The Federal Computing Machine Program

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THE GOAL OF THIS PAPER is a modest one, namely, to lay before those who have not had the occasion or the opportunity to consider the total interest of the government in the computing machine program in this country some of the aims and problems that enter into our thinking when we try to determine policies and plans in this field. Since there is obviously not complete unanimity of opinion, it must be understood that I shall limit this discussion to my own opinions; and, since the government's interest must obviously include activities that cannot be discussed here, there will be no attempt to cover the field completely. In fact, I shall not refer even to all unclassified machines. For an adequate discourse on the military applications of automatically sequenced electronic computers, I direct you to recent Steve Canyon comic strips in which a wonderful electronic brain that could see and shoot down planes at great distances was saved from the totalitarian forces of evil.

The problem of choosing material for this discussion has been a difficult one. There are those who know well the status of virtually all the machine developments in this country, and whose chief interest is in the technical advances in machine construction that have occurred during the past few months. On the other hand, a number of us are interested primarily in getting a bird's-eye view of the situation. I shall address most of my attention to this second group.

Analog Computers

Although the substantial government interest, expressed in plans and money, is, and has been for some time, in the digital field, it would be false to give the impression that no considerable sums of money have been invested by the government in analog computers; or that such machines and other analog computers built without government support are not playing an important and useful role in the scientific and industrial laboratories of the country. To be sure, the Bush differential analyzer is probably being used less extensively now than during World War II, and this for reasons largely economic. But other machines whose primary function is to solve ordinary differential equations are proving to be extremely useful, and will, I believe, continue to carry their load of problems for a long time. I mention in particular the REAC, developed by the Reeves Instrument Company under a Special Devices Center contract for the Office of Naval Research. This is an electromechanical machine which has been used at Reeves on problems submitted primarily by aircraft companies, and dealing with the design of guidance and control systems, with stabilization, with the dynamics of the combustion process, and with related problems. The rapid rate at which solutions are obtained, and the ease with which parameters may be varied or additional factors introduced, permit a broad investigation before design is undertaken. Goodyear Aircraft, under an Air Force contract, has developed a similar machine.

In addition to pure simulation, this type of computer may be used as a testing device. For example, in the auto-pilot problem, instead of simulating the automatic pilot by means of an equation, the actual auto pilot may be incorporated in the machine in such a manner that its response to typical operating conditions can be observed in the laboratory. In this case the machine has only the equations of aircraft motion patched in, and produces a voltage proportional to the pitch rate. This is used to drive a pitch table at a rate equal to that in the true aircraft. The auto pilot mounted on this table reacts as it would under flight conditions, and its output signals, which are normally used to position the control surfaces, are fed back to the computer.

REAC machines are available commercially, and more than sixty of them are in use at industrial and government laboratories; in many cases changes and adaptations of the machine have been made to make it more suitable for the problems of the local laboratory.

[1] Based on an address delivered, by invitation, at the meeting of the Association for Computing Machinery, in Washington, D. C., September 8, 1950.

Whether these machines will continue to be used extensively after digital machines become widely available, and their use is no longer surrounded by difficulties of operation, seems hardly worth discussing at this time.

Other machines of the differential analyzer type, which are electronic and thus attain greater speed, but with somewhat less accuracy, have been built in the Research Laboratory of Electronics at MIT, and by George A. Philbrick Researches. The MIT electronic differential analyzer was built merely because, like analog machines in so many other laboratories, it was a handy gadget to solve problems arising in the laboratory. The Philbrick machine is sold commercially. These electronic differential analyzers are well suited to solve not only linear but nonlinear ordinary differential equations, and they have been used effectively on certain partial differential equations for which their very fast time of solution particularly suits them.

Other analog machines, such as the flight simulator at MIT, have been sponsored recently under direct government contract; and the biggest differential analyzer of them all, TYPHOON, has just been dedicated.

Some important analog machines such as the ANACOM at Westinghouse have been developed by commercial companies and universities. All these machines, and others too numerous to mention, are proving their usefulness, and are enthusiastically supported by their users. Some, such as Professor McCann's machine at California Institute of Technology, built without government support, sell their time, and are very busy with problems originating in industry. Others spend their full time solving problems originating in their own laboratories.

There is, of course, vastly more analog than digital equipment that has been built without government support; but in the case of many of the larger installations, at least, the government and its contractors make extensive use of the equipment.

The machines I have been discussing have their principal uses in problems arising outside what we usually think of as a strictly scientific environment. One machine which the Office of Naval Research has sponsored, and which Professor Raymond Pepinsky described at a meeting of the Association for Computing Machinery at Oak Ridge a little over a year ago, is being used extensively at Penn State College for the analysis of crystallographic structure problems. (This is by no means the only analog machine designed for this purpose, as D. R. Hartree has pointed out in his book on *Calculating Instruments and Machines* [Champaign: Univ. Ill. Press, pp. 47, 48, 1949]). The enthusiasm of scientists working in the field of structure analysis here and abroad has led to the suggestion that copies of Pepinsky's machine be made available for sale commercially. Undoubtedly the computing involved in the crystallographic structure problem is extensive. My own impression, however, after listening to two days of discussions at a meeting of crystallographers from Europe and the United States, was that the substantial appeal of the machine was rather in its clever and fast display equipment than in the computing element itself. A special-purpose computer using digital techniques, but with display equipment as effective as that in the Pepinsky computer, would probably be vastly more satisfactory than the present machine, which requires the crystallographer to take a trip around the laboratory turning little knobs before the machine is ready to go—and to repeat this trip whenever a variation of the problem is tried. Since the problem is solved by successive variations of the signs of appropriate coefficients in a multiple Fourier sum, the analysis of a structure involves a fair amount of exercise—a device for avoiding the sedentary habits of the academic profession which may be desirable.

Thus, though the Pepinsky computer is undoubtedly serving an extremely useful purpose for scientists engaged in crystallographic structure analyses, and is turning out important results long before digital machines have become available for this work, it seems clear that this is not an argument for the continuation of extensive analog techniques in this field. If I may paraphrase a remark made by S. H. Caldwell at the Oak Ridge meeting of the association, I should like to emphasize again the advantages to be derived in scientific as well as in military applications of computers from adopting the broad point of view that recognizes merit in both the analog and the digital aspects of the computer art and derives assistance from whatever phase is relevant to the problem in hand. As one who has suspected from the beginning that all oscilloscope displays were manipulated by a little man standing in hiding near by, I am happy now to concede that in several of the problems we are now attacking the introduction of visual display equipment has substantial merit.

I should like to suggest that at this stage in the computer art, a rough basis for the selection of an appropriate type of machine to perform a given computation is not only the degree of accuracy desired, but also the number of inputs to be considered and varied. In problems involving differential equations, for example, the electronic differential analyzers seem particularly suitable for a very fast survey of the results obtained as relatively few parameters are varied; the REAC and the Goodyear type of machine are intermediate in the number of parameters handled and in accuracy; whereas the digital machines, when fully exploited (and when and if the programmers and coders exist for their proper use) will in many cases permit more inputs and yield greater accuracy.

Digital Machines in the Government

I turn now to a brief consideration of digital machines of interest to government agencies. The Ordnance Department of the Army and the Bureau of Ordnance in the Navy were the pioneers in this field and are jointly responsible for the extensive array of machines now at the Ballistics Research Laboratory at Aberdeen and for the machines at the U. S. Naval Proving Ground at Dahlgren. Moreover, the Army Ordnance Department sponsorship of the automatically sequenced high-speed electronic computer at the Institute for Advanced Study has provided support for Professor von Neumann's group there; and the work coming out of this group has inspired designers in many parts of the world in the development of digital computers, and has actually given rise to groups that are copying the machine nearing completion. IBM, too, has contributed importantly to the development of the digital computer art. This company's collaboration with Professor Howard Aiken at Harvard in the building of the Mark I represented only one phase of its contribution. Throughout World War II and continuing into the present there has been heavy reliance in virtually all computer laboratories on IBM equipment. Thus it will be understood that, when I speak of the present activities of the Bureau of Standards in coordinating much of the Federal activity in the field, I am in no way suggesting that their activities represent the sole or even the principal Federal support for the development of electronic digital computers in this country.

After World War II the concern to exploit the potentialities of digital computers for the benefit of Federal departments that were not engaged extensively in military activities was expressed first by the desire of the Census Bureau to obtain a machine suitable for its use in the 1950 census. The monitoring of this development was enthusiastically undertaken on behalf of the Census Bureau by the Bureau of Standards at a time when operating, automatically sequenced, electronic digital machines seemed to be about eighteen months in the future. (They continued to seem about eighteen months in the future for the next three years.) Actually the Census machine is still not available to the Census Bureau, but I understand that some Census problems are being run on the Seac now at the Bureau of Standards.

Other Federal bureaus, including the Office of Naval Research, were happy to use the services of the Bureau of Standards as a purchasing and monitoring agency, and thus the machine development section of what later became the Bureau's National Applied Mathematics Laboratories came into existence. When the Office of Naval Research contracted for its machine, there were optimistic predictions that the machine would be built quickly without substantial research or development, by using existing techniques. It is interesting to note that the Bureau of Standards, about two years ago, having failed to secure delivery from its various contractors, itself began, under the financial sponsorship of the USAF, to construct in its own laboratories two machines which were, again, to be built "with a minimum of development;" and that these two machines, the Seac, now on display in Washington, and the Swac, recently dedicated in Los Angeles, have actually reached the early test and operating stages before any of the machines for whose purchase the Bureau has contracted.

Outside the program monitored by the Bureau of Standards, the Office of Naval Research has had a very limited program in support of electronic digital computers. In particular, ONR is giving partial support to the so-called Caldic at the University of California in Berkeley. The guiding principle for the design of this computer has been minimization of overall cost, including construction, maintenance, programming, and power. Careful plans have been drawn for this machine, and drawings and design information will be available to small research centers that need an installation on the spot.

In line with these objectives, a magnetic drum memory having a storage capacity of 10,000 nine-decimal digit numbers, has been completed. This capacity was provided not only to accommodate large problems, but also to simplify the input-output equipment and the programming—a feature that will be appreciated by those who have written programs for machines with small memories.

Howard Aiken has recently emphasized the desirability of having a relatively simple and cheap machine available to small universities. It was precisely a concern that an adequate machine should be available quite generally and inexpensively to university people that induced ONR two years ago to encourage the California group to proceed with the design and construction of what we have referred to as an "intermediate" computer. Professor Morton, the designer of the Caldic, has now actually completed the design and taken substantial steps in the building of such a machine. We expect that cheapness, like other components, will develop with new ideas, stepwise and not by command, but Professor Morton's estimate of the cost to reproduce this machine in a university laboratory is under $50,000.

I have no doubt that many of the larger research centers will prefer to copy other machines that are now nearing completion. And I believe that these are the machines to which Louis Ridenour, of the University of Illinois, referred in his recent article in the *Journal of Applied Physics* when he said,

> Some workers in the computing-machine field seem quite pessimistic about the ultimate wide availability of such machines, on the grounds that they are complicated, expensive, and difficult to keep in order. This is a point of view with which I entirely disagree. I fully expect that a competent high-speed computer will very soon be regarded as an important and inevitable part of the research equipment of any university having even the most modest research pretentions (21, [4], [April 1950]).

Present State of the Computer Art

I shall try now to summarize briefly recent changes in the state of the computer art. Several electronic digital computers, including the SEAC (the Bureau of Standards Eastern Automatic Computer) and the SWAC (the Bureau of Standards Western Automatic Computer), have been assembled during the past year and are under test, and others are almost entirely assembled. One can therefore expect during the coming year that many debatable questions concerned with such things as number base, word length, and checking systems will have partial answers as experience is gained in the use of these computers. It must be realized that these machines are at present experimental laboratory equipment. One of their main uses in the next few years will be as research tools from which we may hope to learn much about computing and computing equipment.

The EDVAC, the BINAC, and the SEAC are the acoustic computers completed thus far in this country, and a UNIVAC and a Raytheon computer should be completed within the next year. The EDVAC has been moved to Aberdeen, where it has been reassembled and is undergoing tests. The arithmetic element and mercury delay memory have operated satisfactorily, and the dispatcher has been made to perform all machine orders. The input-output equipment is being redesigned. The BINAC has been moved to Northrop Aircraft, where it is being reassembled.

The Eckert-Mauchly Computer Corporation, designer of the UNIVAC, has recently stepped up production schedules; one complete system is being assembled, and parts of another are ready for assembly. These will be followed by a lot of at least three additional systems. It is anticipated that production of the first lot will be completed and tested this year.

At Raytheon, the construction of the machine proceeds slightly behind schedule. The auxiliary six-channel magnetic tape storage uses a newly designed thin magnetic head, and a particularly efficient tape-handling mechanism, which Raytheon is now manufacturing for other machine construction groups.

The National Bureau of Standards SEAC, now assembled at the Bureau, is a general-purpose electronic digital computer which incorporated into its design much that had been learned by others working in the field. The construction of this computer was undertaken with the support of the Office of the Air Comptroller. Initially, the computer was provided with a 512-word internal acoustic memory unit, a prototype 32-word electrostatic memory unit (utilizing the Williams technique), and modified teletype input-output equipment. It is intended that a new type magnetic wire handling mechanism, an experimental high-speed printing device capable of writing 30 lines per second with 50 digits in a line, and magnetic tape input-output mechanisms will be added during 1950. A 45-tube, 512-word electrostatic memory is being constructed for incorporation and evaluation with the computer. The machine has been so designed that both the serial type acoustic and parallel type electrostatic memories can be used simultaneously, and provision has been made for possible increase of the combined memory capacity up to 4,000 words. During the shakedown period of the machine several small problems have been completed. One such completed test problem was the computation of 31 skew rays through a system of 9 lenses for the Electricity and Optics Division of the Bureau of Standards. Linear programming problems for the Office of the Air Comptroller occupy much of the time of the machine, though statistical problems have been run for the Census Bureau, and some problems in mathematical physics have been explored.

The principal general-purpose computers with magnetic drum memory are the Aiken MARK III, which is being reassembled after being moved from Harvard to Dahlgren, and a computer on order for Wright Field under contract with the Bureau of Standards, which was designed and is under development in the laboratory of the General Electric Company at Syracuse, New York. Among the design considerations, accuracy and reliable operation were foremost, and only proved principles are utilized. Operation and maintenance procedures are simplified. Unitized construction, employing about 16 basic circuits as plug-in assemblies, is used to aid design, speed maintenance, and provide for adding future improvements.

The principal machines using an electrostatic memory are the von Neumann–Bigelow–Goldstine machine at the Institute for Advanced Study (and its descendants in various other places), WHIRLWIND at MIT, and the SWAC.

The Institute for Advanced Study computer is virtually assembled. It will use a memory of the Williams type as redesigned for parallel operation by Julian Bigelow. The memory, the arithmetic element, and the arithmetic control have been built and tested, and the central control is substantially complete. Considerable effort has been expended to minimize the number of tubes and amount of other equipment required and to make the units as compact and accessible as possible. A clever three-dimensional wiring system has been worked out, whereby leads cross at right angles to minimize cross-talk, and compactness and accessibility are secured.

For WHIRLWIND a specially designed electrostatic storage tube has been developed. At present a bank of 16 storage tubes, each storing 256 binary digits, has been installed, along with the necessary circuits for transferring information to and from the memory in a parallel fashion. The final memory is expected to be composed of 32 tubes, each storing 1,000 binary digits. In order to decrease the number of errors occurring during operation of the computer, a marginal checking arrangement for detecting deteriorating components has been worked out. In this scheme, voltages are varied in large circuit groups, inducing inferior parts to cause failure, and a test program detects and localizes possible failure.

The SWAC has recently been dedicated at the Institute for Numerical Analysis in Los Angeles. At the time of the dedication the device had an internal storage of 256 numbers of 45 binary digits each. Selection commands were available that in many cases permitted storing more short numbers than there were available storage spaces by storing two or more numbers per storage position. The machine has been used to construct tables of squares by adding successive odd numbers; and a program had been pursued which made the machine count by adding one to the number already stored in one of the storage positions.

It is hoped that the storage in each tube can be increased so that the memory capacity will become 1,000 words. A magnetic drum is to be installed as an auxiliary memory device. Numbers are to be transferred from the drum in blocks so that the numbers will become available as fast as they are needed.

THE SHAPE OF THINGS TO COME

We see, then, that the warning that I have been in the habit of giving for the past several years is no longer strictly appropriate—namely, that none of these automatically sequenced electronic machines is actually working. Nevertheless, real operating experience is now available in this country only for the earlier types of machine, the ENIAC, the MARK I and II, and the Bell Telephone Laboratories computers. But some experience with electronic automatically sequenced machines does come to us from England.

The importance of these remarks for the Federal program is only partly that we are now able to breathe a sigh of relief and hope that our predictions of great things may soon be realized. Their importance is even more that, charged as we are in the Federal government, and particularly in the military, to be at least two years ahead of the time, and operating under the pressure of the present international emergency, we are now dreaming of the special uses to which the components and machines that are now beginning to perform satisfactorily may be put—and worrying about important new components whose development we should sponsor. The obvious directions are toward simplification of circuits; the investigation of the possible use of semiconductor devices, such as transistors to replace vacuum tubes; and the exploration of promising avenues for the further development of a high-speed memory. Some work over and above that being supported by industry is being sponsored by the government in all these directions. A symposium on computer tubes will be held in December under the auspices of the Defense Department's Panel on Electron Tubes, the IRE, and AIEE; one purpose of this conference will be to bring together the user and the manufacturer in the hope of securing better tubes for computer uses through selective standardization.

We are now entering the period when attention is being given to the building of special-purpose digital machines. Already Northrop Aircraft, Inc., has developed the MADDIDA, a digital differential analyzer using a magnetic drum memory. The block diagram of the solution of a differential equation on the MADDIDA is similar to that of the same equation on an analog differential analyzer, but the amount of equipment is impressively small. This machine gives promise of important uses not only in its present form but in projected extensions of that form.

In the early discussions of very high-speed computers, great emphasis was placed on the need to develop a machine that would accept a small amount of information, perform very rapidly extensive operations upon this information, and turn out a small amount of information as its answer. Problems of this sort are surely no less critical today than they were five years ago. In this area lie many of the really difficult problems of mathematical physics.

Current interest, however, seems to lie in a further exploration of the use of machines to accept large amounts of data, perform very simple operations upon them, and print out, possibly, very large numbers of results. Some special-purpose machines of this sort are under discussion. The Department of the Air Force is planning to ask the Bureau of Standards to design a machine especially adapted to the determination of optimum programs for the Air Comptroller. This machine must be capable of handling extremely large matrix problems. In addition the Air Force is planning to study the special requirements of its statistical control and statistical research centers and to proceed with development of a moderate-size machine intended for such applications. Both the machine for computation of optimum programs and that for statistical operations will require printing out of large amounts of information, and in this connection a prototype model of a very high-speed printer has been developed.

Much has been said about the critical urgency of developing qualified personnel to handle the digital machines as they go into operation. Some of the lessons learned at Aberdeen and Dahlgren in the operation of their computers are: (1) Human error causes considerably more trouble than machine error. Errors in coding and in the setting of dial switches have been a frequent source of irritation in the operation of the Aiken Relay Calculator at Dahlgren. (2) There is need for a simplification of coding procedures. Even for very small calculators, the time required for coding problems has often been considerably greater than the time required for solution on the machine. Surely in the programming and coding of problems we must improve the competence of the operating staff to a very considerable extent.

There is also an important need to explore more fully the mathematical formulation appropriate to the types of problems that arise frequently in applications. The highly competent staffs at Aberdeen and at Dahlgren have been impressed by the extensive difficulty of determining even approximately optimum formulation of their problems and of relying on existing mathematical proofs to assure the convergence of various processes they have had to use. Thus there remains an important creative area for the mathematician in facilitating and implementing the uses of digital machines.

A small attempt at meeting this need is being undertaken by the Office of Naval Research through its support of work in numerical analysis related to the use of digital computers at the Institute for Advanced Study at Princeton, and at the Institute for Numerical Analysis of the Bureau of Standards. But until more machines come into operation, and more practicing scientists experience difficulties in solving their own problems, we must expect that significant progress will be slow. I believe that as the new computers become available to research workers we shall enter a new and exciting period in scientific research, to which physical scientist, mathematician, and engineer have much to contribute.

Building an Effective Technical Library

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SCIENTISTS AND ENGINEERS for the most part are not concerned with the question of why they need a technical library in their work. Their reaction to such a question would probably be one of surprise, since "everybody knows" that a technical library is necessary in scientific and engineering pursuits. The "why" is a question that concerns the scientist or engineer only when he assumes administrative responsibility for a research and development program. Then he finds he not only must know why but also must be acquainted with the what, when, where, and how (which usually becomes how much). This paper is an attempt to point out the factors to be considered in establishing an effective library for a scientific or technical organization.

Size and Scope

To determine the type of library best suited to the organization, it is necessary to consider the nature of work performed, as the library reflects the subject interests of the organization as a whole. An activity engaged in basic research, for example, would need a much more extensive library than a testing facility, since the former covers broader subject fields.

The size of the library is dependent upon five principal factors: the number of subject fields to be covered, the extent to which each subject is to be covered, the number of people in the organization served by the library, the total budget of the establishment, and the proximity of the library to other technical libraries. In a metropolitan area the library could be quite small, as library materials could be obtained through arrangements with other libraries, possibly even on a contract basis. In areas not close to existing libraries, it is, of course, necessary to build up more complete and self-sustaining collections. The library might range from the storehouse type of collection with its "book-keeper," to the maximum of a large, diversified collec-