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NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

Computer Development (SEAC and DYSEAC) at the National Bureau of Standards Washington, D. C.

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Foreword

Since 1946 the National Bureau of Standards has been active in the general field of electronic digital computers, largely for other agencies of the Government. The Bureau's computer program has been conducted jointly by the Electronics Division and the Applied Mathematics Division. The work of the Electronics Division in Washington has included the development and construction of two computers (SEAC and DYSEAC), components research and development, and various technical and advisory services. The work of the Applied Mathematics Division has included research in numerical analysis of importance in the solution of problems by computers and the design and construction of a computer (SWAC) at the Bureau's Institute for Numerical Analysis in Los Angeles.

This volume presents reports on various aspects of the computer program through 1953, based largely on the work and experience relating to SEAC and DYSEAC. Such topics as systems development, engineering development, design, construction, and maintenance of computer equipment are covered. The introduction summarizes the history of this program in the Electronic Computers Laboratory of the Electronics Division.

A. V. ASTIN, *Director*.

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Introduction

S. N. Alexander

The development of electronic digital computing machinery at the National Bureau of Standards started in 1946 because of the interest of the Bureau of the Census in the possible use of electronic digital techniques for tabulating purposes. In particular, the Bureau of the Census hoped to attain trial use of an electronic installation in connection with the 1950 decennial census, and the National Bureau of Standards was asked to provide technical guidance and developmental support to this long-range program. Concurrently, NBS was seeking to obtain an electronic digital computer as a scientific instrument for its own use. Immediately following the establishment of these two tasks, a 2-year program for the development of improved components for digital computers was established under the sponsorship of the Office of the Chief of Ordnance, Department of the Army.

The relatively short time schedule desired for the delivery of the two complete machine installations, together with suitable auxiliaries and operational supplies, made it advisable from the outset to seek commercial sources for such equipment. In this way, it seemed possible to compress the research, development, and construction of such equipment into an integrated effort and thereby meet the time schedules. This decision was buttressed by further requirements from the Office of Air Comptroller, Department of the Air Force, and the Army Map Service for similar equipment with comparably short time schedules. NBS agreed to serve as technical agent in monitoring the design, construction, and installation of these machines from two commercial suppliers, while its own laboratories were fully occupied with the component development program.

Because of an unanticipated sequence of technological and contractual difficulties, it became evident early in 1948 that the delivery of complete machine installations would be delayed considerably beyond the target dates. The unexpected difficulties associated with the developmental phases of all such programs, both commercial and university, emphasized the uncertainty of availability of electronic digital computing facilities of any sort. This motivated a request for a "stopgap" installation to serve some of the urgent needs of both the Air Comptroller and NBS during the interim period until full-scale equipment could be obtained from commercial sources within a more realistic time schedule. During the summer of 1948, NBS explored the possibilities of designing and constructing an interim machine that would have sufficient power for general use and yet be simple enough to be constructed in a short time. The feasibility of this program was based on the preceding 2 years of active experience in component development and the availability of the best technology that had been reported by other computer groups, particularly those in the universities.

The original modest objectives for an interim machine were reconsidered toward the end of 1949, when it became evident that the proposed SEAC computer would be the only equipment available to NBS and collaborating Government agencies for at least 2 years. To cope with this altered situation, the plan for the machine was adjusted so that a full-scale installation could be attained by subsequent expansion of an initial nucleus. However, the prime objective was still to have the initial nucleus in operation at the earliest possible date. The resulting machine began useful operation in May 1950, less than 2 years after the start of the program, and SEAC completed nearly a year of scheduled operation for NBS and its collaborators before any other installation was available to them. Furthermore, SEAC was the one installation that was readily available to serve the intermittent computational needs of many other Government agencies, and for over 2 years was used on a round-the-clock basis for the full 7-day week. Even now, after 3 years of regularly scheduled operation, the SEAC is still employed for an extended work week in the solution of problems.

The task of designing a large-scale digital computer such as SEAC from original conception to final realization was, of course, the effort of many minds and the work of many hands. The team chosen for this task encompassed a wide spectrum of talents and skills. The successful completion of SEAC at a time when the availability of such a facility was of urgent importance to the Government was recognized by the Award for Exceptional Service from the Department of Commerce to the

SEAC staff as a group. In addition to this group-citation to the 33 scientists and technicians who contributed to the SEAC accomplishment, particular mention was made of the individual contributions by S. N. Alexander, W. W. Davis, R. D. Elbourn, S. Greenwald, R. C. Haueter, A. L. Leiner, S. Lubkin, C. H. Page, J. L. Pike, R. J. Slutz, and J. R. Sorrells. The early contributions of H. Senf and W. Martin also deserve recognition, even though they did not remain to participate in the completion of SEAC.

As soon as the central nucleus of SEAC was functioning reliably enough to warrant regularly scheduled operations, the program of expansion and additions began. Indeed, the machine became a proving ground for the evolution of advances in computer components, design techniques, and maintenance procedures. The expansion and testing were carried out in the midst of a regular work load of important computing that was tightly scheduled because of priorities. Thus it was necessary to plan carefully in order to meet the requirements for scheduled computation and also include the necessary development work. The fact that these two conflicting objectives were meshed in an effective manner is a compliment to the fine cooperation and management between the scientists and engineers who designed SEAC and the mathematicians who used it.

During this period of expansion, over 90 percent of the time available in a full 168-hour week was effectively scheduled and used for either problem solution, development work, or preventive maintenance. During this period, 83 hours a week were scheduled for problem solution, of which 65 percent was logged as productive time, and 52 hours a week were scheduled for development work. Only 20 percent of the time scheduled for either development work or problem solution was recorded as being ineffective because of machine malfunctions. This is considered a gratifying performance for a pioneering installation, particularly when the difficult tasks of operating and expanding the machine were under way at the same time.

The initial program for expansion was directed primarily at the task of improving the input-output facilities, which resulted in the addition of magnetic wire and magnetic tape units to increase the speed of computation on problems that could not readily be kept within the confines of the 512 words available in the high-speed memory. As more of these magnetic units became available, an external selector panel was added to the machine to permit automatic selection of the desired input-output unit under programmed control of the computer as well as by manual operation of the console switches. This, in turn, made it necessary to design and construct both an inscriber and an outscriber to facilitate the transition between the documents containing the coded problem and the typed sheets giving the results of the computation by the machine. In addition, arrangements were made to permit transfers to and from punched cards which were either the source for data or the final form desired for the solution. Most of the effort in this area was planned and directed by R. J. Slutz, with the able collaboration of S. Greenwald, R. C. Haueter, E. F. Ainsworth, J. L. Pike, L. Cahn, P. R. Westlake, W. H. Bridge, and P. D. Shupe, Jr.

While the input-output system of SEAC was being augmented, steady planning and construction by a group under the leadership of W. W. Davis were also under way for the addition of an experimental electrostatic memory, primarily for trial and evaluation but with the eventual goal of regular service as an additional 512-word high-speed memory. This equipment also served as an exacting evaluation of experimental cathode-ray tubes specifically designed for storage purposes and of testing procedures that were being developed for selecting tubes suitable for operation in the memory.

The central control of the machine also underwent considerable revision and expansion. Some of these changes related to the inclusion of additional machine operations, but the more significant changes related to the inclusion of an automonitor function and a three-address control system, which is described in detail in one of the following papers. These revisions and expansions resulted from suggestions arising out of operational experience and the desire to make the machine more versatile. The detailed planning of these changes was the work of A. L. Leiner, who had been responsible for most of the final system plans for the SEAC nucleus. The physical realization and installation of these new features are a tribute to a combination of careful engineering and patience on the part of R. C. Haueter, S. Greenwald, and P. D. Shupe.

Sporadic performance of the experimental electrostatic memory directed specific attention to the development of an improved cathode-ray tube for storage purposes. By this time, the Bureau had begun the planning of a far more powerful machine than SEAC to be used in the SCOOP program of the

Office of Air Comptroller. This machine definitely required a rapid-access memory, and for this reason the development of both cathode-ray tubes and improved electrostatic storage techniques was pursued vigorously, under A. W. Holt and D. C. Friedman. Meanwhile, other approaches to rapid-access storage were being explored, one of which resulted in the Diode-Capacitor memory system suggested by A. W. Holt and reported in a companion paper.

During the expansion of SEAC and the evaluation of components aimed toward the creation of a SCOOP machine, it became evident that the dynamic circuitry devised for SEAC was susceptible to considerable electronic standardization. In turn, this became the basis for a repetitive physical configuration out of which the high-level pulse circuitry could be assembled. The advantages and possibilities of a standardized package design were realized by R. J. Slutz, and its detailed design and execution were the results of combined efforts of R. P. Witt and R. D. Elbourn.

The computer group at the U. S. Air Force Missile Test Center, Patrick Air Force Base, Cocoa, Florida, collaborated in the mechanical design of the first satisfactory packages, and these were successfully employed in the outscriber that was constructed for SEAC. This packaged design, with some refinements, was used in two computing machines that have recently been completed, one at the Air Force Missile Test Center and the other at the Willow Run Research Center of the University of Michigan. The Bureau revised this package design to incorporate etched circuit techniques. These are the packages that were used in the construction of DYSEAC, a new machine sponsored by the Research and Development Board for the evaluation of a number of organizational and engineering innovations. All three of these machines are based on the circuit techniques and some of the organizational features of SEAC, but they are distinguished one from the other by variations on the SEAC organization that were included to meet specific application requirements.

In order to cover adequately the 5 years of development that stemmed from the SEAC program, the component improvement program, and the subsequent DYSEAC program, the senior personnel of this laboratory have shared the responsibility for reporting on the achievements of the entire group. The authors of any of these particular papers are not necessarily, therefore, the only major contributors to the solution of problems discussed; and many of these authors, with others, have made important contributions to other programs as well as to those on which they are now reporting. Here again, it is important to recognize the team nature of the developmental activity that is being carried on at NBS.

While the detailed planning of the SCOOP computer was deferred in order to identify more clearly its operating characteristics and to have at hand a proved rapid-access memory, the design and constrution of DYSEAC, which was to result in a complete machine that would serve certain specialized needs and also provide a thorough evaluation of the packaging techniques, was undertaken. Although DYSEAC employs an acoustic memory and a serial arithmetic unit, the basic organization is considerably more sophisticated than that of SEAC, for it contains some of the system features that had been planned for the SCOOP machine. In addition, special features have been incorporated to permit the machine to serve as a tool for experimentation on the handling of large masses of business-type data and for experimentation in using digital equipment in a control system.

The task of planning the organization of DYSEAC and its detailed execution through the preparation of wiring tables was carried out under the direction of A. L. Leiner, with the able collaboration of W. A. Notz, J. L. Smith, A. Weinberger, and W. H. Bridge. The physical realization of the machine involved many original design problems related to the use of packages and a modular type of construction for the chassis. The decision to install DYSEAC in a pair of vans was made after the program was well under way. This added many new mechanical and electrical considerations. The formidable task of constructing DYSEAC was accomplished in approximately 18 months by a team of about 25 people directed by R. P. Witt, ably supported by R. W. Smith, H. P. Belcher, and R. Hand.

One of the major purposes in the SEAC program was to evaluate the reliability and serviceability of techniques that appeared highly promising but were at that time still unproved. Subsequent operating experience has established the soundness of many of the engineering choices that were significant departures from the techniques then current. Operating experience established another important feature: the significant benefits that accrued from using an operating machine as a proving ground for new component and operating techniques. SEAC has served as a valuable focal point that prompted the exchange of ideas among the components researcher, the machine designer, the maintenance engineer, and the user. The DYSEAC holds promise of becoming a comparable source of ideas for further machine development.

1. SEAC

S. Greenwald, S. N. Alexander, and Ruth C. Haueter

1. INTRODUCTION

The first major contribution of the National Bureau of Standards to the development of electronic computing machinery occurred with the completion of the SEAC (Standards Eastern Automatic Computer) in May 1950. This digital machine was the culmination of almost 2 years of intensive design and construction work which was sponsored by the Office of Air Comptroller, Department of the Air Force. The initial objective set during the summer of 1948 was to provide at the earliest possible date a machine of limited computing power that would meet the immediate computational needs of the National Bureau of Standards. This installation would serve as a "stopgap" for the interim period during which full-scale equipment from a commercial source was being completed for delivery to the Government. Toward the end of 1949 this point of view was gradually abandoned, as it became evident that there would be no other equipment available for 2 years or possibly longer. As a result, the ultimate objective was altered so that a full-scale machine could be attained by expansion of the initial nucleus without delaying its completion.

Still another aspect of building an expandable machine was the ability to use it as a proving ground for experimental equipment.

At the present time, after more than 3 years of regularly scheduled operation, SEAC is still actively employed in the solution of problems for both NBS and many Government agencies. What is perhaps more important is that for the initial 2 years of its operation it was the most powerful computer installation readily available to the Government, and consequently was scheduled around-the-clock for a full 7-day week.

Since the machine was first put into operation, a significant fraction of the total time available has been devoted to the engineering work associated with the expansion of SEAC. The magnitude of this effort can be estimated from the fact that the number of vacuum tubes in the system was increased from approximately 750 to 1,300 and the number of germanium diodes from approximately 10,500 to 16,000. This expansion and testing program was carried out in the midst of a regular work load of important computation that was tightly scheduled because of priorities.

A number of circuit and equipment innovations were included in the SEAC program in order to evaluate the reliability and serviceability of techniques that were highly promising but unproved. One example in this area is the extensive use of diode switching. Another is the achieving of a-c coupling by using pulse transformers for highly variable duty factor service. Success with these techniques made practical the use of vacuum tubes as a means of power amplification rather than as gating devices.

At the present, two machines based on a packaged version of the SEAC "transformer-coupled dynamic circuitry" have been completed. One is located at the Air Force Missile Test Center in Florida and the other at the Willow Run Research Center of the University of Michigan. A still further extension of these techniques was employed at the National Bureau of Standards in the construction of the DYSEAC, which is described in a companion paper.

2. OPERATING CHARACTERISTICS

The SEAC is an automatic high-speed digital computer that operates at a 1-Mc pulse repetition rate. The machine is predominately serial in nature and uses the binary number representation. Both instruction words and number words consist of 45 binary digits, which are equivalent to approximately 13 decimal digits. When the machine was first put into operation in May 1950, 11 different types