetic Scheduler," 7/11 (Nov.), 24
- "Double-Length Double-Strength Magnetic Tape" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
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- "Economic Planning by Electronic Computer: Planning of Sweden's Power," by D. G. Pacy (in Novel Applications of Computers), 7/3 (Mar.), 9
- "Economic System Studied by Analog Computer" (in Novel Applications of Computers), 7/3 (Mar.), 9
- "Editorial Policy of 50 Technical Magazines on Publishing Discussion and Argument on the Social Responsibility of Scientists and Engineers," by Edmund C. Berkeley, 7/12 (Dec., 1958), 21
- Education: "Better Education," by Edmund C. Berkeley (in Readers' and Editor's Forum), 7/4 (Apr.), 28
  - "Data Processing Concepts An Elective Course for High School Seniors" (in Readers' and Editor's Forum), 7/11 (Nov.), 6
  - "Hughes Aircraft to Grant 150 Fellowships in Science Work" (in Industry News Notes), 7/3 (Mar.), 23
  - "Implications of Electronic Data Processing for Business Education in High School," by Enoch J. Haga, 7/9 (Sept.), 24
  - "University of Michigan 10-Day Summer Course in Automatic Control,'
  - by L. L. Rauch (in Readers' and Editor's Forum), 7/3 (Mar.), 34
- "An Effort to Understand What They Are Doing and Why They Are Doing It," by Rabbi Louis Finkelstein (in Social Responsibility of Computer Scientists -- Oct. 1958 Round-up), 7/10 (Oct.), 25
- ``An Electromechanical Letter-Sorting Machine" (in Some Important Applications of Computers), 7/10 (Oct.), 9

- "An Electro-Mechanical Model of Simple Animals," by William R. Sutherland, Malcolm G. Mugglin, and Ivan Sutherland: 7/2 (Feb.), 1, 3, 6; 7/2B (Feb. 28, 1958), 1, 4, 5
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- ERMA, "The Special Purpose Computer ERMA for Handling Commercial Bank Checking Accounts," by Staff of the Stanford Research Institute Journal: Part 1, 7/5 (May), 20; Part 2, 7/7 (July), 16
- "Esso Cuba Refinery Uses Fischer & Porter Analog Computer-Logger" (in Industry News Notes), 7/1 (Jan.), 29; 7/1B (Jan. 31, 1958), 8
- F: Feed formulation, "Least-Cost Feed Formulation Using Electronic Computers," by W. A. O'Brien (in Some Important Applications of Computers), 7/10 (Oct.), 20
- Ferrite memory cores, "Millions of Tiny Ferrite Memory Cores" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
- "Films for Instruction in Electronic Data Processing," by Stanley Cohn (in Readers' and Editor's Forum), 7/3 (Mar.), 6
- Fink, J. L., "Regulated Power Supplies for Computers," 7/5 (May), 9
- Finkelstein, Rabbi Louis, "An Effort to Understand What They Are Doing and Why They Are Doing It" (in Social Responsibility of Computer Scientists-Oct. 1958 Round-up), 7/10 (Oct.), 25
- Fischer & Porter, "Esso Cuba Refinery Uses Fischer & Porter Analog Com-puter-Logger" (in Industry News Notes), 7/1 (Jan.), 29; 7/1B (Jan. 31, 1958), 8
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- Flight, "Air Flight and Combat by Com-puter" (in Novel Applications of Computers), 7/3 (Mar.), 10
- Flight control system, "Automatic Flight Control System for Helicopters" (in Industry News Notes), 7/7 (July), 1, 6, 22
- Flynn, Thomas C., "Automatic Digital Recording and Translating on Photographs" (in Some Important Applications of Computers), 7/10 (Oct.), 10
- "Foreign Language Translation by Auto-matic Computer," by J. Speck (in Novel Applications of Computers), 7/3 (Mar.), 11
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- Friedman, Carl, "Weapon Evaluation by Computer Simulation" (in Some Important Applications of Computers), 7/10 (Oct.), 9 Front cover: "Computer as Musician,"
- 7/3 (Mar.), 1, 6;
- "Inspection of Giant Computer by Hospital Plan Subscriber," 7/4 (Apr.), 1, 6;
- "International Bridge-Playing by Computer," 7/11 (Nov.), 1, 6;



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- "Machina Versatilis," 7/2 (Feb.), 1,
- 3; 7/2B (Feb. 28, 1958), 1, 4; "Machine Tool Digital Control Sys-
- tem," 7/9 (Sept.), 1, 6; "Magnetic Core Memory Plane," 7/1 (Jan.), 1, 29; 7/1B (Jan. 31, 1958), 1, 8;
- "Miniature Electronic Tube," 7/5 (May), 1, 6;
- "One Thousand Characters Per Second," 7/12 (Dec., 1958), 1, 6; "Rapid Retrieval," 7/10 (Oct.), 1,
- 6, 8;
- "See No Hands!", 7/7 (July), 1, 6, 22;
- "Semi-Automatic Data Reduction," 7/8 (Aug.), 1, 6;
- "Symbol Generator and Viewer," 6/12 (Dec., 1957), 1, 7; 6/12B (Dec. 31, 1957), 1, 3
- G: Garnett, Tom, "Butcher Knives and Dynamite" (in Social Responsibility of Computer Scientists—Oct. 1958 Roundup), 7/10 (Oct.), 24
- up), 7/10 (Oct.), 24 Gildersleeve, Tom, "Tit-Tat-Toe by Automatic Computer" (in Readers' and Editor's Forum), 7/4 (Apr.), 28
- Glamour, "Computer Glamour" (in Readers' and Editor's Forum), 7/10 (Oct.), 6
- Goda, B., S. Markowitz, and E. Jacobi, "A Line Printer Memory Utilizing Magnetic Cores," 7/8 (Aug.), 12
- netic Cores," 7/8 (Aug.), 12 Graf, C. F., Jr., "The Transportation Problem," 7/7 (July), 14
- Granholm, Jackson W., "Interesting Computer Society Meetings," I, (in Readers' and Editor's Forum), 7/8 (Aug.), 6
- "Greetings to Computers" (in Readers' and Editor's Forum), 6/12 (Dec., 1957), 7; 7/12 (Dec., 1958), 6
- "Greetings to Computers (Solution)" (in Readers' and Editor's Forum), 7/1 (Jan.), 10; 7/1B (Jan. 31, 1958), 6
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  - "Small Automatic Computers and Input/Output Equipment — A Report from the Manufacturers — May 9, 1958" (in Readers' and Editor's Forum), 7/2 (Feb.), 13; 7/2B (Feb. 28, 1958), 11
- H: Haga, Enoch J., "Implications of Electronic Data Processing for Business Education in High School," 7/9 (Sept.), 24
- Hale, Alvin, "Instruction," 7/2 (Feb.), 21; 7/2B (Feb. 28, 1958), 19
- Helicopters, "Automatic Flight Control System for Helicopters" (in Industry News Notes), 7/7 (July), 1, 6, 22
- Hetzel, William, "Non-Nuclear Engineering Problems in Shipbuilding Solved by High Speed Automatic Computers" (in Readers' and Editor's Forum), 6/12 (Dec., 1957), 9
- "High-Speed Printer" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
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- Hopper, Grace M., "Automatic Programming for Business Applications," 7/2 (Feb.), 14; 7/2B (Feb. 28, 1958), 12
- "Horror and Freedom," by Morton M. Astrahan (in Social Responsibility of Computer Scientists—Oct. 1958 Roundup), 7/10 (Oct.), 25
- Houle and Harley, "Thinking to Some Purpose," 7/4 (Apr.), 13
- Huggins, Phyllis, "Bridge-Playing by Computer" (in Novel Applications of Computers), 7/3 ,Mar.), 13;
  - "A Computer Case History: Miniature Complex Cams," 7/4 (Apr.), 10; "Nuclear Reactor Simulation on a Medium-Size Computer" (in Novel Applications of Computers), 7/3 (Mar.), 10;
- "Three-Part Music With a Computer As One Part" (in Novel Applications of Computers), 7/3 (Mar.), 1, 6, 8
- "Hughes Aircraft to Grant 150 Fellowships in Science Work" (in Industry News Notes), 7/3 (Mar.), 23
- Hulsey, H., "Inventory by Automatic Data Processor in a Military Medical Supply Depot" (in Some Important Applications of Computers), 7/10 (Oct.), 14
- I: "IBM Growth" (in Industry News Notes), 7/1 (Jan.), 29; 7/1B (Jan. 31, 1958), 8
- "IBM 1957 Gross Income Over One Billion Dollars" (in Industry News Notes), 7/3 (Mar.), 22
- IBM 704, "Low Cost Conversion Adapts Univac High-Speed Printer to IBM 704 Outputs," by Fred Ketchum, 7/11 (Nov.), 14
- "Impetus of Data Processing on Component Manufacturers," by W. W. Stifler (in Industry News Notes), 7/3 (Mar.), 22
- "Implications of Electronic Data Processing for Business Education in High School," by Enoch J. Haga, 7/9 (Sept.), 24
- Index, "Annual Index in January" (in Readers' and Editor's Forum), 7/12 (Dec., 1958), 6
- Index, Dec. 1956 to Nov. 1957: Part 1, 6/12 (Dec. 1957), 4; 6/12B (Dec. 31, 1957), 2; Part 2, 7/1 (Jan.), 19; 7/1B (Jan. 31, 1958), 7
- "Industry News Notes": 7/1 (Jan.), 29; 7/1B (Jan. 31, 1958), 8; 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15; 7/3 (Mar.), 22; 7/4 (Apr.), 24; 7/7 (July), 22
- "Inertial Navigation," by E. F. von Arx and Ken Bringham, 7/1 (Jan.), 6; 7/1B (Jan. 31, 1958), 3
- "Inspection of Giant Computer by Hospital Plan Subscriber" (in Readers' and Editor's Forum), 7/4 (Apr.), 1, 6
- "Instruction," by Alvin Hale, 7/2 (Feb.), 21; 7/2B (Feb. 28, 1958), 19
- "Interesting Computer Society Meetings," I, by Jackson W. Granholm (in Readers' and Editor's Forum), 7/8 (Aug.), 6
- "International Bridge-Playing by Computer" (in Readers' and Editor's Forum), 7/11 (Nov.), 1, 6
- "International Conference on Information Processing, Paris, June 15-20, 1959" (in Readers' and Editor's Forum), 7/11 (Nov.), 6

- "International Conference on Scientific Information — Request for Papers" (in Readers' and Editor's Forum), 7/2 (Feb.), 13; 7/2B (Feb. 28, 1958), 11
- "Inventory by Automatic Data Processor in a Military Medical Supply Depot," by H. Hulsey (in Some Important Applications of Computers), 7/10 (Oct.), 14
- Inventory, "Reduction of Inventory by Data Processing Machines" (in Some Important Applications of Computers), 7/10 (Oct.), 18
- Investments, "Analysis of Investments by Automatic Computer" (in Novel Applications of Computers), 7/3 (Mar.), 13
- IRE National Convention, New York, March 24-27, 1958 — Papers Related to Computers and Automation (in Readers' and Editor's Forum), 7/3 (Mar.), 6
- "IRE 7th Regional Conference and Trade Show — Sacramento, Calif. April 30-May 2, 1958," by Ewald W. Berger (in Readers' and Editor's Forum), 7/2 (Feb.), 3; 7/2B (Feb. 28, 1958), 4
- "Is the Computer Field Staying Together or Separating?" (in The Editor's Notes), 7/6 (June), 6
- J: Jacobi, E., B. Goda, and S. Markowitz, "A Line Printer Memory Utilizing Magnetic Cores," 7/8 (Aug.), 12
- Jenkinson, George H., "Communicating With Computers," 7/9 (Sept.), 18 Johnson, L. Wayne, "Applications of
- Johnson, L. Wayne, "Applications of Computers to a Teacher's Paper Work" (in Readers' and Editor's Forum), 7/12 (Dec., 1958), 6
- K: Ketchum, Fred, "Low-Cost Conversion Adapts Univac High-Speed Printer to IBM 704 Outputs," 7/11 (Nov.), 14
- L: Language translation: "Foreign Language Translation by Automatic Computer," by J. Speck (in Novel Applications of Computers), 7/3 (Mar.), 11
  - "Prediction of Translation by Computers from Other Languages to Russian," by John W. Carr, III (in Novel Applications of Computers), 7/3 (Mar.), 12
- "Languages, Logic, Learning, and Computers," by John W. Carr, III, 7/4 (Apr.), 21
- "The Largest Single Electronic Data Processing System in Any Bank" (in Some Important Applications of Computers), 7/10 (Oct.), 14
- Learning, "Languages, Logic, Learning, and Computers," by John W. Carr, III, 7/4 (Apr.), 21
- "Least-Cost Feed Formulation Using Electronic Computers," by W. A. O'Brien (in Some Important Applications of Computers), 7/10 (Oct.), 20
- Letter-sorting, "An Electromechanical Letter-Sorting Machine" (in Some Important Applications of Computers), 7/10 (Oct.), 9
- "Library for a Computer" (in Industry News Notes), 7/3 (Mar.), 22
- "A Line Printer Memory Utilizing Magnetic Cores," by B. Goda, S. Markowitz, and E. Jacobi, 7/8 (Aug.), 12

- "Locks for Front Doors," by Neil Macdonald (in Readers' and Editor's Forum), 7/8 (Aug.), 24
- Logic, "Languages, Logic, Learning, and Computers," by John W. Carr, III, 7/4 (Apr.), 21
- "Low-Cost Conversion Adapts Univac High-Speed Printer to IBM 704 Outputs," by Fred Ketchum, 7/11 (Nov.), 14
- M: Macdonald, Neil, "An Attempt to Apply Logic and Common Sense to the Social Responsibility of Computer Scientists," 7/5 (May), 22;
  - "Computing Services Survey," 7/7 (July), 9;
  - "Computing Services Survey (Supplement)", 7/10 (Oct.), 26;
  - "Computing Services Survey (Supplement)", 7/12 (Dec., 1958), 30; "Locks for Front Doors" (in Readers' and Editor's Forum), 7/8 (Aug.), 24;
  - "Music by Automatic Computer" (in Novel Applications of Computers), 7/3 (Mar.), 8;
  - "Survey of Commercial Computers," 7/11 (Nov.), 8;
- "Survey of Special Purpose Computers and Data Processors," 7/9 (Sept.), 8
- "Machina Versatilis," 7/2 (Feb.), 1, 3; 7/2B (Feb. 28, 1958), 1, 4
- Machine control computers, "Automatic Quality Control Computers and Other Machine Control Computers," by George H. Amber and Paul S. Amber, 7/4 (Apr.), 14
- "Machine Tool Digital Control System" (in Readers' and Editor's Forum), 7/9 (Sept.), 1, 6
- "Magnetic Core Memory Plane," 7/1 (Jan.), 1, 29; 7/1B (Jan. 31, 1958), 1, 8
- Magnetic cores, "A Line Printer Memory Utilizing Magnetic Cores," by B. Goda, S. Markowitz, and E. Jacobi, 7/8 (Aug.), 12
- Magnetic tape, "Double-Length Double-Strength Magnetic Tape" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
- The Manchester Guardian, "Curse or Blessing?", III, (in Readers' and Editor's Forum), 7/1 (Jan.), 9; 7/1B (Jan. 31, 1958), 5
- Markowitz, S., B. Goda, and E. Jacobi, "A Line Printer Memory Utilizing Magnetic Cores," 7/8 (Aug.), 12
- McGann, John A., "Comparing Digital Computing Systems: An Increasing Problem," 7/2 (Feb.), 10; 7/2B (Feb. 28, 1958), 8
- Medical supply, "Inventory by Automatic' Data Processor in a Military Medical Supply Depot," by H. Hulsey (in Some Important Applications of Computers), 7/10 (Oct.), 14
- Meetings SÉE: Conferences
- Mickelson, Richard, "Data Reduction Notes from Telecomputing Corporation," 7/7 (July), 13
- Military medical supply depot, "Inventory by Automatic Data Processor in a Military Medical Supply Depot," by H. Hulsey (in Some Important Applications of Computers), 7/10 (Oct.), 14

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- "Miniature Electronic Tube" (in Readers' and Editor's Forum), 7/5 (May), 1, 6
- Mugglin, Malcolm G., William R. Sutherland, and Ivan Sutherland "An Electro-Mechanical Model of Simple Animals," 7/2 (Feb.), 1, 3, 6; 7/2B (Feb. 28, 1958), 1, 4, 5
- "Music by Automatic Computers," by Neil Macdonald (in Novel Applications of Computers), 7/3 (Mar.), 8
- Music, "Three-Part Music with a Computer as One Part," by Phyllis Huggins (in Novel Applications of Computers), 7/3 (Mar.), 1, 6, 8
- N: National Bureau of Standards, "Chemical Structure Searching With Automatic Computers," 7/11 (Nov.), 16; "Pictorial Information Processed on a Digital Computer," 7/5 (May), 16; "Post Office Operations — A Report on Progress of Mechanization," 7/2 (Feb.), 18; 7/2B (Feb. 28, 1958), 16
- Nautilus, "The Navigation of the Nautilus" (in Readers' and Editor's Forum), 7/8 (Aug.), 6
- Navigation, "Inertial Navigation," by E. F. von Arx and Ken Brigham, 7/1 (Jan.), 6; 7/1B (Jan. 31, 1958), 3
- "The Navigation of the Nautilus" (in Readers' and Editor's Forum), 7/8 (Aug.), 6
- "Nerve Excitation in a Squid Simulated by Analog Computer" (in Readers' and Editor's Forum), 7/4 (Apr.), 28

- "New Horizons With Computer Technology — 1959 Western Joint Computer Conference" (in Readers' and Editor's Forum), 7/7 (July), 6 "New Patents," by Raymond R. Skolnick:
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- "Novel Applications of Computers," 7/3 (Mar.), 8
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- O: O'Brien, W. A., "Least-Cost Feed Formulation Using Electronic Computers" (in Some Important Applications of Computers), 7/10 (Oct.), 20
- of Computers), 7/10 (Oct.), 20 "Obsolete — At Age 29," by M. D. Witty, 7/12 (Dec., 1958), 26
- "Oil Industry Comments on Computers," 7/2 (Feb.), 20; 7/2B (Feb. 28, 1958), 18
- "One Thousand Characters Per Second" (in Readers' and Editor's Forum), 7/12 Dec., 1958), 1, 6



- Organizations SEE: Roster of Organizations
- "Orthotronic Control" (in Industry News Notes), 7/7 (July), 22
- P: Pacy, D. G., "Economic Planning by Electronic Computer: Planning of Sweden's Power" (in Novel Applications of Computers), 7/3 (Mar.), 9
- Palley, Arnold D., "Highway Construction Fund Analysis on an Automatic Computer" (in Some Important Applications of Computers), 7/10 (Oct.), 16
- Parry, David, "Western Joint Computer Conference - Los Angeles, May 6 to 8, 1958" (in Readers' and Editor's Forum), 7/2 (Feb.), 13; 7/2B (Feb. 28, 1958), 11
- Patent infringement, "Computer Industry Notified of Infringement of Magnetic Core Patent," by Paul Steen (in Industry News Notes), 7/3 (Mar.), 22
- Patents SEE: "New Patents"
- Pauling, Linus, "Round-Up on Social Responsibility of Computer Scientists," IV, (in Readers' and Editor's Forum), 7/7 (July), 6
- "'Peace Games' to be Analyzed by Computer," by John H. Davenport (in Social Responsibility of Computer Scientists - Oct. 1958 Round-up), 7/10 (Oct.), 24
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- Phister, M., Jr., "The Application of Digital Control Systems in the Process Industries," 7/8 (Aug.), 14
- Photographs, "Automatic Digital Recording and Translating on Photographs,' by Thomas C. Flynn (in Some Important Applications of Computers), 7/10 (Oct.), 10<sup>.</sup>
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- on the Computer Field," 7/12 (Dec., 1958), 6
- "Post Office Operations A Report on Progress of Mechanization," by National Bureau of Standards, 7/2 (Feb.), 18; 7/2B (Feb. 28, 1958), 16
- Power supplies, "Regulated Power Supplies for Computers," 7/5 (May), 9
- 'Prediction of Translation by Computers from Other Languages to Russian," by John W. Carr, III (in Novel Applications of Computers), 7/3 (Mar.), 12
- Printer, "High Speed Printer" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
- Private wire data processing, "Communications for Private Wire Data Process-

ing," by George O. Vincent, 7/9 (Sept.), 14

- "Products and Services for Sale or Rent: Buyers' Guide for the Computer Field" (cumulative), 7/6 (June), 57
- "Products and Services for Sale or Rent: Buyers' Guide for the Computer Field: List of Headings," 7/6 (June), 58
- Programming, "Automatic Programming for Business Applications," by Grace M. Hopper, 7/2 (Feb.), 14; 7/2B Feb. 28, 1958), 12;
- "Tape Readers for Programming Manufacturing Operations" (in Industry News Notes), 7/4 (Apr.), 24
- Punched paper tape, "Selecting Areas in Punched Paper Tape According to Address" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15
- Purdue Statistical and Computing Laboratory, "Standard Routines Available for the Datatron Computer at Purdue Statistical and Computing Laboratory,' by V. L. Anderson and L. D. Pyle, 7/7 (July), 13
- Pyle, L. D., and V. L. Anderson, "Standard Routines Available for the Datatron Computer at Purdue Statistical and Computing Laboratory," 7/7 (July), 13
- R: "Rapid Retrieval" (in Readers' and Ed-
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- "Reduction of Inventory by Data Processing Machines" (in Some Important Applications of Computers), 7/10 (Oct.), 18
- "Regulated Power Supplies for Computers," by J. L. Fink, 7/5 (May), 9
- "A Reinforced Concrete Building Designed by an Automatic Computer,' bv Eve Peasner (in Some Important Applications of Computers), 7/10 (Oct.), 12
- Retail department store, "A Small Electronic Computer Applied in a Retail Department Store, by C. Fred Flannell, 7/8 (Aug.), 8
- Retrieval of information, "Rapid Retrieval of Information," by Bernard K. Dennis (in Some Important Applications of Computers, 7/10 (Oct.), 1, 6, 8
- Rogers, L. J., "Deviation from a Pattern of Normal Common Sense and the Common Laws Governing the Community Climate" (in Social Responsibility of Computer Scientists - Oct. 1958 Round-up), 7/10 (Oct.), 24
- "Roster of Organizations in the Computer Field" (cumulative), 7/6 (June), 10
- "Round-Up on Social Responsibility of Computer Scientists," by Lawrence Wainwright, Milton H. Aronson, Linus Pauling, and the Editor (in Readers' and Editor's Forum), 7/7 (July), 6
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- S: "Scientific Abstracting by Computer," by H. T. Rowe (in Novel Applications of Computers), 7/3 (Mar.), 12
- "See No Hands!" (in Readers' and Editor's Forum), 7/7 (July), 1, 6, 22
- "Selecting Areas in Punched Paper Tape

According to Address" (in Industry News Notes), 7/2 (Feb.), 17; 7/2B (Feb. 28, 1958), 15

- "Semi-Automatic Data Reduction" (in Readers' and Editor's Forum), 7/8 (Aug.), 1, 6
- Silvey, Ted F., "A Ball-Point Pencil Is a Computer?", 7/2 (Feb.), 19; 7/2B (Feb. 28, 1958), 17
- "Small Automatic Computers and Input/ Output Equipment - A Report from the Manufacturers - May 9, 1958" (in Readers' and Editor's Forum), by Fred Gruenberger, 7/2 (Feb.), 13; 7/2B Feb. 28, 1958), 11
- "A Small Electronic Computer Applied in a Retail Department Store," by C. Fred Flannell, 7/8 (Aug.), 8
- Smith, Joseph E., Jr., and Richard J. Bengston, "A Component Case History: Information Storage Devices: A Key to Automation": Part 1, 7/4 (Apr.), 11; Part 2, 7/5 (May), 14
- Social responsibility: "An Attempt to Apply Logic and Common Sense to the Social Responsibility of Computer Scientists," by Neil Macdonald, 7/5 (May), 22;
  - "Ballot on Discussion of Social Responsibility of Computer Scientists" (in Readers' and Editor's Forum), 7/5 (May), 6;
  - "Curse or Blessing?" (in Readers' and Editor's Forum), 7/1 (Jan.), 9; 7/1B (Jan. 31, 1958), 5;
  - "Editorial Policy of 50 Technical Magazines on Publishing Discussion and Argument on the Social Responsibility of Scientists and Engineers," by Edmund C. Berkeley, 7/12 (Dec., 1958), 21;
  - "Forty-nine Computer People on Social Responsibility of Computer Scientists" (in Readers' and Editor's Forum), 7/9 (Sept.), 6; "Locks for Front Doors," by Neil Mac-
  - donald (in Readers' and Editor's Forum), 7/8 (Aug.), 24;
  - "Round-Up on Social Responsibility of Computer Scientists," by Lawrence Wainwright, Milton H. Aronson, Linus Pauling, and the Editor (in Readers' and Editor's Forum), 7/7 (July), 6
- "The Social Responsibility of Computer Scientists" (in Readers' and Editor's Forum), 7/4 (Apr.), 6
- "Social Responsibility of Computer Scientists - Oct. 1958 Round-up," by L. J. Rogers, J. H. Davenport, T. Garnett, M. M. Astrahan, H. W. Baldwin, and L. Finkelstein, 7/10 (Oct.), 24
- "Some Important Applications of Computers, 7/10 (Oct.), 8
- Southwestern Computing Service, "Current Application of Computers at Southwestern Computing Service," by J. H. Van der Weide, 7/7 (July), 12
- Space traffic, "A Computer as a Space Traffic Policeman" (in Some Important Applications of Computers), 7/10 (Oct.), 18
- "The Special Purpose Computer ERMA for Handling Commercial Bank Checking Accounts," Part 1, by Staff of the Stanford Research Institute Journal, 7/5 (May), 20; Part 2, 7/7 (July), 16

- Special purpose computers, "Survey of Special Purpose Computers and Data Processors," by Neil Macdonald, 7/9 (Sept.), 8
- Speck, J., "Foreign Language Translation by Automatic Computer" (in Novel Applications of Computers), 7/3 (Mar.), 11
- Squid, "Nerve Excitation in a Squid Simulated by Analog Computer" (in Readers' and Editor's Forum), 7/4 (Apr.), 28
- "Standard Routines Available for the Datatron Computer at Purdue Statistical and Computing Laboratory," by V. L. Anderson and L. D. Pyle, 7/7 (July), 13
- Stanford Research Institute Journal, Staff of, "The Special Purpose Computer ERMA for Handling Commercial Bank Checking Accounts": Part 1, 7/5 (May), 20; Part 2, 7/7 (July), 16
- Steen, Paul, "Computer Industry Notified of Infringement of Magnetic Core Patent" (in Industry News Notes), 7/3 (Mar.), 22
- Stifler, W. W., "Impetus of Data Processing on Component Manufacturers" (in Industry News Notes), 7/3 (Mar.), 22
- Storage devices, "A Component Case History: Information Storage Devices: A Key to Automation," by Richard J. Bengston and Joseph E. Smith, Jr.: Part 1, 7/4 (Apr.), 11; Part 2, 7/5 (May), 14
- "Supermarket Chains Competing Through Calculations" (in Novel Applications of Computers), 7/3 (Mar.), 9
- Survey: "Computing Services Survey," by Neil Macdonald, 7/7 (July), 9; Supplement, 7/10 Oct.), 26; Supplement, 7/12 (Dec., 1958), 30
- "Survey of Commercial Computers," by Neil Macdonald, 7/11 (Nov.), 8
- "Survey of Special Purpose Computers and Data Processors," by Neil Macdonald, 7/9 (Sept.), 8
- Sutherland, Ivan, William R. Sutherland, and Malcolm G. Mugglin, "An Electro-Mechanical Model of Simple Animals": 7/2 (Feb.), 1, 3, 6; 7/2B (Feb. 28, 1958), 1, 4, 5
  Sutro, Louis, "Comments On 'Destruction
- Sutro, Louis, "Comments On 'Destruction of Civilized Existence by Automatic Computing Controls'" (in Readers' and Editor's Forum), 7/5 (May), 6
- Sweden, "Economic Planning by Electronic Computer: Planning of Sweden's Power," by D. G. Pacy (in Novel Applications of Computers), 7/3 (Mar.), 9
- "Symbol Generator and Viewer": 6/12 (Dec., 1957), 1, 7; 6/12B (Dec. 31, 1957), 1, 3
- "Symbolic Logic and Automatic Computers," by Edmund C. Berkeley; Part 1, 7/11 (Nov.), 18; Part 2, 7/12 (Dec., 1958), 28
- Symposiums SEE also Conferences "Symposium: Thinking Machines of the Future" (in Industry News Notes): 7/1 (Jan.), 29; 7/1B (Jan. 31, 1958), 8
- T: "Tape Reader for Programming Manufacturing Operations" (in Industry News Notes), 7/4 (Apr.), 24
- Teaching, "Applications of Computers to a Teacher's Paper Work," by L. Wayne Johnson (in Readers' and Editor's Forum), 7/12 (Dec., 1958), 6
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29

- Telecomputing Corporation, "Data Reduction Notes. from Telecomputing Corporation," by Richard Mickelson, 7/7 (July), 13
- "There is Indeed a Horror Point," by Milton H. Aronson (in Social Responsibility of Computer Scientists -- Oct. 1958 Round-up), 7/10 (Oct.), 25
- "Thinking Machines of the Future: Symposium" (in Industry News Notes), 7/1 (Jan.), 29; 7/1B (Jan. 31, 1958), 8
- "Thinking to Some Purpose," by Harley and Houle, 7/4 (Apr.), 13
- "Three-Part Music with a Computer As One Part," by Phyllis Huggins (in Novel Applications of Computers), 7/3 (Mar.), 1, 6, 8
- (Mar.), 1, 6, 8 "Tit-Tat-Toe by Automatic Computer," by Tom Gildersleeve (in Readers' and Editor's Forum), 7/4 (Apr.), 28
- Editor's Forum), 7/4 (Apr.), 28 "The Transportation Problem," by C. F. Graf, Jr., 7/7 (July), 14
- "Truck Maintenance Costs Obtained Using an Automatic Computer," by Eve Peasner (in Some Important Applications of Computers), 7/10 (Oct.), 18
- U: "The Ultimate Copy," by Mel Carlson (in Readers' and Editor's Forum), 7/8 (Aug.), 24
- Univac High-Speed Printer, "Low Cost Conversion Adapts Univac High-Speed Printer to IBM 704 Outputs," by Fred Ketchum, 7/11 (Nov.), 14
- "University of Michigan 10-Day Summer Course in Automatic Control," L. L. Rauch (in Readers' and Editor's Forum), 7/3 (Mar.), 34
- V: Van der Weide, J. H., "Current Application of Computers at Southwestern Computing Service," 7/7 (July), 12 Vincent, George O., "Communications
- Vincent, George O., "Communications for Private Wire Data Processing," 7/9 (Sept.), 14
- von Arx, E. F., and Ken Brigham, "Inertial Navigation," 7/1 (Jan.), 6; 7/1B (Jan. 31, 1958), 3
- W: Wainwright, Lawrence, "Round-Up on Social Responsibility of Computer Scientists," II, (in Readers' and Editor's Forum), 7/7 (July), 6

- "Weapon Evaluation by Computer Simulation," by Carl Friedman (in Some Important Applications of Computers), 7/10 (Oct.), 9
- Weiss, Harold, "Comments on 'Are Automatic Computer Speeds Faster Than Business Needs?" (in Readers' and Editor's Forum), 7/4 (Apr.), 9
- "Western Joint Computer Conference Los Angeles, May 6 to 8, 1958" (in Readers' and Editor's Forum), by David Parry, 7/2 (Feb.), 13; 7/2B (Feb. 28, 1958), 11
- Western Joint Computer Conference, "New Horizons With Computer Technology—1959 Western Joint Computer Conference" (in Readers' and Editor's Forum), 7/7 (July), 6
- "Who's Who in the Computer Field," entry form: 7/5 (May), 2; 7/11 (Nov.), 28
- "Who's Who in the Computer Field (Supplement)": 7/9 (Sept.), 32; 7/11 (Nov.), 27
- Witty, M. D., "Obsolete At Age 29," 7/12 (Dec., 1958), 26



### ADVERTISING INDEX

Following is the index of advertisements. Each item contains: Name and address of the advertiser / page number where the advertisement appears / name of agency if any.

- Aeronutronic Systems, Inc., a Subsidiary of Ford Motor Co., 1234 Air Way, Glendale, Calif. / Page 27 / Honig-Cooper, Harrington & Miner
- Bendix Aviation Corp., Computer Div., 5630 Arbor Vitae St., Los Angeles, Calif. / Page 29 / The Shaw Co.
- Berkeley Enterprises, Inc., 815 Washington St., Newtonville 60, Mass. / Page 21 / ---
- C. P. Clare & Co., 3101 Pratt Blvd., Chicago 45, Ill. / Page 10 / Reincke, Meyer & Finn
- ElectroData, Div. of Burroughs Corp., 460 N. Sierra Madre Villa, Pasadena, Calif. / Pages 25, 32 / Carson Roberts Inc.
- Electronic Associates, Inc., Long Branch, N.J. / Page 7 / Halsted & Van Vechten, Inc.

- ESC Corp., 534 Bergen Blvd., Palisades Park, N.J. / Page 5 / Keyes, Martin & Co.
- General Electric Co., Huntsville Computer Center, Huntsville, Ala. / Page 17 / Deutsch & Shea, Inc.
- Lockheed Missiles Systems Div., 962 W. El Camino Real, Sunnyvale, Calif. / Page 19 / Hal Stebbins Inc.
- Marquardt Aircraft Co., 16569 Saticoy St., Van Nuys, Calif. / Page 30 / Grant Advertising, Inc.
- Philco Corp., Government & Industrial Div., 4700 Wissahickon Ave., Philadelphia 44, Pa. / Page 3 / Maxwell Associates, Inc.
- Radio Corp. of America, Semiconductor Products, Harrison, N.J. / Page 9 / Al Paul Lefton Co.
- Southwest Research Institute, 8500 Culebra Rd., San Antonio 6, Tex. / Page 18 / —
- Sylvania Electric Products, Inc., 189 B St., Needham 94, Mass. / Page 2 / Deutsch & Shea, Inc.
- Technical Operations, Inc., Burlington, Mass. / Page 31 / Dawson MacLeod & Stivers

COMPUTERS and AUTOMATION for January, 1959



$$\dot{x}_{j+1}(t) = \dot{x}_j(t-h) \text{ if } x_j(t-h) - x_{j+1}(t-h) = \beta S_c$$

• Problem: what doctrine for a motorized military convoy will mean the highest over-the-road speed? Solving such a problem by experimental, trial-and-error methods is difficult, long, and costly...yet answers to such questions are vital to our modern, mobile U. S. Army. Scientists of *tech/ops* solved this one by devising and applying a mathematical model to describe a convoy, programming this model for a large digital computer. *Result:* another application of *tech/ops'* research techniques to solve a problem whose solution by conventional means would have been prohibitively expensive... and a typical example of *tech/ops'* pioneering work in operations research and broad scientific research and development for industry, business and government.

Two other formulas complete this model:  

$$x_{j+1}$$
 (t) = V<sub>e</sub> if  $\beta S_e < x_j$  (t-h) -  $x_{j+1}$  (t-h)  $\leq S_e$  (2)

 $\begin{array}{l} x_{j+1} \ (t) = \frac{1}{T} \left[ x_j \ (t-h) - x_{j+1} \ (t-h) \right] \ \text{if} \ x_j \ (t-h) - x_{j+1} \ (t-h) > S_c \eqno(3) \\ \\ \text{The symbols have these significances: } x_j \ (t) \ \text{is the position of the } j^{\text{th vehicle at}} \\ \\ \text{time t; } V_c \ \text{is the assigned convoy speed; } S_c \ \text{is the assigned spacing between} \\ \\ \text{succeeding vehicles in the convoy; } h \ \text{is the driver reaction time; } \beta \ \text{is a constant.} \\ \\ \text{Boundary conditions: } \dot{x}_j(t) \geq 0; \ \dot{x}_l(t) \ \text{is a given (known) function.} \end{array}$ 

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