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Electronic Computers - A Historical Survey in Print

Saul Rosen

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ELECTRONIC COMPUTERS
A HISTORICAL SURVEY

Saul Rosen
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Computer Sciences Department
Purdue University
Lafayette, Indiana
INTRODUCTION

During the academic year 1965-1966, as an ACM lecturer, I presented a talk with the title, "History of Electronic Computers" to a number of ACM chapters and to the Southeastern Regional Conference of the ACM. This paper consists mainly of material prepared for that talk. There is far more text than could be presented in an hour talk, and no single presentation covered all of it. I planned to publish it in the spring of 1966 as a companion paper to my historical survey "Programming Systems and Languages" published two years earlier [80]. For a number of reasons the final draft of the paper was delayed until the spring of 1968. Because of the delay, it seemed desirable to make a few changes, almost all of them to provide additional information to bring this history up to date.

A complete history of electronic computing would be a very large volume. This paper makes no attempt at completeness. It is an essay that tries to capture and present some of the atmosphere of the development of the computer industry from its beginnings in university laboratories to its present size and status. I have been an interested observer, and to some extent a participant, since the very early days. Some of the statements made here are based on recollection and hearsay. Some may be false, although none are intentionally so. A number of people who heard the talk asked that I make copies available to them, and, somewhat belatedly, this is my response to them.
The title of this paper should perhaps be "Electronic Computers in the United States", except for the fact that a few developments in Great Britain are included. A more complete history would include the very significant contributions made in France and Germany and in the Scandinavian countries, and in many other parts of the world. The reader is referred to Hoffmann [77] for a brief history and an extensive bibliography on computers developed outside as well as inside the United States.
1. The University Projects

The first large-scale electronic computer was the ENIAC [1,2], the Electronic Numerical Integrator and Computer, built by professors Eckert and Mauchly and their coworkers at the University of Pennsylvania for The Ballistic Research Laboratory of the United States Army Ordnance Corps. The Ballistic Research Laboratory in Aberdeen, Maryland had the responsibility for the calculation of trajectories and firing tables, and had been actively involved in the development of electromechanical computers. They were quite receptive to a proposal in 1943 by a group of engineers and mathematicians associated with the Moore School of Electrical Engineering of the University of Pennsylvania, to build an all-electronic computer based on the very high-speed vacuum-tube switching devices that had been known for some years [3].

The really radical aspect of the ENIAC project was that it proposed to build a machine containing 18000 vacuum tubes, a machine whose ability to function at all would depend on almost all of these tubes functioning simultaneously, without failure, over reasonable periods of time. Nothing comparable had ever been attempted, and some interpretations of tube reliability statistics were very pessimistic.

Stories are told about how all the lights in West Philadelphia would dim when the ENIAC was turned on, and how the starting transient would always burn out three or more
tubes. Yet the ENIAC was quite successful. It was completed in 1946 and was used as a productive computer for about 10 years at Aberdeen, from its dedication on February 15, 1946 until it was turned off for the last time on October 2, 1955.

The ENIAC, as originally designed, was not a stored-program computer. Programs were installed and changed by engineers who changed the wiring among its various components. The idea of the general-purpose stored-program computer was first published in 1945 in a draft of a report that proposed a new computer, the EDVAC (Electronic Discrete Variable Computer) [4,5]. The draft was written on behalf of the ENIAC project by Dr. John Von Neumann, a consultant to the project, who is considered by some to have been the inventor of the stored-program computer. Others, including myself, feel that Dr. John Mauchly and Dr. J. P. Eckert deserve recognition along with Dr. Von Neumann as co-inventors of the stored-program digital computer as we know it now.

The general-purpose stored-program digital computer required large amounts of storage, more than it was economical to provide when using vacuum-tube flip-flops as storage elements. Acoustic delay-lines with mercury as the transmission medium had been used for data storage in radar applications, and although far from ideal as a computer memory device, these mercury delay-lines did represent a practical working component
around which computers could be designed. The first of these computers, the EDVAC, was started at the Moore School in 1946. The first to be completed was the EDSAC (Electronic Delay Storage Automatic Calculator) at Cambridge in England in 1947. The EDSAC was started early in 1947 by Professor Maurice Wilkes who had spent the preceding summer with the computer design group at the University of Pennsylvania. The EDSAC performed its first computations, the first performed by a stored-program computer anywhere, in May of 1949. The completion of the EDVAC was delayed, among other things, by the fact that Professors Eckert and Mauchly left the University of Pennsylvania to form their own computer manufacturing company.

In the United States and in England other university computer projects soon followed. At the Institute for Advanced Study at Princeton, New Jersey the IAS computer was started in 1946 by Professor Von Neumann and his colleagues. A series of reports published by that project were among the most important tutorial documents in the early development of electronic computers [7]. The IAS computer used a random-access electrostatic or cathode-ray tube storage system and parallel binary arithmetic and was very fast, especially when compared with the delay-line computers with their sequential memories and serial arithmetic. By 1952 when the IAS computer was completed, a number of other computers had been started using the same design. Several others have been built since. These include
the ORDVAC and the ILLIAC built at the University of Illinois, the JOHNIAC at Rand Corporation, the MANIAC at Los Alamos, and the WEIZAC at the Weizman Institute in Israel.

The Servomechanisms Laboratory at the Massachusetts Institute of Technology was one of the very active groups in the early history of electronic computers. At MIT Whirlwind I which was started in 1947 was probably the first computer designed with eventual real-time application in mind. The computer used 1/2 microsecond circuitry and could multiply two 16-bit numbers in 16 microseconds [8].

One of the major contributions of the Whirlwind project was a set of detailed, very-well-annotated logical diagrams of the computer. Although not formally published, they achieved fairly wide private circulation, and helped to educate many early workers in the computer field (including the author).

The most important contribution of the MIT Computer projects was their development of the coincident-current magnetic-core memory. They built the Memory Test Computer to test their first core memory and later installed one in Whirlwind. The core memory designs developed at MIT were made available to the computer industry and served as the basis for the memories built by IBM and by some other computer manufacturers.
The University of Manchester in England began building computers in 1947. The first practical electrostatic storage system, the Williams Tube Memory, was developed there [9]. The idea of the index register grew out of the B line on a 1949 Manchester computer. This is the reason index registers were often called B registers or B boxes in the early literature. That same computer [10] had a magnetic-drum auxiliary storage system organized into fixed-length blocks which were called pages, and which were the units that were moved into high-speed electrostatic storage during program execution. This was the beginning of a continuing interest at Manchester in efficient utilization of hierarchies of storage that years later led to the design of the Atlas Computer, a very influential computer of a second generation, which will be discussed in a later section.

The National Bureau of Standards played a very important part in the early development of digital computers.

By 1948 they had already made plans to purchase two very large "Hurricane" computers under development by Raytheon Corporation. One of these computers was to be installed in Washington, the other at the Bureau of Standards' Institute for Numerical Analysis which had been established on the campus of the University of California at Los Angeles.

Production of the Raytheon computers was proceeding quite slowly, and the Bureau of Standards decided to build its own interim computers, one in the East and one in the West. The
western computer, a relatively modest effort, was originally called the Zephyr, to contrast its size and objectives with very large efforts like Raytheon's Hurricane, MIT's Whirlwind, and large analog computers like REAC's Cyclone and RCA's Typhoon.

The Zephyr was eventually rechristened the SWAC (Standards Western Automatic Computer)\(^1\). It was one of the fastest of the early computers, though limited in the scope of its applications by its very small (256 words) electrostatic storage.

The eastern interim computer was the very successful SEAC (Standards Eastern Automatic Computer)\(^2\). The SEAC was placed in operation in 1950, the first stored-program computer running in the United States. It continued in use into the early 1960's. Originally it had only mercury delay-line storage, but other memory systems were added. Several other computers, of which the best known was the KIDAC at the University of Michigan, were based on the SEAC design.
2. **The Computer Industry - The First Generation**

**UNIVAC**

In 1947 Professors Eckert and Mauchly left the University of Pennsylvania and organized the Eckert-Mauchly Computer Corporation. In their first years as an independent company they built a relatively small binary computer, the BINAC [157], for Northrop Corporation, and they started the design of the UNIVAC, the UNIVersal Automatic Computer [147]. Their first major contract, negotiated with the National Bureau of Standards, called for the delivery of a UNIVAC to the Bureau of the Census for use in connection with the 1950 census.

The BINAC apparently never worked satisfactorily, but the UNIVAC was in many ways an outstanding technological achievement. The first UNIVAC was delivered on June 14, 1951. For almost five years after that it was probably the best large-scale computer in use for data-processing applications. Internally it was the most completely checked commercial computer ever built. Perhaps its most impressive achievement was its magnetic tape system, a buffered system that could read forward and backward at speeds comparable to some quite recent tape systems.

The financial backer of the Eckert-Mauchly Computer Corporation was killed in an airplane accident, and the company ran into financial difficulties. It turned out that
they had underestimated both the time and the money needed to produce the very ambitious UNIVAC system. With firm orders for delivery at about $250,000 per system it became apparent that it would cost much more than that to build them. Under these circumstances it was attractive to accept an invitation to become the Eckert-Mauchly division of Remington Rand corporation. Prices were immediately increased, although some deliveries had to be made at bargain prices. Some orders, most significant perhaps those from the Prudential Life Insurance company, were cancelled.

Remington Rand was launched into the computer field with a product that was years ahead of any of its competitors. In 1952 Remington Rand further solidified its position of leadership in the computer field by acquiring Engineering Research Associates of St. Paul, Minnesota. Engineering Research Associates had already achieved a considerable reputation in the design of computing systems and components [157]. They had done important work in the design of their one-of-a-kind 1101 and 1102 Magnetic Drum computers, and in cooperation with a government security agency they had designed the ERA 1103, a very powerful scientific computer using parallel arithmetic and cathode-ray tube storage. Eckert-Mauchly and Engineering Research Associates were eventually incorporated into the UNIVAC Division of Remington Rand. The UNIVAC computer became known as UNIVAC I, and the 1103 and its successors were called UNIVAC Scientific Computers.
It is of some interest, in retrospect, to ask why Remington Rand, starting with computer hardware so far ahead of the rest of the field, fell so far behind. Part of the answer has to do with the fundamental difficulty of integrating a number of previously independent companies into the framework of an existing organization. Remington Rand had absorbed two of the outstanding companies in the young computer field, but they never succeeded in getting them to work together as parts of a larger unit.

From the beginning the UNIVAC I sales effort was insufficient, unaggressive, and unimaginative. The Eckert-Mauchly personnel had mainly a scientific rather than a business orientation. They realized the limitations of their machine. They would tend to dampen the enthusiasm of prospective customers who came to them with with prophetic visions of the potential of electronic data-processing. They knew that these visions would become reality only on a later generation of computers, and they did not encourage the very expensive experimentation which would almost invariably prove them to have been right. Most of this experimentation was eventually carried out on competitor's equipment, spurred on by promises made by salesmen who often understood little or nothing about the capabilities of the equipment they were selling.
There were, of course, some basic problems other than lack of sales effort. During the first crucial years Remington Rand would only sell, and would not lease UNIVAC I Systems. A leasing policy would have required a great deal of capital, and Remington Rand, which had recently emerged from some serious financial difficulties, was not prepared to undertake the expansion that would have been necessary.

The early UNIVAC I system was incomplete, especially in the area of peripheral equipment. Punched-card-to-tape conversion equipment which had been developed by Eckert-Mauchly for the Census Bureau handled only 80-column cards. For several years there thus existed an anomalous situation where Remington Rand UNIVAC I systems were normally supported by IBM punched-card installations, and could not use Remington Rand's 90-column cards.

For the first few years, prior to the development of the UNIVAC 600-line-a-minute printer, the only printer for the UNIVAC system was the Uniprinter which operated at electric-typewriter speed directly from magnetic tape.

On the input side UNIVAC I introduced the concept of direct recording onto magnetic tape from a typewriter keyboard. A keyboard-operated tape verifier, which was supposed to be part of the input-preparation system was never fully operational. Verification and correction usually had to be done on the
computer, and the computer time required for these tasks was quite appreciable. This kind of operation may be revived in the new generation of computers with on-line keyboards and very large random-access memories. It was not a successful concept in terms of computers in the UNIVAC I class.

The UNIVAC I was the only mercury-delay-line-storage computer that achieved the status of a commercial product. By 1953 it was apparent that computers with magnetic-core memories could be produced that would make the UNIVAC I obsolete. In 1954 IBM announced its 705 computer, and Remington Rand responded about a year later with the announcement of the UNIVAC II, a computer with magnetic-core memory that would be able to run UNIVAC I programs, and that would, in addition be far more powerful than the UNIVAC I. Plans called for the UNIVAC II to be designed in Philadelphia and produced in St. Paul. So many difficulties arose in this process that the production responsibility was finally shifted back to Philadelphia. Deliveries kept being delayed and orders dwindled as many customers switched to the 705. IBM delivered its first 705 by the end of 1955. It was two years later that the first UNIVAC II was delivered. These two years were sufficient to give to IBM a lead in the large-scale commercial computer field that no manufacturer has since been able to challenge.
IBM

IBM, the International Business Machines Corporation, entered the field of automatic computation by way of electro-mechanical equipment designed to complement its line of punched-card machines. In the 1930's they introduced their 600 series of calculating punches. Between 1939 and 1944, they cooperated with Professor Howard Aiken of Harvard University, to build the MARK I Calculator [16], which, according to Dr. Bowen [17], was "the first machine actually to be built which exploits the principles of the analytical engine as they were conceived by Babbage a hundred years before." The MARK I was the largest electromechanical computer ever built. At Harvard Professor Aiken went on to build the MARK II [18], a large relay computer, and then the MARK III and MARK IV, which were one-of-a-kind magnetic drum computers. At its headquarters in New York IBM built the huge SSEC [19] (Selective Sequence Electronic Calculator) which was put into operation in January, 1948. The SSEC was only partly electronic, it used 13000 vacuum tubes along with 23000 electromechanical relays.

By 1947 IBM had an Electronic multiplier in its product line, and by the end of 1948 they had started to deliver the 604 Electronic Calculating Punch, which made electronic computing speeds available in punched-card handling systems. They had this area of electronic calculation almost completely to themselves for years. It was only in 1951 that Remington Rand
came out with its 409-2 electronic calculator that introduced some slight competition into this field. Without very great fanfare IBM produced and installed hundreds (later thousands) of their electronic calculating punches. While some of the other office equipment manufacturers were still debating the practicality of electronic computing, and looked at electronics as something that might eventually invade the business office, most of the major business offices had already taken a first step into electronic computing, at least on the level of the 604, a machine with over 1400 vacuum tubes.

The 604 was quite limited in its sequencing and calculating abilities. In 1946 one of IBM's customers on the West Coast joined a calculating punch to a 400 series accounting machine, and this concept was developed and marketed by IBM as the Card Programmed Calculator (CPC). The CPC was not a stored program computer, but it did have the ability to execute programs of arbitrary length. A program consisted of a deck of cards. Each card contained a code which called on a more or less complex program sequence within the 604. In addition to performing calculations each step could print a line or punch a card. The CPC was only semi-automatic in the sense that punched-card machines are semi-automatic. It required a human operator to feed cards and to remove cards. Iterative programs could be run by feeding the same cards through over and over again. The CPC was slow by electronic-computer standards,
running at a maximum speed of 150 instruction cards per minute. Yet it is hard to exaggerate its role as an interim computer, carrying the major computing load in dozens of computation centers while they were waiting for the stored-program computers to live up to their promise in terms of delivery and performance.

Even though IBM was a leader by far in the use of electronic calculation in punched-card machines, they were quite slow in entering the commercial large-scale computer field. While the Bureau of Standards was negotiating its contract to obtain the UNIVAC I for the Census Bureau, IBM contended that magnetic tape was unreliable, untested, and risky. They suggested that the census would be well advised to stick to punched-card methods. To some people in IBM, magnetic-tape processing must have loomed as a threat to the punched-card processing field in which IBM had been able to establish a near monopoly, with practically no effective competition.

The Korean war that started in 1950 brought about a great expansion in the defense-related industries and a greatly increased need for computation of all kinds. It was then that IBM announced its Defense Calculator, a large-scale scientific computer using a 2048 word Williams-tube memory backed up by magnetic-drum and magnetic-tape storage. Its random-access storage and parallel arithmetic would make the Defense Calculator much faster than the UNIVAC I for scientific calculation.
The first Defense Calculator, now known as the IBM 701 was
delivered early in 1953 [20]. By that time IBM had announced
the 702, a completely separate computer development for the
commercial data-processing field [21]. The 702 was a character-
oriented computer with 10,000 characters of Electrostatic
Williams-tube memory. The first 702 was delivered early in
1955, but long before that it had become clear that the
machine was inadequate in a number of very important respects.
The Electrostatic memory did not have the reliability required
in data-processing applications. The computer was too slow.
It had a 23-microsecond-per-character memory cycle, and took
115 microseconds to read out a standard five-character
instruction. The magnetic-tape system could read forward only
and was completely unbuffered. The computer used slow on-line
card readers and printers. Some of these drawbacks could be
overlooked in view of the early state of development of the
computer art, except for the fact that was quite obvious to
anyone who cared to make the comparison, that the competing
Remington Rand, UNIVAC I, was a superior data-processing system.

One of the most important characteristics that has contrib-
uted to the success of IBM has been its ability as a company
to react very quickly and with a great deal of energy to
crisis created either by its own mistakes or by competitive
pressures. The 702 presented such a crisis. A better machine
was needed to replace it even though the 702 itself was still
far from delivery. A parallel effort was started to develop
a similar but much more capable computer. The 705 was announced and the 702 was withdrawn from the market. In order to meet delivery commitments a number of 702's were completed and delivered, but the computer had been declared obsolete, and deliveries of the 705 started less than a year after the delivery of the first 702. The effort was a major strain on the resources of IBM, which was not yet then the huge immensely wealthy corporation it has since become. The effort was successful, even though there are some who argue that the 705, at least in its earliest delivered form, was still inferior to the UNIVAC I that had been delivered four and a half years earlier.

In the 705 the Cathode-Ray tube memory was replaced by the faster and more reliable magnetic-core memory [22]. Logically it was still a character-oriented machine, but physically the memory was organized into groups of five characters each and access time was 17 microseconds for five-character instructions and for five-character data units.

One of the early 702 customers was Commonwealth Edison Corporation which had investigated the UNIVAC and had great respect for the power of a buffered tape system. Since they would not order a system without this feature, IBM agreed to develop a special external buffering system which eventually led to the Tape Record Coordinator (TRC). This was a tape controller containing 1024 characters of magnetic core storage.
plus associated logical circuitry. The addition of several TRG's to a 705, though very expensive, made it into a quite powerful data processor, especially when, in the model II the amount of internal core storage was significantly increased. The model III introduced in 1958, provided a faster core memory and internal buffering. Backward reading tapes on IBM computers had to await a later computer generation, and as a result sorting speeds on the 705 were always slower than on comparable competitive equipment.

By 1959, the year that marks the start of the second, transistorised computer generation, the 705 was firmly established as the standard of the large-scale data-processing field. Like all of the vacuum tube computers it was very vulnerable to competition from the much less expensive more powerful computers that could then be built.

Scientific Computers

The electrostatic storage system on the IBM 701 was very unreliable compared with the mercury delay-line storage then in use. The mean time between memory failure at 701 installations was often less than 20 minutes. All serious programs had to provide for frequent storage of the contents of the 2048-word main memory on a magnetic drum for use in restart procedures. In spite of its storage problems the 701 was so
much faster than most other computers available at the time that it was reasonably successful. Eighteen 701's were installed in the period from 1953 to 1956.

When magnetic-core storage became available, a 701M computer was planned, but the resulting product was sufficiently different to warrant the use of a new model number, 704.

The 704 provided three index registers and built-in floating-point instructions, and a minimum of 4096 words of magnetic-core storage with 12 microsecond cycle time. Three bits were used to select an index register, and additional bits were needed to address the expanded main memory. The 704 therefore dropped the two-instructions-per-word format of the 701. It kept the 36-bit word with one one-address instruction per word.

The 704, first delivered in 1956, was quite outstanding for its time, and achieved for IBM a near monopoly in the large-scale scientific computer field.

The only competition was provided by Remington Rand's 1103 series, the 1103A in which the electrostatic memory of the 1103 was replaced by magnetic-core memory, and the 1103AF that added floating-point hardware. The 1103 was the first computer to provide a program interrupt feature [23]. This feature was added at the request of a customer, Richard Turner, who was in charge of an 1103 for NACA (now NASA) in Cleveland, Ohio. An interrupt system was later included in the design-of
IBM's 709 computer, and interrupt systems have been used in most computers built since that time. The 1103 series used an efficient two-address instruction format in a 36-bit word. Its magnetic-drum storage was a directly addressable extension of main memory. These computers, collectively known as Univac Scientific Computers were considered by many of their users to be superior to the IBM 700 series, but there were relatively few installations. A record of late delivery and poor support contributed to the poor sales record of the 1103 series.

The early scientific computers were designed in accordance with a philosophy that assumed that scientific computing was characterized by little or no input or output. The 701, and early installations of the 704 used an on-line card reader (150 cards per minute) for input, and printed output could be obtained only from an on-line printer that could print 150 short lines or 75 full lines per minute.

By the time the 704 was being delivered the need for off-line peripheral equipment was quite apparent and arrangements were made to use card-to-tape and tape-to-printer equipment that had been designed for the 705. There were a number of unfortunate incompatibilities between the 704 and the 705. They had been designed by different divisions of IBM. Character codes were different, and the 704 used odd parity checking while that on the 705 was even. The 705 peripheral equipment would not (until much later) handle binary cards. The
off-line equipment was widely used in spite of these inconveniences. Really adequate off-line peripheral conversion equipment became available much later, in the 1960's, with the introduction of the 1401 and other small peripheral computers by IBM and other manufacturers.

In the 701 and 704 there was no buffering provided for tapes or drums or on-line input-output devices. All information going to and from main memory passed through the MQ register in the arithmetic unit. An increasing understanding of the data-handling needs of scientific computing, and the realization that large binary computers could be used for data-processing applications caused IBM and others to reassess the input-output needs of such computers. At IBM this led to the development of the 709. The 709 used the same 12-microsecond core memory as the 704, and was only slightly faster. It had all of the instructions of the 704 and some useful new features such as indirect addressing. The major difference, and the really important advance over the 704 was a new input-output system that permitted reading from tape or cards, writing to tape or printer, and computation to proceed simultaneously. This was done by time-sharing the core memory between the central computer and up to six data channels. Variations of this approach to internal buffering have become standard on most computers, even quite small computers, in recent years.
The 709 had a very brief career. The first 709 was delivered in 1958, and by that time transistors suitable for economical use in high-speed computers had been developed, and the vacuum-tube 709 computer was obsolete. It gave way quite soon to a much more powerful successor, the 7090 which will be discussed in a later section.

A buffered version of the UNIVAC Scientific Computer, the 1105 was introduced slightly later than the 709. The 1105 replaced the UNIVAC I at the Census Bureau for use in connection with the 1960 census. It too was one of the vacuum-tube computers whose career was cut short by the newer, more powerful transistorized computers.

Raytheon and Honeywell

Raytheon Corporation was very active in the earliest days of electronic computers. In 1948 they had under development a very large mercury-delay-line computer [251] which they had reason to believe would make them the leading supplier of computers to the United States government. The first Raytheon computer, then called the Hurricane, was scheduled for a West coast Naval station as part of a defense network that would eventually have a number of the large computers. The Bureau of Standards ordered two of the Raytheon computers, one for its Washington headquarters, and one for its Institute.
for Numerical Analysis in Los Angeles. The Raydac, as the computer was eventually called, incorporated a number of advanced features in arithmetic checking and built-in binary-to-decimal and decimal-to-binary conversion. Production proceeded quite slowly, and the Bureau of Standards changed its plans and built its own interim computers, the SEAC and SWAC which were discussed on page 6. By the time the Raydac was completed it was already quite obsolete for the purposes for which it had been intended. The first and only Raydac built was installed at Point Mugu in California and was run as a general purpose computer for several years.

Raytheon had developed a computer design capability, but the Raydac was not a marketable product. In 1954, Minneapolis Honeywell Corporation, interested in getting into the computer field, and Raytheon, which already had some reasons for wanting to get out, jointly set up the Datamatic corporation which became the heir to the Raytheon computer department. Raytheon eventually sold its share of Datamatic corporation to Honeywell, and it became the Datamatic Division and eventually the computer division of Honeywell. The first product offered by Datamatic was the Datamatic 1000 [26], a magnetic core memory data-processing computer designed to compete with the very largest data-processing systems. Built on a grand and expensive scale, the Datamatic 1000 had enough air conditioning
to not only cool the computer but also the room in which it would be installed. Its most interesting feature was its tape system with three-inch-wide magnetic tape. Fixed-length blocks were used, with the interblock gap equal to the block length. When reading in one direction the interblock gap was the recording area that was used when reading in the reverse direction. The three-inch-wide tapes, and the fact that there was no waste space in the interblock gaps combined to permit the storage of very large files of information on relatively few tapes. By the end of 1957 when the first Datamatic 1000 was delivered, IBM had been delivering 705's for two years, and the 1000's were too late and too high priced for the market at that time. Sales were so poor in 1957 and 1958 that the computer was withdrawn from the market, and there were strong rumors circulating that Honeywell was about to leave the computer field. They decided instead that the new generation of transistorized computers would provide them with a new opportunity for a more successful entry into the computer market, with the Honeywell 800 which is discussed below.

**RCA**

RCA, the Radio Corporation of America, has been active in the computer field almost from its very beginning. The RCA research laboratories in Princeton, New Jersey, have been one of the centers of research in computer memory systems since the mid forties. The design of the Institute for Advanced Study computer which was started in 1946 called for the use of RCA
Selectron electrostatic storage tubes which were then under development. The Selectron did not turn out to be quite satisfactory. The IAS computer switched to Williams tubes, and research at RCA turned toward the development of magnetic-core memories.

RCA was probably the first computer manufacturer to build an operational coincident-current magnetic-core memory, the type of memory that has since become standard throughout the computer industry [27]. They felt that this development gave them an important competitive advantage which they set out to exploit in the Bizmac [28], a very large data-processing system designed specifically for business use. The magnetic-core storage was new and expensive, and the Bizmac was therefore designed to use a small magnetic-core memory backed up by a large magnetic drum. Programs were stored on the drum and executed from core. Block transfers of up to thirty-two instructions “surged” from drum to core for execution.

The Bizmac was advertised as the first and only truly variable-word-length computer. Only significant information, and no filler information, had to be stored on magnetic tape.

The Bizmac magnetic tape system design attempted to almost completely eliminate tape mounting and dismounting. A system would have one hundred, two hundred, or more low-cost tape transports, and a reel of tape would more or less permanently occupy its own transport.
In addition to general-purpose computers, a Bizmac system could have one or more sorters, which were special-purpose computers with built-in programming for performing tape sorts. All components of the system were interconnected through a relay switching center. By use of a telephone dialing scheme at the Bizmac control center, tapes could be switched between computers and sorters. The resulting sorted files could then be switched to output devices for printing or punching. No tape handling was involved. Everything was remotely controlled by a pair of mutually checking operators.

A very large Bizmac system was installed at the Ordnance Tank Automotive Command (OTAC) headquarters in Detroit. Several smaller Bizmac systems were built, one of which was installed on a trial basis at Higbe's department store in Cleveland.

The Bizmac ranks with the Raydac and the Datamatic 1000 as one of the very interesting failures that characterized the first generation of large-scale data-processing systems.

Perhaps the most important reasons was the failure of that generation of RCA computer people to recognize the tempo of development in the computer industry. In 1952 and 1953 RCA engineers felt that they were ahead of the rest of the industry. The details of the Bizmac project were carefully guarded company secrets. By 1956 when the first Bizmac was delivered and put into operation it was already very obsolete.
As soon as large magnetic-core memories became available on large-scale computers, a computer based on a small core memory backed up by a drum was competitive only with other drum computers.

Several computing systems other than the Bizmac made use of special-purpose electronic sorters. In almost every case users came to the conclusion that sorting could be handled better on a general-purpose computer. In areas like sorting, special-purpose equipment is almost always too limited. The actual applications require far more logical ability than is built into a special-purpose device.

The idea of switching many low-cost tape transports seems to have been poorly conceived. The trend has been toward faster and more sophisticated, and therefore more expensive tape units on large computers.

The concept of a computing system based on an automatic switching center through which large numbers of peripheral devices can be switched to a number of computing elements is sufficiently attractive that other attempts have been and will be made to produce a practical realization.

One such attempt, also completely unsuccessful, was made in 1958-1961, by Ramo-Wooldridge in connection with their 400 system [29] that was designed around a large electronic switching system.

It is possible to see analogies to many Bizmac features in a number of the most recent computing systems.
Magnetic-Drum Computers

Magnetic drums and discs were among the earliest devices considered for use in digital computer storage systems. Eckert [307] refers to a thesis written by Crawford at MIT in 1942 and states that "Out of this thesis grew the magnetic-drum and magnetic-disc memory system." He further states that "In 1944 the author (Eckert) submitted to the Moore School of Electrical Engineering at the University of Pennsylvania a memorandum which recommended the use of drums or discs for the general storage of all data required by a computer--not only the numbers being processed, but also instructions .... This memorandum became the basis for the design of the EDVAC memory. The EDVAC design was subsequently switched from magnetic discs and drums to mercury tanks, ..."

By 1948 or 1949 practical magnetic-drum storage systems had been developed at Manchester University, at Harvard, and by ERA (Engineering Research Associates) in St. Paul, Minnesota.

Magnetic drum storage provided relatively slow random access, and even the earliest magnetic drum computers made use of devices such as recirculating tracks and minimum-access-time coding to improve performance.

At Harvard University in 1949-1950 the MARK III computer [30A] was built for the Naval Proving Ground at Dahlgren. Around the same time ERA designed its 1101 computer [317]. Both of these were relatively large computers. They were not very successful mainly because the magnetic drum was too slow to be the main memory of a large-scale computer.
Magnetic drums could provide large amounts of medium speed storage, 5-25 milisecond access time, at a very low price per bit compared with mercury-delay-line or electrostatic or magnetic-core storage. Using the magnetic drum as the main memory, it was possible to build relatively low-priced computers. While these computers could not compare in speed and capacity with the very large, very expensive computers that were being built, they provided computational and data processing capabilities that were not otherwise attainable to those who could not justify or afford the large systems.

Many companies entered the computer field between 1950 and 1953 with new magnetic-drum computers. It was almost too easy to design and build a prototype computer. It was not quite as easy to develop a production facility, a marketable product, and adequate support.

On the west coast a new company, Computer Research Corporation, built a very compact binary computer, the CADAC [33]. The CADAC, and the later production model, the CRC 102A relied on minimum-access-time coding to make up for its 12.5 millisecond average access time. Computer Research Corporation was merged into National Cash Register Corporation (NCR), which marketed the 102A and introduced an expanded decimal version, the 102D. Along with the 102D they introduced a magnetic tape unit that did not use tape reels, but allowed tape to fall freely into the bottom of the unit. Performance was marginal, and only a few 102D systems were installed before the system was withdrawn from the market.
On the East Coast Dr. Samuel Lubkin started the Electronic Computer Corporation. Dr. Lubkin had worked with the computer group at the University of Pennsylvania, and his company included a number of engineers who had helped develop UNIVAC. By making a very low bid, the newly formed company obtained a contract to design and build a small computer, the Elecom 100 [34], for the Ballistic Research Laboratory at Aberdeen. Electronic Computer Corporation was absorbed into the Underwood Corporation, and went on to produce the Elecom 120 and 125. The 125 system included an independent file processor for off-line electronic sorting and other basic data-processing tasks. Underwood ran into equipment difficulties and financial difficulties and eventually withdrew from the computer field in 1957.

Consolidated Engineering Corporation of Pasadena, California set up a computer division that designed and built the CDC-201 computer [35]. This was a slightly larger, more powerful computer than the CADAC or Elecom systems, and, possibly for this reason, it was more successful. A "high speed" recirculating-loop memory stored 80 words with an average random-access time of .85 msec, one tenth the 8.5 msec average random access time to the 4000-word main-drum memory. A 20 word block transfer could move a segment of program or data into high-speed memory in one drum revolution time (17 msec).

The computer division of Consolidated Engineering was spun off as the ElectroData Corporation and the computer was called the Datatron. Deliveries started in 1953. One of the early
customers, Socony Mobil Oil Company, insisted on punched-card input-output, and a card converter was designed to permit the use of a relatively fast card collator as input and an IBM 407 tabulator as output.

A magnetic tape system was developed with a search command that permitted the tape system to be searching for a 20-word block by block number while the computer was engaged in other processing.

The Datatron was the first product-line computer that featured a hardware index register. By properly specifying the sign digits, the index register could also be used as a relocation register during input of programs.

ElectroData Corporation was merged into the Burroughs Corporation in 1956.

The useful life of the Datatron system was extended several years by the introduction of floating-point hardware, by the development of the Cardatron that provided buffering and editing features for card equipment, and the Datafile that provided relatively fast-access bulk storage on strips of magnetic tape [32].

For a time the smaller companies had the medium-scale computer market to themselves, but in 1953 IBM announced its magnetic-drum computer, the 650 [38]. The 650 had a number of advantages over most of its competitors. Its drum rotated at 12,500 rpm, which was considerably faster than the typical
3600 rpm drums used by most other computers. The 1+1 addressing system was well suited to minimum-access coding. It was designed as a card-handling computer, with buffered card equipment integrated into the system. On the negative side it had a relatively small drum, only 2000 10 digit words of storage. Initially, at least, it was a limited system with cards as its only input and output. Other systems, like the Datatron, offered magnetic tape auxiliary storage and on-line printers and typewriters.

Perhaps the biggest advantage that the 650 had was the position of IBM in the punched-card field that made the 650 seem to be the natural next step in hundreds of business organizations. IBM itself underestimated the importance of this factor. They planned to produce about 50 650's to be sold mostly to scientific users. They produced and sold over 1000.

The 650 was eventually expanded to permit tapes and on-line printers. A disc storage unit, the RAMAC was developed, for use with another small computer, the IBM 305 [37], but also as auxiliary storage for the 650. Late models of the 650 could have a 4000-word drum plus 60 words of core storage, which made the large 650 system a quite powerful, though rather expensive machine. Vacuum-tube successors of the 650 were considered, but they never reached the market, and the eventual IBM successors were the transistorized computers, the 1620 in the area of small scientific computers, the 1400 series in the small data-processing installations, and the 7070 series in the medium-to-large-size computer field.
Remington Rand had two quite separate magnetic-drum machine developments. The Univac File Computer was developed in St. Paul. The early model, model 0, was a plug-board controlled calculator with auxiliary magnetic-drum storage. The later model 1 was a full-scale stored-program computer. Large drums provided fast-access file storage. The system could have an off-line tape sorter and could become quite large. The model 1 equipment was late in delivery and in a higher price class than most other magnetic-drum computers. It was not a very successful product.

Remington Rand management did not feel that the company could support two magnetic-drum computers in the field at the same time. By 1955 the UNIVAC center in Philadelphia had built a very high-performance magnetic-drum computer for the Air Force Cambridge research center [39]. The computer used magnetic amplifiers as active elements and had only 15 vacuum tubes. Commercial versions were designed and were eventually known as the Solid State 80 and 90, the numbers referring to the use of 80-column and 90-column cards respectively. These computers were withheld from the market for several years while Remington Rand was trying to promote the File Computer into a successful product. Under the name UCT they were marketed in Europe before they were released in the United States. The first Solid State computers were delivered in the United States in 1958, when IBM had already installed many hundreds of 650’s. Even so over 500 systems were installed.
The Solid State computers used a 16,500 RPM drum providing 1.7 msec average access time to 4000 words. Recirculating tracks were used to obtain .425 msec average access to an additional 1000 words. The 1+1-address instruction code permitted minimum-access-time coding to further reduce access delay.

The Remington Rand designers had used magnetic amplifiers at a time when they thought that transistors were not yet practical. The Univac III, announced successor to the Univac I and II was also their successor to the Solid State line.

There were many other magnetic-drum computers. The two computers that achieved the greatest success in the very-small computer field were the LGP 30 manufactured by Librascope Corporation, and the Bendix G-15 computer [39] manufactured by the computer division of Bendix Corporation. The LGP 30 was a very basic computer with a very limited instruction code. The G-15 was much more sophisticated, essentially a micro-programmed computer. It became popular only after software developments made it unnecessary for the users to write its programs in machine code.
Burroughs

In 1948 Burroughs set up its research division in Philadelphia with personnel who had participated in most of the major computer projects up to that time. Burroughs built its first magnetic-drum computer, a prototype of the UDEC, in 1950 and seemed on the way to becoming a power in the computer field.

In spite of this auspicious start, by 1956 Burroughs had produced only one product-line computer, the E101, which was on so small a scale that it prompted an English scientist, visiting the Burroughs Research center at Paoli, to comment on a mountain that had labored to produce a'mouse.

Burroughs was hampered very much by its tradition as a producer of key-driven machines in competition with punched-card systems. The E101 was about as far as they could go with manual input. Paper tape might have been adequate for small scientific computers, but it was not adequate for the commercial applications that were of interest to Burroughs. Burroughs' management can hardly be blamed for being hesitant about producing computing systems that would rely on a major competitor, IBM, for all of their input and output.

When Burroughs bought control of a small company by the name of Control Instrument Corporation in 1951, they inherited a project that was on the way to producing a very high-speed tabulating machine that would read—900 cards a minute and
print 900 lines a minute. They continued this development and set up a product line of so-called series G equipment consisting of high-speed card readers and printers. This equipment was offered as peripheral equipment on other computers, like the IBM 705, but after many difficulties it was finally withdrawn.

With the series G equipment as input and output, Burroughs was able to design a large-scale data-processing system, the BEAM IV (Burroughs Electronic Accounting Machine No. IV). Number I, II, and III had been designed but had never reached the status of products. Before the first BEAM computer was completed, Burroughs decided to purchase Electrodata corporation which had had some success in marketing its magnetic-drum systems. The BEAM was a much larger computer, designed to be competitive with the 705 class, but the almost completed BEAM IV was scrapped in favor of a new medium-sized computer the 220 to be designed by the newly acquired Electrodata division.

The 220 was the last of the vacuum-tube computers. The strategy was to come on the market just ahead of the transistorized computers. This strategy met with some success, especially when IBM's rumored vacuum-tube successor to the 650 did not materialize.
3. The Second Generations - Transistorized Computers

Almost from the time it was invented in 1948 [407], the transistor was expected to become the key to revolutionary new advances in computer technology.

A major factor in the step from the EDVAC to the EDVAC and later stored-program computers was the development of computer circuits that permitted the use of large numbers of germanium diodes in combination with relatively few vacuum tubes. A typical computer might have 1000 tubes and 50000 diodes. The tubes were the active elements that determined the speed and capability of the computer, but they were expensive. They consumed large amounts of power and generated large amounts of heat. The transistor would make it possible to replace vacuum tubes by semiconductor devices similar to the diodes. They would be small and would produce very little heat. This would make it possible to think in terms of computers with active components in numbers orders of magnitude greater than in the largest vacuum-tube computers. As an example the Stretch computer, a relatively early though very large transistorized computer, used over 150,000 transistors. The more recent 6600 contains over 500,000 transistors, and it is reasonable to expect that computers with over 1,000,000 transistors will be built in the next few years.

With almost any new component there is a period of what appears to be stagnation; a period in which the component seems to be available, and yet it is hardly being used. This may be
a period of engineering development. It may be the period
during which problems of production in economic quantities
are being solved. Many promising ideas and components never
emerge from this period, as practical considerations keep
delaying their use. For a while it looked as if the transis-
tor might be delayed for a very long time because of consider-
ations of this kind. Reliable switching speeds were relatively
slow. It was difficult to produce transistors with uniform
characteristics, and circuits had to be designed with excessive
latitude, or had to require careful selection of transistors
to insure that a replacement transistor would perform in the
same way as the one it was replacing. Bell Telephone Labora-
tories and others built experimental transistorized computers.
IBM announced the 608, a transistorized calculating punch, but
it was high-priced and offered no advantage over existing vacuum-
tube machines. The earliest transistorized computers offered
commercially were medium-speed business-oriented systems in
which very high switching speeds were not considered essential.

A breakthrough in the use of transistors for very high-
speed computing appeared from a quite unexpected source with
the 1954 development of the surface-barrier transistor by
Philco Corporation. This was the transistor used in the
Lincoln Laboratories TX-O "41" computer and in several other
of the early high-speed transistorized computers. It was the
first of a series of transistor developments that produced
transistors suitable for the highest-speed computer requirements.
There was no longer much doubt that it was practical to achieve and exceed the performance of vacuum-tube circuits with all of the advantages of the small-low power solid-state components. Within four years of the development of the surface-barrier transistor the vacuum tube was obsolete as a computer component.

**Business-oriented computers**

As mentioned above, the earliest transistorized computers were medium-speed business-oriented systems. National Cash Register was one of the first major companies to withdraw from the vacuum tube computer market with the announced intention of returning with a transistorized model. Their 304 [42] was a joint effort, designed by NCR and built by General Electric. It was the first all-transistorized computer in its class, but it was quite slow and of very limited capacity, and very few were sold.

RCA also tried to reestablish itself in the computer field with its transistorized 501 computer [43]. This too was quite slow, and much of the success it achieved was due to one of the very earliest COBOL compilers. The COBOL compiler was also very slow, but for many users a slow COBOL was better than no COBOL.

IBM's announced successor to the 650 and the 705 was the 7070 [44], a little bit later, but more powerful than the competitive machines mentioned above. The 705 series was
supposed to die with the 705 model 3, and customers were expected to convert willingly to the word-oriented 7070. Some of the customers, with huge investments in 705 programs, were not at all willing to convert, and IBM was forced, against its own technical judgment, to produce the 7080, a transistorized extension of the 705, a large clumsy uneconomical expensive machine, but the fact that it could run 705 programs assured it of success.

The Honeywell 800 '45', created quite a stir when it was announced. It was priced in the medium price range, but the performance it promised was beyond that of other computers in its price class. I remember the comment of a Philco executive to the effect that “We sell them their transistors and we know that they can't make a profit on that machine at that price”. I am told that the IBM reaction was similar. The 800 had a very interesting hardware-assisted multi-programming system '46' with 8 sets of sequencing and control registers time-sharing the arithmetic and control circuitry. They also engaged in what was for that time an unusually extensive software effort. Their FACT business compiler, although not completely successful, did help to sell a fair number of 800 systems.

Burroughs came out a bit later than the others with its very interesting B 5000 '47' computer. The 5000 was very strongly influenced by the Algol effort. It contains hardware which make its arithmetic registers behave as if they
were at the top of a push-down stack. The hardware also assists in the implementation of Algol features like recursive subroutine calls and dynamic storage allocation at run time.

The 5000 was late in delivery and disappointingly slow when delivered in 1961. A more recent and faster version, the 5500 is now being delivered and has a number of enthusiastic supporters.

The development of transistors along with the development of relatively low-cost magnetic-core memories made it possible to build relatively small computers that were quite powerful compared with even the large vacuum-tube computers. The IBM 1400 series and 1600 series came along in 1960 and proved that some models of computers could be marketed by the thousand. Other manufacturers found, often to their surprise, that there was a huge market for small computers. Many hundreds of RCA 301's and CDC 160's were sold. There were also the Burroughs 200 series, the Honeywell 400 series, the GE 200 series, the NCR 300 series and others.

**Philco Corporation**

The development of the surface-barrier transistor projected Philco into the computer industry. Under contract with a government security agency they built a small high-speed transistorized computer patterned after the Univac 1103 series, and under contract with the Navy they designed a larger computer called the CXPQ. The first of these was the Transac S-1000.
The CXPQ was a partial prototype of the Transac 3-2000. Philco executives felt that they were a year or more ahead of most companies in the developments of big transistorized computers, and by the end of 1957 they had decided to launch a major production and marketing effort based on the large-scale Transac 3-2000 [48], later known as the Philco 2000. The 2000 is a high-speed binary computer which is in many ways a modern successor to the old Institute for Advanced Study computer. Among other features, the 2000 provided a tape system with automatic switching of all tapes to all channels that was not available in competitive systems. The 2000 was expected to prove very attractive as a replacement for the IBM 704, and for the 709 systems that IBM had just started to deliver. Several of the early orders were for such replacement at United Aircraft corporation, and at the GE-KAPL and Westinghouse-Bettis AEC-Naval Reactor Board installations.

Although Philco had a head start, its momentum was slow. By standards of the computer industry the Philco computer effort was small and poorly financed, and Philco was not ready to undertake the expansion that would have been necessary for a large penetration of the computer market. Before the first complete 2000 system had been delivered in January of 1960, the IBM 7090 was in production with a 2.18-microsecond memory as compared with the 10-microsecond memory on the 2000,
and with faster arithmetic speeds. The first complete 2000 delivered was a model 211 which had already changed from the surface-barrier transistor of the original model 210 to the faster MADM transistors. Also, a commitment had been made to replace the memory by a 2-microsecond memory under development. The 2-microsecond memory called for an even faster main frame, and the model 212 of the Philco 2000 series with look-ahead and very fast arithmetic was developed in an effort to bolster Philco's position in the industry. The model 212, delivered early in 1963, may very well have been the most powerful computer then being delivered, comparing favorably with the CDC 3600 and the IBM 7094 Model II. In order to support a system with this kind of computing capacity a more advanced tape system and other peripheral devices were necessary.

By this time the Philco corporation, whose financial condition had been poor for a number of years, was merged into the Ford Motor Company. Although Ford certainly had the necessary resources, they decided against a large investment in the computer industry. There was a final flurry of activity, and the announcement of a new model 213 at the Fall Joint Computer Conference in 1964, but as of this writing the Philco computer effort has for all practical purposes ceased to exist.
Control Data Corporation (CDC)

CDC's story is one of the many Cinderella stories in the computer industry. A group of UNIVAC employees, including some of the original ERA people, broke away and formed Control Data Corporation in 1957. They had worked on the design of military transistorized computers while with UNIVAC and they had a computer designed and ready for marketing, and their first order from the US Naval Postgraduate School in Monterey, in almost no time at all. Their first 1604 was delivered in early 1960. Their computer was a basic 48-bit binary computer, not as powerful as the 7090 or 2000, but very much lower priced. Initially they provided no software support. They sold to Universities at a discount, and were low bidder on a number of government contracts.

The company thrived. Their 3600 (49), which they started to deliver in 1963 was a much faster much improved version of the 1604. It made CDC a major factor in the large-scale computer market. In the past few years they have grown at a tremendous rate, and their products cover almost the whole range from very small computers and peripheral devices to the super-computers in the 6000 series.
IBM's 7090 Series

Early in 1958 the Ballistic Missile Early Warning System (BMEMS) project requested bids from computer manufacturers to supply a number of very large fast computers for data analysis and general computation. They made it clear that they would not consider vacuum-tube computers, since several manufacturers had already announced transistorized computers that would be able to handle the job. As is the case in many such procurements, the time allowed for delivery was quite short, and penalties for late delivery would be high. IBM seemed to be out of the running since their large transistorized computer, the Stretch, was far too expensive and delivery was still several years away. IBM won the contract by offering to deliver the 709, a vacuum-tube computer, almost immediately to permit design and checkout of programs. They then undertook to deliver, in little over a year, a completely transistorized, logically compatible computer, the 709TX. The 709 was a synchronous computer in which the time for each instruction was defined as an integral number of memory cycles. The 709TX was to be five times as fast as the 709. Each instruction would take the same number of memory cycles, but each memory cycle would be only 2.4 microseconds compared with 12 on the 709. A two-microsecond memory was under development for the Stretch project, and the Stretch word of 64 information bits and 8 check bits was conveniently adapted to handle pairs of 36-bit 709TX words.
For a short time IBM held back from offering the TX computer to other customers. They had only recently started delivering the 709 system. It was reasonable to expect that the new system would completely eliminate 709 sales, since it was logically compatible, very much more powerful, and not very much more expensive. IBM had to admit that the 709 had been very poorly timed and would have to be written off. Transistorized computers like the Transac S-2000 and the CDC 1604 would have made the 709 obsolete very soon anyway, although perhaps not quite as completely and dramatically as their own 709 TX did. The new computer, now called the 7090, was officially introduced and met with tremendous acceptance. Before the first delivery was made the speed was increased by cutting the memory cycle to 2.18 microseconds, and by decreasing the number of memory cycles needed for multiplication and several other instructions.

The first two 7090's were delivered to BNRNS right on schedule in November of 1959. IBM had not quite finished the impossible task of getting the computers designed and built that fast, but they were close, and engineers in numbers variously estimated as between 20 and 200 went along to Greenland with the computers to finish them and get them to work. Commercial delivery of 7090's started soon after, and there was much grumbling in SHARE about how poorly the computers were performing. Competitors were temporarily heartened by rumors that IBM had overreached itself and could not get
the 7090 to run reliably, but the situation turned out to be quite temporary. Bugs were removed and necessary engineering changes were made. An air-cooled memory was designed in place of the earlier oil-cooled memory system. The 7090 became an extremely reliable computer and a tremendously successful one. Hundreds of 7090's systems were sold. A typical 7090 system was valued at over $3,000,000 at delivery.

Most 7090's were eventually converted into the slightly faster 7094 which has built-in double-precision operations and 4 additional index registers. The 7094 model 2 provided even faster arithmetic and a faster, interleaved memory.

In 1962-1963 IBM introduced the very popular 7040 and 7044 computers. These were very similar to the 7090 series, but provided somewhat less in performance at a considerably lower price.

A combination of a 7094 with a 7040 or 7044, with a special memory-to-memory channel, was marketed as the Direct-Coupled System. The smaller computer acted as an input-output processor and supervisor. The 7094's work was limited to the actual execution of jobs staged and buffered through the 7040.

We mention very briefly two other IBM computer efforts in the second generation. The IBM Military Computer was a very large computer designed and built in 1958-1962 for the Strategic Air Command's command and control applications. During the first generation IBM had supplied many computers,
similar in many ways to the 704 and 705, for use by the SAGE air-defense system. They hoped that the powerful transistorized Military Computers (rechristened the AMFSQ-32) would be used as replacements. They were not so used and only a few were built. One of these was installed at the headquarters of System Development Corporation in Santa Monica and years later became quite well-known as the Q-32, the computer on which SDC's large time-sharing system was developed.

In 1960-1961 there were rumors of a completely new large-scale series of computers, the IBM 8000 series. At least one prototype was built but IBM decided, in the spring of 1961, to abandon the 8000 series in favor of a new system design project that would use a new microcomponent technology. The resulting system/360 belongs to the "third generation" and is discussed in section 5.

UNIVAC

In the business data-processing area UNIVAC introduced the UNIVAC III in the early 1960's. This was a quite sophisticated computer which required elaborate software support. It never became very popular, probably because it was too expensive for the middle-priced field in which it was designed to compete.

The N460 [50], a military computer built by UNIVAC in St. Paul was one of the earliest large-scale transistorized
computers. It was Control Data rather than UNIVAC that produced the successful commercial computers that continued that line of development.

UNIVAC's own transistorized successor to the 1103 series was the 1107, introduced much later than competitive scientific computers. The first delivery was made at the end of 1962. The 1107 was advertised as the UNIVAC thin-film computer, since it used 128 registers of magnetic thin-film storage as an addressable control memory along with more conventional magnetic-core and magnetic-drum memory.

The 1107 appeared on the market too late to be a major factor among second-generation scientific computers. Its major importance was to serve as a model for the very successful third-generation 1108, a compatible successor to the 1107 which can use 1107 software and can run 1107 programs. This coupled with IBM's failure to produce an adequate compatible successor to the 7090 series gave UNIVAC the opportunity, finally in 1967-1968, to become a leader in the large-scale scientific computer field.
4. The Super-Computers

At almost any given time in the recent history of computer development there has existed within the computer industry the capability to design computers that would be orders of magnitude more powerful than those being delivered commercially. The industry has always been ready to design and build such computers for anyone who was willing to put up the money for what might prove to be an uneconomic venture.

An early venture of this type was the NORC [51], (Naval Ordnance Research Calculator), built by IBM for the U.S. Naval Weapons Laboratory at Dahlgren. The NORC was started in 1951, and was accepted at Dahlgren in June of 1955. It was rated by its designers as able to perform 15000 three-address operations per second. Floating-point addition takes 15 microseconds, and multiplication takes 31 microseconds. These times are especially impressive in view of the fact that the NORC is a binary-coded decimal computer with a 16-digit word consisting of a sign digit, two exponent digits, and 13 fraction digits. The high-speed multiplication was achieved by the brute force approach of providing nine registers to store the product of the multiplicand by each of the nine non-zero decimal digits. The original main memory of the computer was a 2000 word Williams-Tube storage system. In March of 1960 the Electrostatic Storage was replaced by a magnetic-core memory, and as of this writing the computer is still in use at Dahlgren.
The NORC was strictly a one-of-a-kind development. By the time the NORC was nearing completion industrial use of computers had grown to the point where a number of companies, mainly in the aircraft industry, would be willing to pay the necessary price for the fastest computer available. With the 704 development already under way, IBM refused to be pushed into building additional NORC's. It was probably a wise decision.

By 1956 it was already apparent that transistors could be used in very large numbers and at very high speed to produce computers whose performance would dwarf that of the largest vacuum-tube computers ever built. Several manufacturers were already developing relatively small transistorised computers for the commercial market. The computer industry was investing some of its own money in preliminary research toward the development of the big transistorized computers, but the real venture capital in this area came from the United States Government through the Livermore and Los Alamos research laboratories of the Atomic Energy Commission (AEC). Livermore entered into a contract with Remington Rand UNIVAC for the development of the LARC (Livermore Atomic Research Computer). Los Alamos contracted with IBM for a computer, originally called Stretch, which later, when IBM thought they could sell it commercially, was given the number 7030.
In December of 1956, at the Eastern Joint Computer Conference in New York, in two papers delivered at the same session, brief summaries of the design objectives of LARC and Stretch were presented by J. P. Eckert of UNIVAC and by S. W. Dunwell of IBM [52, 53]. Both were talking in terms of speeds 100 times greater than those of the 1103A's and 704's that their companies had recently started to deliver. Three years later, in a similar session at the 1959 Eastern Joint Computer Conference in Boston, papers by Eckert and Bloch and others presented many of the details of what had been achieved in building the LARC and the Stretch [54, 55, 56].

The timing of the projects and the simultaneous reports at computer conferences give the impression of a design competition between the two giants of the large-scale computer field. To some extent this is misleading, since the ground rules of the two projects were quite different. Eckert in connection with the LARC stated in 1956 that "The system was balanced at a time when all components were in hand, so that the design balance would not be upset by component changes during the design period". At the same time, in connection with Stretch, Dunwell stated that "... we are endeavoring to employ the most advanced techniques and components possible with today's technology. Many of these techniques are still in the research phase of their development."
In line with their stated philosophy the LARC designers used the surface-barrier transistor, a component of proved reliability, and they designed around a four-microsecond cycle magnetic core memory that they had developed. This memory was about three times as fast as the memories then in general use. The Stretch project was planning to use the very much faster drift transistors, and a two-microsecond memory. Both of these components had been successfully demonstrated, but only in small quantities under laboratory conditions. Both eventually proved to be very successful and contributed to the greater speed of Stretch. Any comparison between the two computers should take into account the fact that Stretch was a year or more later than LARC, both in design and delivery. They were both very impressive developments.

An unusual feature of the LARC was the fact that it was basically a binary-coded decimal floating-point computer. This had also been true of the NORC, but almost all other computers designed for large-scale scientific computing have used floating-point binary arithmetic.

The LARC design provided for an input-output processor and one or two computing units all operating in parallel and all communicating with the high-speed core memory. The input-output processor is itself a stored-program computer with its own instruction storage. The use of a programmed computer to handle the details of controlling input and output devices
provided great flexibility in this area. This quite advanced
approach had the unfortunate side effect that the performance
of just about every program run on the machine could be
adversely affected by any inefficiencies in the processor
programs. The LARC designers placed perhaps too much faith
in the ability of the system programmers to produce optimum
performance in a very complicated hardware system.

The first LARC was installed at Livermore early in 1960,
and another one was built and installed at the David Taylor
Model Basin near Washington. The intention was to produce
and market the LARC as a commercial product, but only a few
orders were forthcoming and no more LARCS were built.

The first Stretch was delivered to Los Alamos in 1961.
The original design called for a separate character-oriented
processor and a separate binary arithmetic processor, but
these were combined in the delivered machine. The original
design called for a 1/2-microsecond memory in 2048 word
modules, but this was dropped from the final design. One of
the most interesting and complicated features of the computer
is the look-ahead unit that picks up and decodes and calculates
effective addresses and fetches operands for several instruc-
tions in advance of the instruction that is currently being
executed. A look-ahead unit working with an interleaved
memory can provide instructions and operands to one or more
processing units at a rate much faster than would be possible
in a strictly sequential system. Its purpose is to make a
very high-speed processor with a relatively low-speed memory
perform as fast as it would with a much faster memory. Some
very ingenious logical design went into handling problems
that arise when an instruction word that has already been
decoded is found to have been modified by an instruction
just ahead of it, or when a conditional branch makes look-
ahead appear ambiguous, or when an interrupt has to be pro-
cessed.

For a number of reasons the Stretch computer, though
remarkably fast, failed to achieve the 100 times 704 speed
that was its advertised design objective. In some application
areas it was disappointingly slow. It was difficult to
implement a good multiprogramming system on the computer,
and, except in a few very large programs, it would be neces-
sary to use multiprogramming to realize the full capacity
of the system. The look-ahead system provided more problems
than had been fully anticipated. The transfer rate of the
disc system had to be cut in half in order to insure the
reliability of the high-speed parallel data transfers.

With orders for about 15 systems in hand, IBM was forced
to announce (in May 1961) that the machine would not perform
up to specifications and that there would therefore be a
corresponding reduction in price to those who had already
placed orders. Since the lower price would not provide any
margin of profit for IBM, the 7030 Stretch computer was with-
drawn from the product line. Some orders were cancelled.
Seven 7030's were completed and installed.
Both LARC and Stretch must be evaluated as failures, since both companies involved hoped to produce a marketable product and failed to do so. Yet both were successful in providing a major stimulus to the computer industry in the years from 1956 to 1959. If there had been no project Stretch, IBM might very well have been two years later in the development of the 7090, the most successful large-scale computer any company has marketed. It was really the 7090 that killed the Stretch computer as a marketable product by providing a computer that cost about one third as much which would, for most users, do considerably more than one third as much work. If competition by Philco and Control Data and others had not forced IBM to produce the 7090, the Stretch would almost certainly have had a longer, more successful career in the computer market.

Even before the first Stretch had been accepted at Los Alamos, work had already begun on the 6600 '57' by the Control Data Corporation. This was another computer effort supported by the Livermore Laboratory of the AEC. The original design specifications called for a computer three times as powerful as Stretch, and the machine that was delivered in 1964 was faster than that. Some of the speed of the 6600 comes from the use of multiple arithmetic and logical units. Ten peripheral processors, which are themselves small computers, are an integral part of the system.
The design philosophy of the machine envisioned an executive control vested in these peripheral processors which can direct and monitor and time-share the very powerful central processor. According to the manufacturer the central processor executes, on the average, over 3 million operations per second. By the end of 1965 most large AEC installations either had a 6600 or had one on order.

For several years after the unsuccessful Stretch venture, IBM seemed, at least to observers on the outside, to have lost interest in the very-large computer market. In answer to a direct question about IBM’s reaction to the 6600, an IBM spokesman at SHARE, who could be assumed to be talking for the company, commented that every company had to get something like that out of its system—and IBM had already done so with Stretch.

Soon after the announcement of the 360 series it became apparent that IBM was ready to try again to establish its position in the super-computer field. Negotiations were under way with Los Alamos for the production of a very fast series 90 in the 360 line.

Control Data then announced its 6800 machine, logically identical to the 6600 but four times as fast and no more expensive than the 6600.

IBM countered with the announcement of a model 91, a model 92 and a model 95 in rapid succession.
William Norris, president of Control Data Corporation, in the 1965 report to stockholders of the corporation stated that IBM was "making a highly concentrated effort to hinder our progress by making frequent announcements of changing characteristics and new models, at reduced prices of large computers reported to be under development. Their frequent announcements of a number of new models of large computers, some of which have only remained in the product line for a few weeks or months, has created confusion in the market place."

IBM finally settled on a single product-line model, the 91. This system revived the look-ahead feature of the Stretch. The model 91 has a 60 nanosecond basic cycle, and uses a memory rated at 750 nanosecond cycle time, though its effective speed is less because of its very large size. The design goal was to execute instructions at the rate of approximately one per 60 nanosecond cycle. Memory interleaving, look-ahead, adequate buffers, multiple arithmetic and logical units, very fast arithmetic, are all used in the design to attempt to achieve the stipulated processing speed. The term "pipe-line" system has been used to describe their approach, since a number of instructions are simultaneously in different phases of their execution as they flow through an instruction-execution pipe-line.
Even though the system should be able to operate at almost full processor speed with the 750 nanosecond memory, it is possible to insure that performance by using a very much faster thin-film memory. The model 95 is the same computer as the 91 except for the presence of 1,000,000 bytes of thin-film memory with a 120 nanosecond cycle time. The effective speed is closer to 200 nanoseconds because of the physical dimensions of this large memory.

In a move reminiscent of the end of the Stretch project, IBM in 1967 announced that they would take no more orders for the series 90 computers, and would deliver only the 20 systems for which they had already accepted orders. In 1968 they announced a new very large system, the model 85, logically much simpler but in some areas almost as powerful as the 91. The 85 uses automatic block transfers into a small (16K-32K bytes) integrated circuit memory. It has been suggested that the model 91 was withdrawn because of the advanced state of development of the 85 which provides better price-performance characteristics.

Control Data Corporation withdrew its 6800 computer from the market and announced a new more powerful 7600 system. They have also been marketing, with some success, a 64,000 series very much like the 6600 except that much of the parallelism has been removed and the price is therefore much lower.

In 1968 CDC is starting to deliver its extended core storage (ECS), a large magnetic-core peripheral memory designed for block transfers to main memory at a rate of 10,000,000 60-bit words per second. This ECS is offered as an optional
peripheral device on the 6000 series, but at least 500,000 words will be required on the 7600. A swapping memory of this size and speed can change the nature of processing on the computers to which it is attached.

In quite another area, for a number of years Dr. Daniel Slotnick, while working for Westinghouse, tried to get support for the construction of a highly parallel machine, SOLOMON [59] which would use a large array (the number 1624 was mentioned) of arithmetic units joined together in a square matrix. The Atomic Energy Commission suggested that perhaps it was time for some other agency to pioneer in the super-computer field, but no other support was forthcoming.

Dr. Slotnick moved to the University of Illinois, and in this new environment he was able to obtain support from ARPA to design and build a SOLOMON-like computer, now appropriately named ILLIAC IV [60]. The actual construction of the computer is being done under contract by Burroughs Corporation in Paoli. The ILLIAC IV will have 256 processing elements. Each processing element will have its own thin-film memory of 2000 64-bit words, and its own high-speed adders for full 64-bit floating point operations. The designers predict that the ILLIAC IV will be fantastically fast in certain areas of computation; hundreds of times as fast as the 6600 and thousands of times as fast as the 7094 in specific applications.

*The Advanced Research Projects Agency of the Department of Defense.*
The approach used in the ILLIAC IV has been the subject of a good deal of controversy among computer designers. In an angry session at the 1967 Spring Joint Computer Conference, Dr. Slotnick presented the case for the parallel computer, and Dr. Gene Amdahl of IBM pointed out what he considers to be the weakness of the parallel processor approach. Dr. Amdahl could not discuss IBM's new Advanced Computer System (ACS) that he and others at IBM are designing in Sunnyvale, California. Apparently it will be a single-processor machine, and according to fairly reliable rumors performance goals are in the order of 100 to 200 million operations per second.

5. The Third Generation

Vacuum-tube computers were the first generation, and all of the early transistorized computers are said to belong to the second generation. The distinction between the second generation and the third is not nearly as clean-cut. New computers, and most computers that remained on the market after 1965, are called third-generation computers by their manufacturers. Some contend that they are already in the fourth generation.

The major new technological development has been in the area of integrated circuits. Those manufacturers that have based their new product line on monolithic integrated circuits claim that the use of such circuits is the true distinguishing characteristic of third-generation equipment. Those who still
use discrete components insist that it is the performance of
the system and not the nature of the components that
characterizes a computer as belonging to the third generation.

The IBM System/360

IBM started the design of its system/360 in 1961.\(^1\) A major aim was to standardize within IBM such computer
characteristics as instruction codes, character codes, units
of information, modes of arithmetic, etc. Theoretically at
least the same programs would run, perhaps slowly, on the
small inexpensive 360, and would run much more rapidly on
the larger more expensive models. This compatibility was
achieved by the technique of microprogramming in read-only
memory. The physical and logical organizations of the hardware
on the microprogram level were quite different from one model
to another. In a sense, all of the smaller models were designed
to simulate the largest, conventionally wired model.

On April 7, 1964, IBM officially announced six new computers,
the original models 30, 40, 50, 60, 62 and 70 of system/360.\(^2\) These computers, along with other members of the same family
that would be announced later were intended to replace all
existing IBM computer series. They offered greater power
at lower prices than the earlier systems. There was no attempt
to be directly compatible with any previous series. IBM
introduced the word "emulator" to describe a simulation tech-
nique using routines on the microprogram level. These emulators
would permit 1400 series programs to run on the model 30, and 7000 series program to run on the largest microprogrammed models. Though very efficient compared with software simulators, the emulators represented an inefficient use of the 360 computers, and most applications would have to be reprogrammed for the new equipment.

The 360 is both word-oriented and character (or byte)-oriented. All 8-bit bytes are directly addressable. Word operations use 32-bit words, and in some cases 64-bit double words. It is a binary computer, but decimal arithmetic is provided, which operates on strings of four-bit decimal digits. The system supports a large variety of input-output and peripheral storage devices by way of a "standard I/O interface". There already exists a very extensive literature describing the 360 '64' and its hardware and software features.

Initially only the smaller models, up to the model 50 could have "multiplexor channels" which are necessary to drive card readers and printers and communication equipment. The larger models would need one or more smaller computers attached to handle input and output. This was soon changed, and multiplexor channels were made available on all models so that the large models as well as the smaller ones can operate in single-processor as well as in multiprocessor configurations.

For the 360 systems IBM developed a new technology which they called Solid Logic Technology (SLT). They still used
discrete transistors, but very small ones. Their circuits are hybrid rather than monolithic integrated circuits. Even though the hybrid circuits have some superior characteristics, it would seem to this observer that IBM underestimated the speed with which monolithic integrated circuit technology would develop when they decided to proceed in a different direction.

It soon became apparent that the 360 line did not serve all classes of users. At the low end an incompatible model 20 was introduced. For the medium-priced scientific market a model 44 was designed that stressed calculating speed for scientific and real-time applications, using a subset of the 360 instruction code. At the high end of the line a number of changes were made resulting in the model 65 and 75 (replacing the 60, 62, 70) and the 67, 85 and 91 which are discussed elsewhere.

The 360 represented a major reorientation on the part of IBM and has had tremendous impact on the computer industry. Thousands of 360's have been delivered and many thousands are on order. Many features of the 360 have been accepted as standards by other manufacturers.

RCA Spectra 70

Not very long after the introduction of the 360, RCA announced its Spectra 70 series (651), a series of computers almost completely compatible with the IBM 360. RCA was saying,
in effect, that the standardization that IBM felt would be so valuable within their company might be equally useful if it were adopted by the computer industry, or at least by part of the industry.

The RCA Spectra 70 used model numbers 35, 45, 55 to indicate performance in between IBM's 30, 40, 50, 60 - presumably at prices that would make their product attractive. These RCA models use monolithic integrated circuits. A large number of the Spectra 70 computers have been sold and installed.

Honeywell

In December of 1963 Honeywell announced its very successful 200 computer. It was essentially an improved and very much faster and more powerful version of IBM's 1401 computer. Since IBM was not going to provide a compatible successor to the 1400 series, Honeywell undertook to provide the successor. They reasoned, apparently correctly, that many customers would prefer not to reprogram, and that greater economy could be achieved by compatible hardware than by emulation. A "Liberator" software package was designed to handle those areas in which some incompatibilities existed between the 1401 and the 200.

The 200 has been very successful, and has been developed into a line of computers, from a quite small 100 to a very large 1200. Honeywell has become second only to IBM in the business data-processing computer field.
General Electric

The General Electric 600 Series looks in many ways like a successor to the IBM 7090 series, but it was not intended to be program compatible and has not been very successful as a replacement for the earlier machines. GE has been very active in the area of time sharing and several of its efforts in that area will be discussed in Section 5.

Other third-general systems

All of the major manufacturers of computers are now offering third-generation computer systems. Burroughs is marketing a full line of computers up to the very large 6500, 7500 and 8500. Partly as a result of their own improved peripheral equipment, and partly as a result of greatly increased interest in multiprogramming systems, there has been an upsurge in orders for their 5500 system.

We have already mentioned the very successful UNIVAC 1108. UNIVAC is also marketing a new 9000 series with considerable success.

Control Data Corporation has become a dominant factor in the area of very large computers. They are also marketing a number of new computers in their medium-price 3000 series.

National Cash Register stayed with their 300 series for quite a long time, but in 1968 they have announced a very promising new line, the NCR Century Systems.

A number of smaller companies in the computer field have introduced very interesting and very successful third generation
systems. Among these are the Digital Equipment Corporation PDP series and the Scientific Data Systems' Sigma series. There are many others.
6. Time-Sharing

Manchester University and MIT, which had both made very significant contributions to the early development of computers, were the chief sources of some of the most interesting recent developments.

By 1959, the computer designers at Manchester, in cooperation with Ferranti Ltd., completed the design of the Atlas System. The Atlas uses some ingenious, and incidentally expensive, hardware in an attempt to solve the related problems of overlay and hierarchic storage organization, and the allocation of main memory in a multi-programming environment.

The Atlas approach, the single-level storage system \[67\], permits each programmer to write his program as if he has all of a very large core memory available to himself.

Memory in the Atlas is organized into pages of 512 words each, and the programmer can use up to 2048 logical pages even though the actual core memory of the computer might have as few as 32 physical pages. The same logical page may be in and out of core memory a number of times during the execution of a program and it may thus occupy different physical pages, even during a single run of the program. During execution of a program one or more of its logical pages are in main memory where any logical page may be stored in any physical page. The rest of the program is in fast auxiliary storage. The computer contains rather elaborate address-translation hardware so that an address that refers to a location in any logical page is automatically interpreted as referring to the physical page in which that logical page currently resides. If the logical page is not physically present
it will be fetched into core memory from the drum. Normally there will be some pages of several different programs in core memory, so that the time required to fetch a page needed by one program will be used as execution time by another program.

An interrupt and memory-protect system are also included in the Atlas hardware as are other features to assist the very elaborate executive programs required to keep the necessary records and to keep such a system running at a reasonable level of efficiency.

The Atlas paging scheme is extremely attractive in a computer environment in which large numbers of users are served simultaneously, and in which the reallocation of main memory goes on at a very great rate. At MIT for a number of years the chief subject of interest to the computer group has been the time-sharing of large central computer facilities by large numbers of on-line users. With massive financing by government research agencies, MIT's project MAC had built such a system using IBM 7094 equipment (681). The 7094 performs very poorly in that environment, and in 1963-4 they were looking forward to a new generation of computers in which the hardware might assist rather than hinder the time-sharing executive systems that they wished to design.

MIT had worked very closely with IBM for a number of years, and most observers assumed that the new equipment for project MAC would be IBM equipment, even after the announcement of IBM's system 360 which indicated little or no hardware assistance to multi-console time-sharing systems.

IBM apparently adopted the attitude that the project MAC requirements were for a one-of-a-kind system which they were prepared
to supply when the MIT group would come through with a reasonable set of specifications.

At this point the General Electric computer department which had entered the large-scale computer market with their 635 computer, proposed a number of modifications that would convert the 635 into a new computer, (the 636, later known as the 645), specifically designed for a large time-shared multi-console system as planned by project MAC [697]. One feature would be modularity which would permit multiple processors to communicate with multiple memory modules and peripheral controllers. Another feature was an adaptation and extension of the Atlas paging scheme, in which there is another level of organization, the segment, and a more complicated hardware-assisted address-translation algorithm.

In the middle of 1964 Project MAC ordered a dual processor 645 system from General Electric, and shortly after that the Bell Telephone laboratories announced that they were going to order 4 such systems (later reduced to 3). It was clear that a time-sharing bandwagon was forming and there was going to be a great rush to get on the General Electric delivery list.

IBM reacted almost violently to the situation. Clearly they had made a mistake. This was not a one-of-a-kind or even a small market. Their technical staff had evaluated hardware address-translating systems and had decided that the logical elegance that was gained would cost too much in extra hardware, in very complicated software, and in degradation of performance.
The correctness or incorrectness of the technical judgment was irrelevant. In a sales-oriented company technical judgment cannot be allowed to interfere with sales judgment. By order from the top IBM was fully converted to the principle of maximum support of large time-sharing systems. The IBM sales organization was told to spare no expense to avoid losing any more orders in the large-scale time-sharing field.

It was not too difficult to add paging hardware to the largest microprogrammed models (60 and 62) of the 360 line, and soon models 64 and 66 were being offered, with an order from Lincoln Laboratories for amazingly early delivery of both hardware and software.

It was soon apparent that this was not enough. The 60 and 62 were too slow and expensive and the 64 and 66 didn't go far enough. The only thing to do was to scrap the whole lot of them.

In their place there were announced the much faster model 65 at the price of the slow model 60, and the model 67, with segments, pages, modularity and other features, a number of which had been developed in cooperation with the first model 67 customer, the University of Michigan. (701).

There are many attractive features embodied in the time-sharing concept. Conversational on-line debugging, man-machine interaction, file interrogation, information retrieval, graphical input and output, machine-aided design, computer-assisted instruction; these and other key areas of computer research and application can be made accessible to large numbers of users only by way of multi-access time-shared computing systems. In 1965 the model 67 seemed
to be the most promising of the possible approaches to large-
scale time-sharing, and most major universities and many research
organizations ordered or planned to order systems built around
one or more model 67 processors.

IBM launched a major software development effort to construct
a time-sharing operating system (TSS) for the model 67. Enthusiastic
potential users were planning installations in which hundreds of
consoles would be on-line simultaneously. By the middle of 1966
it became apparent that the performance of the system would be
marginal at best. Simulation studies indicated that the original
software system would find it difficult to support even a very
few consoles.

Most customers withdrew their orders. A number of model 67
systems were delivered in 1967, and the early TSS system release
provides limited service to about 6 on-line typewriter consoles.
Other software development at the University of Michigan, at
General Motors Corporation, and at IBM's Cambridge center have
produced alternate software systems for the 67, and a second
version of TSS promises performance improvements over the first
version. It seems clear (June 1968) that even with the best pos-
sible software, the model 67 performance will fall far short of
the performance expected and promised in the atmosphere of enthusi-
asm for time-sharing that prevailed in 1965. It seems unlikely
that a really satisfactory level of performance will be achieved
in any large-scale time-sharing system without major hardware
developments that may become available in the fourth or fifth
computer generation.
The software effort for the GE 645 is a joint effort of personnel from General Electric, MIT, and Bell Telephone Laboratories [71]. Their Multics system has many interesting features, and introduced and elaborated a number of important concepts, but here too it is almost impossible to be optimistic about the eventual performance of the system on the 645.

Even though the large time-sharing systems have been disappointing, they have had a very major influence on the development of a number of fairly successful smaller systems. General Electric, using a software system developed at Dartmouth College, has been very successful in marketing its 265 computer as a small time-sharing system. The 265 uses the GE 235, a small second-generation computer, in combination with their Datanet 30, a special-purpose communications-handling computer.

Many of the small-scale time-sharing systems are software systems on conventional computers, but there have been a number of special models and special hardware features designed specifically for time-sharing application. The SDS 940, a modification of the more conventional 930, was developed at the University of California and is being successfully marketed by Scientific Data Systems. This computer has been installed by a number of companies offering time-sharing services commercially by way of teletype consoles and voice-grade telephone lines. RCA has added some address-translation hardware and made other modifications to their Spectra 70 model 45, and is marketing the resulting model 46 for time-sharing use. The Control Data 3300, the Digital Equipment Corporation PDP 10, and the Scientific Data System Sigma 7 are
other computers that incorporate special hardware features for use in time-sharing systems.

The use of computers by way of on-line remote consoles is becoming increasingly popular, and will be a very major consideration in future developments.
7. Bibliography

There have been many thousands of publications in the area surveyed here. Only a few of the most relevant ones are listed. The interested reader can find a great deal of additional information in the manuals published by the manufacturers of the various machines. There also exist a number of quite well-known compilations of the characteristics of digital computing systems [72,73,74]. There have been a number of survey articles previously published that contain useful bibliographies [75,76]. A bibliography in an article by Walter Hoffmann [77] contains 697 items. Another good source of information and references in this area is Richards [78,79].

Much additional information about the computers mentioned here and the many others not included can be found in the proceedings of the various organizations in the computer field. The reader is particularly referred to the Proceedings of the Spring and Fall Joint Computer Conferences sponsored by AFIPS, to the Journal and Communications of the ACM, to the IEEE Transactions on Electronic Computers (formerly IRE Transactions), to Datamation, and to the publications of the British Computer Society.


33. R. E. Sprague: The CADAC in \( \gamma 32 \) p 13-17.

34. A. Auerbach: The Elecom 100 in \( \gamma 32 \) p 25-30.

35. L. P. Robinson: Model 30-201 Electronic Digital Computer, in \( \gamma 32 \) p 31-36.

36. F. C. Withington: The Cardatron and the Datafile in the Datatron System. See \( \gamma 24 \).


