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The Advent of Commercial Computing, 1945–1956

"[Y]ou . . . fellows ought to go back and change your program entirely, stop this . . . foolishness with Eckert and Mauchly." That was the opinion of Howard Aiken, Harvard mathematician and builder of the Mark I calculator, expressed to Edward Cannon of the U.S. National Bureau of Standards in 1948. Aiken made that remark as a member of a National Research Council committee that had just recommended that the Bureau of Standards not support J. Presper Eckert and John Mauchly's proposal to make and sell electronic computers (figure 1.1). In Aiken's view, a commercial market would never develop; in the United States there was a need for perhaps for five or six such machines, but no more.[1]

Howard Aiken was wrong. There turned out to be a market for millions of electronic digital computers by the 1990s, many of them personal devices that fit easily into a briefcase. That would not have happened were it not for advances in solid state physics, which provided a way of putting the circuits of a computer on a few chips of silicon. Nevertheless, the nearly ubiquitous computers of the 1990s are direct descendants of what Eckert and Mauchly hoped to commercialize in the late 1940s.

The Eckert-Mauchly Computer Corporation did not remain an independent entity for long; it was absorbed by Remington Rand and became a division of that business-machine company. Eckert and Mauchly's computer, the UNIVAC, was a technical masterpiece but was eclipsed in the market by computers made by Remington-Rand's competitor, IBM. So one could say that they were indeed foolish in their underestimation of the difficulties of commercializing their invention. What was not foolish was their vision, not only of how to design and build a computer but also of how a society might benefit from large numbers of them.

Figure 1.1
Staff of the Eckert-Mauchly Computer Corporation, ca. 1948, in Philadelphia. Eckert is at the lower left; Mauchly at the lower right. The apparatus behind them is a portion of the BINAC, which the company was building for the Northrop Aircraft Company. *Back row, left to right*: Albert Auerbach, Jean Bartik, Marvin Jacoby, John Sims, Louis Wilson, Robert Shaw, Gerald Smoliar. *Front row*: J. Presper Eckert, Frazier Welsh, James Wiener, Bradford Sheppard, John Mauchly. (*Source*: Unisys Corporation.)

Computing after 1945 is a story of people who at critical moments redefined the nature of the technology itself. In doing so they opened up computing to new markets, new applications, and a new place in the social order. Eckert and Mauchly were the first of many who effected such a transformation. They took an expensive and fragile scientific instrument, similar to a cyclotron, and turned it into a product that could be manufactured and sold, if only in small quantities.[2] In the mid-1950s the IBM Corporation developed a line of products that met the information-handling needs of American businesses. A decade later, alumni from MIT's Project Whirlwind turned the computer into a device that one interacted with, a tool with which to augment one's intellectual efforts. In the mid-1970s, a group of hobbyists and enthusiasts transformed it into a personal appliance. Around 1980, it was transformed from a piece of specialized hardware to a standardized consumer product defined by its now-commercialized software. In the 1990s it is going through another transformation, turning into an agent of a worldwide nexus, a communications medium. The ''computer age''—really a series of ''computer ages''—was not just invented; it was willed into existence by people who wanted it to happen. This process of reinvention and redefinition is still going on.

The UNIVAC in Context

Eckert and Mauchly brought on the first of these transformations in 1951 with a computer they called ''UNIVAC.'' The acronym came from ''Universal Automatic Computer,'' a name that they chose carefully. ''Universal'' implied that it could solve problems encountered by scientists, engineers, and businesses. ''Automatic'' implied that it could solve complex problems without requiring constant human intervention or judgment, as existing techniques required. Before discussing its creation, one needs to understand how computing work was being done in different areas and why a single machine, a UNIVAC, could serve them equally well. One must also understand how existing calculating machines, the results of decades of refinement and use, were deficient. It was that deficiency that made room for the UNIVAC, which broke with past practices in many ways.

Punched Cards

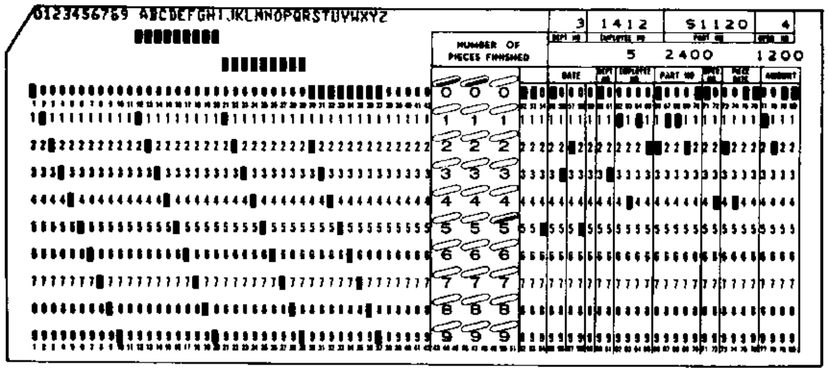
During the Second World War, Eckert and Mauchly designed and built the ENIAC at the University of Pennsylvania's Moore School of Electrical Engineering. The ENIAC was an electronic calculator that inaugurated the era of digital computing in the United States. Its purpose was to calculate firing tables for the U.S. Army, a task that involved the repetitive solution of complex mathematical expressions. It was while working on this device that they conceived of something that had a more universal appeal.

The flow of information through the UNIVAC reflected Eckert and Mauchly's background in physics and engineering. That is, the flow of instructions and data in the UNIVAC mirrored the way humans using mechanical calculators, books of tables, and pencil and paper performed scientific calculations.[3] Although the vacuum tube circuits might have appeared novel, a scientist or engineer would not have found anything unusual in the way a UNIVAC attacked a problem.

However, those engaged in business calculations, customers Eckert and Mauchly also wanted their machine to serve, would have found the UNIVAC's method of processing unusual.[4] In the late nineteenth century, many businesses adopted a practice that organized work using a punched card machine; typically an ensemble of three to six different punched-card devices would comprise an installation.[5] To replace these machines with a computer, the business had also to adopt the UNIVAC's way of processing information. Punched-card machines are often called "unit record equipment." With them, all relevant information about a particular entity (e.g., a sales transaction) is encoded on a single card that can serve multiple uses by being run through different pieces of equipment; for example, to count, sort, tabulate, or print on a particular set of columns.[6] Historical accounts of punched-card machinery have described in great detail the functioning of the individual machines. More relevant is the "architecture" of the entire room—including the people in it—that comprised a punched-card installation, since it was that room, not the individual machines, that the electronic computer eventually replaced.

In a typical punched-card installation, the same operation was performed on all the records in a file as a deck of cards went through a tabulator or other machine (figure 1.2). The UNIVAC and its successors could operate that way, but they could also perform a long sequence of operations on a single datum before fetching the next record from memory. In punched-card terms, that would require carrying a "deck" of a single card around the room—hardly an economical use of the machinery or the people. Processing information gathered into a deck of cards was entrenched into business practices by the mid-1930s, and reinforced by the deep penetration of the punched-card equipment salesmen into the accounting offices of their customers.[7]

By the 1930s a few scientists, in particular astronomers, began using punched-card equipment for scientific problems. They found that it made sense to perform sequences of operations on each datum, since often the next operation depended on the results of the previous one. One such person was Wallace Eckert (no relation to J. Presper Eckert), who with the aid of IBM established the Thomas J. Watson Computing Bureau at Columbia University in New York in 1934. In 1940 he summarized his work in an influential book, *Punched Card Methods in Scientific Computation*. In it, he explained that punched-card machines "are all designed for computation where each operation is done on



WHAT THE
PUNCHED HOLE WILL DO

1 It will add itself to something else.
2 It will subtract itself from something else.
3 It will multiply itself by something else.
4 It will divide itself by something else.
5 It will list itself.
6 It will reproduce itself.
7 It will classify itself.
8 It will select itself.
9 It will print itself on an IBM card.
10 It will produce an automatic balance forward.
11 It will file itself.
12 It will post itself.
13 It will reproduce and print itself on the end of a card.
14 It will be punched from a pencil mark on the card.
15 It will cause a total to be printed.
16 It will compare itself to something else.
17 It will cause a form to feed to a predetermined position, or to be ejected automatically, or to space one position to another.

The IBM card has 80 vertical columns. Each column accommodates a hole (or holes) represnting a single number or letter. Information to be included in the card is determined by requirements of the final reports and documents.

Data to be processed by IBM machines must be punched in the card according to a standard arrangement. Consequently, columns of the card are grouped and reserved for the recording of each fact about a business transaction.

An IBM card – once punched and verified – is a permanent record. It can be read by machines to do transcribing and other processing at high speed.

Figure 1.2
IBM punched card. From IBM Corporation, "IBM Data Processing Functions," Brochure 224-8208-5, ca. 1963. (*Source*: IBM Corporation.)

many cards before the next operation is begun.''[8] He emphasized how one could use existing equipment to do scientific work, but he stated that it was not worth the ''expense and delay involved'' in building specialized machines to solve scientific problems.[9] A decade later, that was precisely what J. Presper Eckert and John Mauchly were proposing to do—go to great expense and effort to create a ''universal'' machine that could handle both business and scientific problems.

Ironically, Wallace Eckert was among the first to venture away from traditional punched-card practices and toward one more like the digital computers that would later appear. Despite his recommendation against building specialized equipment, he did have a device called a control switch designed at his laboratory. He installed this switch between the multiplier, tabulator, and summary punch. Its function was to allow short sequences of operations (up to 12) to be performed on a single card before the next card was read.[10] Following his advice, IBM built and installed two specially built punched-card machines at the U.S. Army's Ballistic Research Laboratory at Aberdeen, Maryland. IBM called these machines the ''Aberdeen Relay Calculators''; they were later known as the PSRC, for ''Pluggable Sequence Relay Calculator.''[11]

In late 1945, three more were built for other military labs, and these were even more complex. During the time one of these machines read a card, it could execute a sequence of up to forty-eight steps. More complex sequences-within-sequences were also possible.[12] One computer scientist later noted that this method of programming demanded ''the kind of detailed design of parallel subsequencing that one sees nowadays at the microprogramming level of some computers.''[13] When properly programmed, the machines were faster than any other nonelectronic calculator. Even after the ENIAC was completed and installed and moved from Philadelphia to Aberdeen, the Ballistic Research Lab had additional Relay Calculators built. They were still in use in 1952, by which time the BRL not only had the ENIAC but also the EDVAC, the ORDVAC (both electronic computers), an IBM Card Programmed Calculator (described next), and the Bell Labs Model V, a very large programmable relay calculator.[14]

The Card-Programmed Calculator

The Aberdeen Relay Calculators never became a commercial product, but they reveal an attempt to adapt existing equipment to post–World War II needs, rather than take a revolutionary approach, such as the

UNIVAC. There were also other punched-card devices that represented genuine commercial alternatives to Eckert and Mauchly's proposed invention. In 1935 IBM introduced a multiplying punch (the Model 601); these soon became popular for scientific or statistical work. In 1946 IBM introduced an improved model, the 603, the first commercial IBM product to use vacuum tubes for calculating. Two years later IBM replaced it with the 604, which not only used tubes but also incorporated the sequencing capability pioneered by the Aberdeen machines. Besides the usual plugboard control common to other punched-card equipment, it could execute up to 60 steps for each reading of a card and setting of the plugboard.[15] The 604 and its successor, the IBM 605, became the mainstays of scientific computing at many installations until reliable commercial computers became available in the mid 1950s. It was one of IBM's most successful products during that era: over 5,000 were built between 1948 and 1958.[16]

One of IBM's biggest engineering customers, Northrop Aircraft of Hawthorne, California, connected a 603 multiplying punch to one of their tabulating machines. That allowed Northrop's users to print the results of a calculation on paper instead of punching them on cards. With a slight further modification and the addition of a small box that stored numbers in banks of relays, the machine could use punched cards run through the tabulator to control the sequences carried out by the multiplier.[17]

Logically, the arrangement was no different from an ordinary punched card installation, except that a set of cables and control boxes replaced the person whose job had been to carry decks of cards from one machine to the next. One of the Northrop engineers recalled years later that they rigged up the arrangement because they were running a problem whose next step depended on the results of the previous step. What this meant was that the normal decks of cards that ran through a machine were reduced to "a batch of one [card], which was awkward."[18] In other words, with cables connecting the machines, the installation became one that executed instructions sequentially and was programmable in a more flexible way than plugging cables.

IBM later marketed a version of this ensemble as the Card-Programmed Calculator (CPC).[19] Perhaps several hundred in all were installed between 1948 and the mid 1950s—far fewer than the thousands of tabulators, punches, and other equipment installed in the traditional way. But even that was many times greater than the number of electronic computer installations worldwide until about 1954. For engineeringoriented companies like Northrop, the CPC filled a pressing need that could not wait for the problems associated with marketing stored-program computers to be resolved.[20]

The Aberdeen calculators and the 604 were transitional machines, between calculators, tabulators, and genuine computers like the UNIVAC. The CPC carried the punched-card approach too far to be of value to computer designers. By the time of its introduction, it was already clear that the design used by the UNIVAC, in which both the instructions and the data were stored in an internal memory device, was superior. The Card-Programmed Calculator's combination of program cards, plugboards, and interconnecting cables was like the epicycles of a late iteration of Ptolemaic cosmology, while the Copernican system was already gaining acceptance.[21] Customers needing to solve difficult engineering problems, however, accepted it. It cost less than the computers then being offered, and it was available. Other southern California aerospace firms besides Northrop carefully evaluated the Card-Programmed Calculator against vendors' claims for electronic computers.[22] Nearly all of them installed at least one CPC.

The Stored-Program Principle

No one who saw a UNIVAC failed to see how much it differed from existing calculators and punched card equipment. It used vacuum tubes—thousands of them. It stored data on tape, not cards. It was a large and expensive system, not a collection of different devices. The biggest difference was its internal design, not visible to the casual observer. The UNIVAC was a "stored program" computer, one of the first. More than anything else, that made it different from the machines it was designed to replace.

The origins of the notion of storing a computer's programs internally are clouded in war-time secrecy. The notion arose as Eckert, Mauchly, and others were rushing to finish the ENIAC to assist the U.S. Army, which was engaged in a ground war in Europe and North Africa. It arose because the ENIAC's creators recognized that while the ENIAC was probably going to work, it was going to be a difficult machine to operate.

Applying the modern term "to program" to a computer probably originated with the ENIAC team at the Moore School. More often, though, they used the phrase "set up" to describe configuring the ENIAC to solve different problems.[23] Setting up the ENIAC meant plugging and unplugging a maze of cables and setting arrays of switches. In effect, the machine had to be rebuilt for each new problem it was to solve. When completed in late 1945, the ENIAC operated much faster than any other machine before it. But while it could solve a complex mathematical problem in seconds, it might take days to set up the machine properly to do that.

It was in the midst of building this machine that its creators conceived of an alternative. It was too late to incorporate that insight into the ENIAC, but it did form the basis for a proposed follow-on machine called the ''EDVAC'' (Electronic Discrete Variable Computer). In a description written in September of 1945, Eckert and Mauchly stated the concept succinctly: ''An important feature of this device was that operating instructions and function tables would be stored exactly in the same sort of memory device as that used for numbers.''[24] Six months later, Eckert and Mauchly left the Moore School, and work on the EDVAC was turned over to others (which was mainly why it took five more years to finish building it). The concept of storing both instructions and data in a common storage unit would become basic features of the UNIVAC and nearly every computer that followed.[25]

The stored-program principle was a key to the UNIVAC's success. It allowed Eckert and Mauchly, first of all, to build a computer that had much more general capabilities than the ENIAC, yet required fewer vacuum tubes. It led to the establishment of ''programming'' (later ''software'') as something both separate from and as important as hardware design. The basics of this design remained remarkably stable during the evolution of computing from 1945 to 1995. Only toward the end of this period do we encounter significant deviations from it, in the form of ''massively parallel'' processors or ''non–von Neumann'' architectures.

John von Neumann's Role

Although Eckert and Mauchly had realized as early as 1944 that computers would need to store the program, the ''First Draft of a Report on the EDVAC,'' by John von Neumann, dated June 30, 1945, is often cited as the founding document of modern computing.[26] From it, and a series of reports co-authored by von Neumann a few years later, comes the term ''von Neumann Architecture'' to describe such a design.[27] According to Herman Goldstine, an army officer assigned to the ENIAC project, John von Neumann (1903–1957) learned of the ENIAC from a chance meeting with him in the summer of 1944 at the

Aberdeen, Maryland, railroad station.[28] Despite his involvement in many other projects, including the design of the atomic bomb, von Neumann was sufficiently intrigued by what was going on at the Moore School to have himself introduced to Eckert and Mauchly and brought onto the project.

Eckert and Mauchly were at that time busy thinking of ways to improve the process of setting up a computer faster.[29] One possibility was to use perforated paper tape to feed instructions, as several relay machines of the 1940s did, but this was too slow for the high speeds of the ENIAC's calculating circuits. So were the decks of cards used by the Card-Programmed Calculator. In Mauchly's words, "calculations can be performed at high speed only if instructions are supplied at high speed."[30]

In the midst of the ENIAC's construction in 1944, Eckert wrote a "Disclosure of a Magnetic Calculating Machine," in which he described the use of "[d]iscs or drums which have at least their outer edge made of a magnetic alloy" on which numbers can be stored.[31] Although it focused on ways of designing a machine that was "speedier, simpler as well as providing features of utility, ruggedness and ease or repair," the disclosure did not articulate the design concepts that later would become known as the stored-program principle.[32] Von Neumann's 1945 Report on the EDVAC went farther—it described a machine in terms of its logical structure rather than its hardware construction. The memorandum that Eckert and Mauchly submitted in September 1945, stated the principle succinctly: they wrote that instructions and numerical data would be stored "in exactly the same sort of memory device."[33]

From the above sequence of reports and memorandums it appears that Eckert and Mauchly had conceived of something like a stored-program principle by 1944, but that it was von Neumann who clarified it and stated it in a form that gave it great force. Von Neumann's international reputation as a mathematician also gave the idea more clout than it might have had coming solely from Eckert and Mauchly, neither of whom were well-known outside the Moore School. Although the term "von Neumann Architecture" is too entrenched to be supplanted, Eckert and Mauchly, who demonstrated such a deep understanding of the nature of electronic computing from an engineering perspective, deserve equal credit.[34]

In the summer of 1946, the Moore School and the U.S. military cosponsored a course on the "Theory and Techniques for Design of Electronic Digital Computers." The course was a recognition of the school's inability to accommodate the numerous requests for information following the public unveiling of the ENIAC.[35] That series of course lectures and the mimeographed reports that appeared a year or two later firmly established the Moore School's approach to computer design. Machines soon appeared that were based on that concept. An experimental computer at the University of Manchester, England, was running test programs by mid-1948. Maurice Wilkes, of Cambridge University, implemented the idea in his EDSAC, operational in the spring of 1949. Eckert and Mauchly completed the BINAC later that year.[36] And of course the UNIVAC would also employ it. Others would continue to propose and build electronic computers of alternate designs, but after the summer of 1946, computing's path, in theory at least, was clear.

The von Neumann Architecture and Its Significance

Before providing a description of the UNIVAC, it is worth a brief look at the essentials of the architecture that von Neumann described in his 1945 report, especially those aspects of it that have remained stable through the past half-century of computer design.

Aside from the internal storage of programs, a major characteristic of a von Neumann computer is that the units that process information are separate from those that store it. Typically there is only a single channel between these two units, through which all transfers of information must go (the so-called von Neumann Bottleneck, about which more later). This feature arose primarily for engineering reasons: it was easier to design storage cells that did not also have to perform arithmetic on their contents.

The main characteristic is that instructions and data are stored in the same memory device, from which any datum can be retrieved as quickly as any other. This concept arose from considering that the processing unit of a computer should not have to sit idle awaiting delivery of the next instruction. Besides that, the ratio of instructions to data usually varies for each problem, so it would not make sense to dedicate separate, expensive storage devices to each. This design implies that one may treat a coded instruction as a piece of data and perform an operation on it, thus changing it into another instruction, but that was not fully understood at first. To give a sense of how this was first implemented, the UNIVAC main store could hold up to 1,000 "words," which could either be numbers (11 digits plus sign), characters (12 characters per word), or instructions (6 characters per instruction; 2 in each word).[37]

Finally, the basic cycle of a von Neumann computer is to transfer an instruction from the store to the processor, decode that instruction, and execute it, using data retrieved from that same store or already present in the processor. Once the processor executed an instruction, it fetched, decoded, and executed another, from the very next position in memory unless directed elsewhere. Having a fast storage device meant that the processor could branch to another stream of instructions quickly whenever it was necessary. Except when explicit branch instructions are encountered, the flow through the instructions stored in the memory was sequential and linear.[38] This concept, of fetching and then executing a linear stream of instructions, is the most lasting of all; even computer designs that purport to be non–von Neumann typically retain the fetch-decode-execute heartbeat of a single-processor machine.[39] As Alan Perlis once remarked, ''Sometimes I think the only universal in the computing field is the fetch-execute cycle.''[40] The UNIVAC could perform this sequence and add two numbers in about half a millisecond.

Since 1990, computer systems with parallel processing structures have become more common, and genuine alternatives to the fetch-execute cycle have been accepted in a few limited markets. Elsewhere the von Neumann architecture, though much modified, prevails. The emergence of practical parallel designs reveals, however, the unifying effect of the von Neumann model as it influenced the computer design of the past five decades.

From ENIAC to UNIVAC: First Transformation[41]

The UNIVAC was going to cut through the Gordian knot of solving complex problems with punched card equipment or plugboard control, and its designers knew that. The ENIAC, though ill-suited for many problems, nevertheless was in such demand that its physical transfer from Philadelphia to Aberdeen had to be put off. With the end of the War there was less urgency to compute firing tables, although the Aberdeen Proving Ground still expected the machine to be moved there for that purpose. After the public unveiling, a flood of interested parties was petitioning to use it. Mauchly reported, for example, that in March of 1948 Pratt & Whitney asked him if they could run an urgent problem ''the week of April 17.'' That gave him a ''chuckle''—by 1948 the ENIAC was already fully booked for the next two years![42]

What was less well known was that the Moore School team had carefully evaluated the architecture of the follow-on computer, the EDVAC, in light of the problems it might be expected to solve. Von Neumann found that although it was initially intended for evaluating mathematical expressions, the EDVAC's stored-program design made it "very nearly an 'all-purpose machine'" and that it was better than punched card equipment for sorting data. This was a crucial observation, as sorting was a central task for commercial work, and punched card equipment had been optimized for it.[43]

Still, the climate that surrounded the small group of engineers at the Eckert–Mauchly Computer Corporation was anything but favorable. Many experts were skeptical. Wallace Eckert still felt that modifications to punched card machines, not a radically new and expensive design, would better serve computing's needs. Howard Aiken could not imagine that "the basic logics of a machine designed for the numerical solution of differential equations [could] coincide with the logics of a machine intended to make bills for a department store."[44] Eckert and Mauchly knew otherwise. The UNIVAC's logical structure meant that it could do those things and more. That knowledge drove them and their company through the late 1940s to enter the commercial area, with what eventually became the UNIVAC.

Their drive was matched by an equal, but opposite drive by the University of Pennsylvania to banish commercial interests from the academy. Administrators at Penn did not have the vision of a research university to support technology, which led eventually to the development of areas like Silicon Valley in California and Route 128 in Massachusetts. Irwin Travis, an administrator at the Moore School, asked that members of the staff sign a release form that would prevent them from receiving patent royalties on their inventions. He brooked no discussion. Eckert and Mauchly refused to sign. They resigned on March 31, 1946.[45] The Philadelphia-Princeton region, once a contender for the title of center for computing technology, never recovered.

Eckert and Mauchly could have found work at other universities, or at IBM, but they chose instead the risky course of founding their own company. They formed a partnership, the Electronic Control Company, in 1946; in December 1948 they incorporated as the Eckert–Mauchly Computer Corporation. Added to the engineering problems of designing and building a universal computer and its associated tape drives, memory units, and input-output equipment, was the bigger problem of raising capital. The National Bureau of Standards was encouraging at first; through it Eckert and Mauchly carried out serious discussions with the U.S. Census Bureau. (Census was not allowed to contract for a machine still in development, so the NBS had to be brought in as an intermediary.) The Census Bureau is not usually considered among the technologically astute, but just as it helped inaugurate modern data processing in 1890 by working with Herman Hollerith, Census also helped make electronic computing's transition from the university to the private sector.

Still there were roadblocks. The NBS commissioned a study, which resulted in conservative and skeptical conclusions about electronic computing in general, and Eckert–Mauchly in particular. Another study conducted by the National Research Council in 1947 produced equally negative conclusions, mentioned at the beginning of this chapter. This latter study later became infamous as the source of the statement about how only a few computers would satisfy the world's needs. The search for funds took the fledgling company everywhere: from the American Totalisator Company, who wanted a computer to calculate betting odds at race tracks, to Northrop Aircraft, who wanted an airborne control system for an unmanned, long-range bomber.

Their frantic search for capital makes for a depressing story. But it had a bright side: people wanted this new machine. And as the example of American Totalisator showed, there were many possible customers beyond the obvious ones of the large military or government agencies.

On January 12, 1948, John Mauchly wrote a memorandum to his staff at the Eckert–Mauchly Computer Corporation in which he listed a total of twenty-two industries, government agencies, or other institutions he had contacted. Optimistically he gauged the status of each as a potential customer for a UNIVAC.[46] In the next few years the under-capitalized company would have a great deal of trouble selling UNIVACs. But in the long run, Mauchly was exactly right: each of those industries, and many more, would find compelling reasons to purchase or lease electronic digital computers, if not from Eckert–Mauchly then from someone else. Here are some of the contacts Mauchly listed in his memo:

> Prudential. [Edmund C. Berkeley] . . . . says that considering the number of persons at Prudential who have now expressed themselves in favor of obtaining electronic equipment, he believes there will be no difficulty in getting an order for one UNIVAC.
>
> Oak Ridge . . . . it was almost 100 percent certain that their purchase order would be approved by Army.

Army Map Service.... Army Map Service has taken an interest in UNIVAC equipment.

Bureau of Aeronautics.... we could possibly obtain a contract.

The Metropolitan Insurance Company has a large problem involving a total file of 18,000,000 policies with 2,000,000 changes per week. There are about twenty digits of information for each policy. It appears that this is a natural application for the UNIVAC.... it would be worthwhile to follow it up.

Presidency College, Calcutta. Professor Mahalanobis...was anxious to contract for a UNIVAC as soon as we were in a position to make definite terms.

Aircraft Companies. A number of aircraft companies are good prospects.... There is no doubt that such companies could use UNIVAC equipment. We have had brief contact with Hughes Aircraft, Glen L. Martin, United Aircraft, North American Aviation, and have been told that Grumman goes in for some rather fancy calculations.

The Information Age had dawned.

UNIVAC

I am pleased that history recognizes the first to invent something, but I am more concerned with the first person to make it work.

—Grace Hopper[47]

On March 31, 1951, the Eckert–Mauchly Division of Remington Rand turned over the first UNIVAC to the U.S. Census Bureau. A formal dedication ceremony was held in June at the Division's modest factory in at 3747 Ridge Avenue in Philadelphia. Thus began the era of commercial sales of large-scale stored-program computers in the United States.[48] The event was, however, less of a milestone than it appeared. That first UNIVAC remained at the plant until late December 1952, when it was shipped to Washington. Eckert and Mauchly needed it there: As the only working model of a machine they hoped to sell in quantity, they wanted to show it to other potential customers.[49] And after having gone through heroic efforts to complete and debug the machine, they were apprehensive about dismantling it, moving it, and setting it up again. The first UNIVAC to leave the factory and be installed on a customer's premises was serial #2, installed at the Pentagon for the U.S. Air Force in June 1952.[50] By 1954 about twenty were built and sold, at prices on the order of a million dollars for a complete system.[51] Table 1.1 lists UNIVAC installations from 1951 through 1954.

J. Presper Eckert and John Mauchly, with the help of about a dozen technical employees, designed and built the UNIVAC (figure 1.3). They

Table 1.1
UNIVAC installations, 1951–1954

Date	Customer
Summer 1951	U.S. Census Bureau
late 1952	U.S. Air Force, the Pentagon
late 1952	U.S. Army Map Service
Fall 1953	U.S. AEC, New York, NY (at NYU)
Fall 1953	U.S. AEC, Livermore, CA
Fall 1953	David Taylor Model Basin, Carderock, MD
1954	Remington Rand, New York, NY
1954	General Electric, Louisville, KY
1954	Metropolitan Life, New York, NY
1954	Wright-Patterson AFB, Dayton, OH
1954	U.S. Steel, Pittsburgh, PA
1954	Du Pont, Wilmington, DE
1954	U.S. Steel, Gary, IN
1954	Franklin Life Insurance, Springfield, OH
1954	Westinghouse, Pittsburgh, PA
1954	Pacific Mutual Life Insurance, Los Angeles, CA
1954	Sylvania Electric, New York, NY
1954	Consolidated Edison, New York, NY
1954	Consolidated Edison, New York, NY

Note: This list is compiled from a variety of sources and does not include one or two UNIVACs that were completed but remained with Remington Rand. In some cases the dates are approximate. Depending on how one interprets "installation," the order listed here may be slightly different. UNIVACs were last installed in late 1958 or early 1959.

designed a machine that used four binary digits (bits) to code each decimal digit. In its central processor, four general-purpose accumulators carried out arithmetic. A word was 45 bits long; each word could represent 11 decimal digits plus a sign, or two instructions. The UNIVAC's clock ran at 2.25 MHz, and it could perform about 465 multiplications per second. That was about the same as the ENIAC's multiplication speed; but the UNIVAC's tape system and stored-program architecture made it a much faster machine overall. "Delay lines" stored 1,000 words as acoustic pulses in tubes of mercury, while magnetic tape units stored up to one million characters on reels of half-inch metal tape.

The UNIVAC was rugged and reliable. Vacuum tube failures, the bane of all early systems, were kept to a reasonably low rate to ensure that the machine would remain useful for practical, day-to-day work. Statistics gathered by one customer, Metropolitan Life Insurance Company,

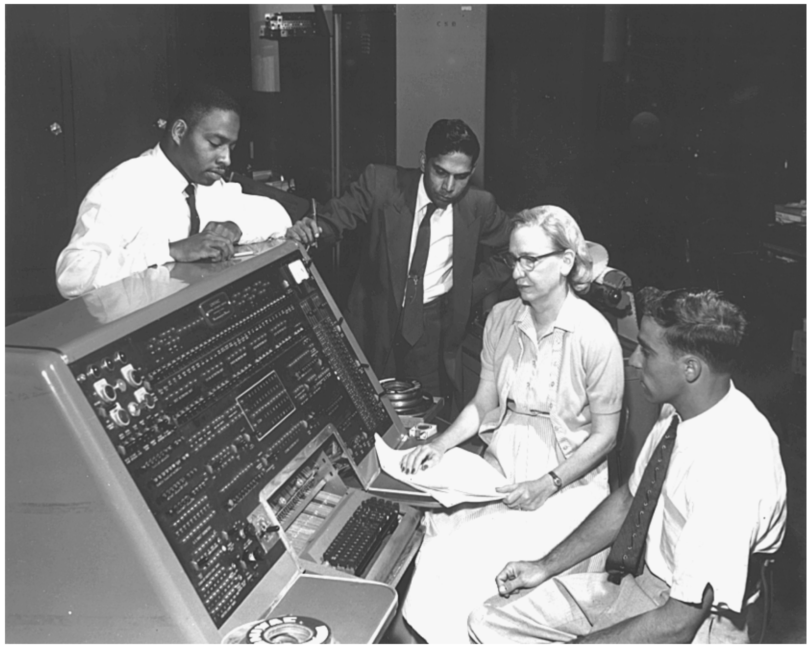


Figure 1.3
Grace Murray Hopper and colleagues seated at a UNIVAC console, ca. 1960. Reels of UNIVAC tape are visible on both sides of the control panel. (*Source*: Smithsonian Institution photo #83-14878, gift of Grace Murray Hopper.)

showed the central processor was available 81 percent of the time, a very high figure compared to contemporary vacuum-tube machines.[52] The Census Bureau said, "We never encountered an incorrect solution to a problem which we were sure resulted from an internal computer error."[53] The machine's design reflected Eckert's philosophy of conservative loads on the vacuum tube circuits, plus enough redundancy, to ensure reliable operation. Its central processor contained over 5,000 tubes, installed in cabinets that were ranged in a 10-foot by 14-foot rectangle. Inside this rectangle were the mercury delay-line tanks.

Many design features that later became commonplace first appeared in the UNIVAC: among them were alphanumeric as well as numeric processing, an extensive use of extra bits for checking, magnetic tapes for bulk memory, and circuits called "buffers" that allowed high-speed transfers between the fast delay line and slow tape storage units.[54]

The UNIVAC in Use

A number of UNIVAC customers were private corporations, not military or defense agencies. And of those defense agencies that purchased UNIVACs, many did so for inventory, logistics, and other applications that in many ways were similar to what business customers bought the machine for. In short, and in contrast to the IBM 701 (discussed next), the UNIVAC inaugurated the era of large computers for what is now called ''data processing'' applications.

For most customers, what was revolutionary about the UNIVAC was not so much its stored-program design or even its electronic processor. It was the use of tape in place of punched cards. To them, the ''Automatic'' nature of the machine lay in its ability to scan through a reel of tape, find the correct record or set of records, perform some process in it, and return the results again to tape. In a punched card installation, these tasks were performed by people who had to carry large decks of cards from one punched card machine to another. That made punched card processing labor-intensive. Published descriptions of the UNIVAC nearly always referred to it as a ''tape'' machine. For General Electric, ''the speed of computing is perhaps of tertiary importance only.''[55] To the extent that its customers perceived the UNIVAC as an ''electronic brain,'' it was because it ''knew'' where to find the desired data on a tape, could wind or rewind a tape to that place, and could extract (or record) data automatically. Customers regarded the UNIVAC as an information processing system, not a calculator. As such, it replaced not only existing calculating machines, but also the people who tended them.

The Census Bureau, which had been pivotal in getting the fledgling computer company going, hoped to use the UNIVAC for tabulating the 1950 Census. By the time it received its machine in 1951, however, much of the work had already been put on punched card machines for processing. In fact, the Census Bureau had to step aside while the U.S. Air Force and the Atomic Energy Commission commandeered the first machine off the production line, UNIVAC 1, for problems deemed more urgent by the federal government.[56]

Nevertheless, UNIVAC 1 was used for the production of part of the Second Series Population Tables for the states of Alabama, Iowa, Louisiana, and Virginia. This involved classifying individuals into one of several hundred groups, further grouping them by geographic location, and preparing tables showing the number of persons in each group for each local area. The data for this operation, initially punched onto eleven million cards (one for each person), was transferred to tape for processing by the UNIVAC.[57] The machine was also used for tabulating another subset of population involving about five million households. Each problem took several months to complete.

UNIVAC 2, installed at the Pentagon for the Air Comptroller, was intended for use in Project SCOOP (Scientific Computation of Optimum Problems), which grew out of wartime concerns with getting war materials and men across the Atlantic. Following the War, the newly created Air Force was faced with a mathematically similar problem in maintaining and supplying air bases scattered across the globe. Project SCOOP played a key role in the discovery of Linear Programming, a cornerstone of modern applied mathematics.[58]

It was for SCOOP that the Air Force had helped fund construction of a computer called SEAC (Standards Eastern Automatic Computer), but that machine's limited Input/Output facilities made it less than ideal for this problem. Soon after its installation, UNIVAC 2 was put to work on SCOOP around the clock.[59] Although the UNIVAC was superior to the SEAC in many ways, it, too, suffered from a slow output mechanism, which hampered its use for SCOOP. The UNIVAC's UNIPRINTER was based around a standard Remington Rand electric typewriter, and it printed at a rate commensurate with such a machine, about ten characters per second, which was too slow for the data processing applications the UNIVAC was being sold for. In 1954 Remington Rand addressed the problem by introducing the UNIVAC High Speed Printer, which printed a full 130-character line at one time.[60]

The UNIVAC installed in 1954 at Air Force's Air Material Command at Wright-Patterson AFB in Ohio performed similar tasks. One of its first jobs was to calculate "the complete Fiscal 1956 Budget estimate for airborne equipment spare parts, involving approximately 500,000 items."[61] The Air Force noted that the machine did the job in one day, replacing a battery of punched card equipment.

Some UNIVACs performed classified weapons work in the spirit of the one-of-a-kind computers that preceded them. UNIVAC 5, installed at the Lawrence Livermore Labs in April 1953, was one of those. But even that machine did at least one calculation that was not for the purpose of weapons designs. In November 1952, before it was shipped to California, Remington Rand used it to predict Eisenhower's victory over Adlai Stevenson in the 1952 presidential election. Narrated on "live" television, the event inaugurated the intrusion of television into national politics, and of computers into the public's consciousness. For a brief period, the word "UNIVAC" was synonymous with computer, as "Thermos" was for vacuum bottles. That ended when IBM took the lead in the business.[62]

A final example of the UNIVAC in use comes from the experience at General Electric's Appliance Park, outside Louisville, Kentucky. This installation, in 1954, has become famous as the first of a stored-program electronic computer for a nongovernment customer (although the LEO, built for the J. Lyons Catering Company in London, predated it by three years).

Under the direction of Roddy F. Osborn at Louisville, and with the advice of the Chicago consulting firm Arthur Andersen & Co., General Electric purchased a UNIVAC for four specific tasks: payroll, material scheduling and inventory control, order service and billing, and general cost accounting.[63] These were prosaic operations, but GE also hoped that the computer would be more than just a replacement for the punched-card equipment in use at the time. For General Electric, and by implication for American industries, the UNIVAC was the first step into an age of "automation," a change as revolutionary for business as Frederick W. Taylor's Scientific Management had been a half-century earlier.

The term "automation" was coined at the Ford Motor Company in 1947 and popularized by John Diebold in a 1952 book by that title.[64] Diebold defined the word as the application of "feedback" mechanisms to business and industrial practice, with the computer as the principal tool. He spoke of the 1950s as a time when "the push-button age is already obsolete; the buttons now push themselves."[65] Describing the GE installation, Roddy Osborn predicted that the UNIVAC would effect the same kind of changes on business as it had already begun to effect in science, engineering, and mathematics. "While scientists and engineers have been wide-awake in making progress with these remarkable tools, business, like Rip Van Winkle, has been asleep. GE's installation of a UNIVAC may be Rip Van Business's first 'blink.' "[66]

To people at General Electric, these accounts of "electronic brains" and "automation" were a double-edged sword. The Louisville plant was conceived of and built to be as modern and sophisticated as GE could make it; that was the motivation to locate it in Kentucky rather than Massachusetts or New York, where traditional methods (and labor unions) held sway. At the same time, GE needed to assure its stockholders that it was not embarking on a wild scheme of purchasing exotic, fragile, and expensive equipment just because ''longhair'' academics—with no concern for profits—wanted it to.

Thus, GE had to emphasize the four mundane jobs, already being done by punched card equipment, to justify the UNIVAC. Once these jobs became routine, other, more advanced jobs would be given to the machine. Although automating those four tasks could have been done with a smaller computer, GE chose a UNIVAC in anticipation of the day when more sophisticated work would be done. These tasks would involve long-range planning, market forecasting based on demographic data, revamping production processes to reduce inventories and shipping delays, and similar jobs requiring a more ambitious use of corporate information.[67] The more advanced applications would not commence until after the existing computerization of ''bread and butter'' work reached a ''break even point . . . enough to convince management that a computer system can pay for itself in terms of direct dollar savings (people off the payroll) without waiting for the 'jam' of more glamorous applications.''[68]

Indeed, the analysis of the UNIVACs benefits was almost entirely cast in terms of its ability to replace salaried clerks and their overhead costs of office space, furnishings, and benefits. Yet at the end of Osborn's essay for the *Harvard Business Review,* the editors appended a quotation from Theodore Callow's *The Sociology of Work,* published that year. That quotation began:

> The Utopia of automatic production is inherently plausible. Indeed, the situation of the United States today, in which poverty has come to mean the absence of status symbols rather than hunger and physical misery, is awesomely favorable when measured against the budgetary experience of previous generations or the contemporary experience of most of the people living on the other continents.[69]

It would not be the last time that the computer would be seen as the machine that would bring on a digital Utopia.

On Friday, October 15, 1954, the GE UNIVAC first produced payroll checks for the Appliance Park employees.[70] Punched-card machines had been doing that job for years, but for an electronic digital computer, which recorded data as invisible magnetic spots on reels of tape, it was a milestone. Payroll must be done right, and on time. GE had rehearsed the changeover thoroughly, and they had arranged with Remington Rand that if their machine broke down and threatened to make the checks late, they could bring their tapes to another UNIVAC customer and run the job there.[71] Over the course of the next year they had to exercise this option at least once. There were several instances where the checks were printed at the last possible minute, and in the early months it was common to spend much more time doing the job with UNIVAC than had been spent with punched card equipment. No payrolls were late.

IBM's Response

At the time of the UNIVAC's announcement, IBM was not fully committed to electronic computation and was vigorously marketing its line of punched card calculators and tabulators. But after seeing the competitive threat, it responded with several machines: two were on a par with the UNIVAC; another was more modest.

In May 1952, IBM announced the 701, a stored-program computer in the same class as the UNIVAC. Although not an exact copy, its design closely followed that of the computer that John von Neumann was having built at the Institute for Advanced Study at Princeton. That meant it used a memory device that retrieved all the digits of a word at once, rather than the UNIVAC's delay lines that retrieved bits one at a time. Beginning in January of that year, IBM had hired John von Neumann as a consultant; as with the Institute for Advanced Study computer itself, von Neumann was not involved with the detailed design of the 701. (IBM engineers Jerrier Haddad and Nat Rochester were in charge of the project.) The first unit was installed at IBM's offices in New York in December, with the first shipment outside IBM to the nuclear weapons laboratory at Los Alamos in early 1953.[72]

IBM called the 701 an ''electronic data processing machine,'' a term (coined by James Birkenstock) that fit well with ''Electric Accounting Machine,'' which IBM was using to describe its new line of punched card equipment. IBM deliberately avoided the word ''computer,'' which it felt was closely identified with the UNIVAC and with exotic wartime projects that appeared to have little relevance to business.

For main storage, the 701 used IBM-designed 3-inch diameter vacuum tubes similar to those used in television sets. (They were called ''Williams tubes'' after their British inventor, F. C. Williams.) Although they were more reliable than those in other contemporary computers, their unreliability was a weak link in the system. One story tells of a 701 behaving erratically at its unveiling to the press despite having been checked out thoroughly before the ceremony. The photographers' flash bulbs were ''blinding'' the Williams tubes, causing them to lose data.

Another account said that because the memory's Mean Time Between Failure (MTBF) was only twenty minutes, data had to be constantly swapped to a drum to prevent loss.[73]

Each tube was designed to hold 1,024 bits. An array of 72 tubes could thus hold 2,048 36-bit words, and transfer a word at a time by reading one bit from each of 36 tubes.[74] Plastic tape coated with magnetic oxide was used for bulk memory, with a drum for intermediate storage. The processor could perform about 2,000 multiplications/second, which was about four times faster than the UNIVAC.

Within IBM, the 701 had been known as the Defense Calculator, after its perceived market. According to an IBM executive, the name also helped "ease some of the internal opposition to it since it could be viewed as a special project (like the bomb sights, rifles, etc., IBM had built during World War II) that was not intended to threaten IBM's main product line."[75] True to that perception, nearly all of the 19 models installed were to U.S. Defense Department or military aerospace firms.[76] Initial rental fees were $15,000 a month; IBM did not sell the machines outright. If we assume the 701 was a million-dollar machine like the UNIVAC, the rental price seems low; certainly IBM could not have recouped its costs in the few years that the machine was a viable product.

The 701 customers initially used the machine for problems, many still classified, involving weapons design, spacecraft trajectories, and cryptanalysis, which exercised the central processor more heavily than its Input/Output facilities. Punched card equipment had been doing some of that work, but it had also been done with slide rules, mechanical calculators, analog computers, and the Card-Programmed Calculator. Eventually, however, customers applied the 701 to the same kinds of jobs the UNIVAC was doing: logistics for a military agency, financial reports, actuarial reports, payrolls (for North American Aviation), and even predicting the results of a presidential election for network television. (In 1956, the 701 correctly predicted Eisenhower's reelection.)[77]

Unlike the UNIVAC, the 701's central processor handled control of the slow input/output (I/O) facilities directly. All transfers of data had to pass through a single register in the machine's processor, which led to slow operation for tasks requiring heavy use of I/O. However, the 701's lightweight plastic tape could start and stop much faster than the UNIVAC's metal tape and thus speed up those operations. The tape drive also employed an ingenious vacuum-column mechanism, invented by James Wiedenhammer, which allowed the tape to start and stop quickly without tearing.

For scientific and engineering problems, the 701's unbalanced I/O was not a serious hindrance. Computer designers—the few there were in 1953—regarded it as an inelegant design, but customers liked it. The nineteen installations were enough to prevent UNIVAC from completely taking over the market and to begin IBM's transition to a company that designed and built large-scale electronic digital computers.[78]

The 701 became IBM's response to UNIVAC in the marketplace, but that had not been IBM's intention. Before starting on the 701, IBM had developed a research project on a machine similar to the UNIVAC, an experimental machine called the Tape Processing Machine, or TPM. Its design was completed by March 1950.[79] The TPM was a radical departure from IBM's punched card machinery in two ways. It used magnetic tape (like the UNIVAC), and its variable length record replaced the rigid 80-character format imposed by the punched card. Like the UNIVAC, it worked with decimal digits, coding each digit in binary.

IBM chose to market a second large computer specifically to business customers based on the Tape Processing Machine. Model 702 was announced in September 1953 and delivered in 1955. In many ways it was similar to the 701, using most of the same electronic circuits as well as the Williams Tube storage. By the time of the first 702 installations, magnetic core memories were beginning to be used in commercial machines. And 701 customers were finding that their machine, like any powerful general-purpose computer, could be used for business applications as well. IBM received many orders for 702s, but chose to build and deliver only fourteen, with other orders filled by another machine IBM brought out a few years later.[80]

Engineering Research Associates

A third firm entered the field of making and selling large digital computers in the early 1950s: Engineering Research Associates, a Twin Cities firm that had its origins in U.S. Navy-sponsored code-breaking activities during World War II.[81] The Navy gave this work the name "Communications Supplementary Activity—Washington" (CSAW), but it was usually called "Seesaw" after its acronym. It was centered in Washington, on the commandeered campus of a girls school. After the War, two members of this group, Howard Engstrom and William Norris, felt that the talent and skills the Navy had assembled for the war effort were too valuable to be scattered, and they explored ways of keeping the group together. They decided to found a private company, and with financial assistance from John E. Parker, they were incorporated as Engineering Research Associates, Inc., in early 1946. Parker was able to provide space in a St. Paul building that during the war had produced wooden gliders (including those used for the Normandy invasion).

Thus, by one of the coincidences that periodically occur in this history, the empty glider factory gave the Twin Cities an entree into the world of advanced digital computing. The factory was cold and drafty, but ERA had little trouble finding and hiring capable engineers freshly minted from the region's engineering schools. Among them was a 1951 graduate of the University of Minnesota, who went over to "the glider factory" because he heard there might be a job there. His name was Seymour R. Cray.[82] We will encounter Cray and his boss, William Norris, several times in later chapters.

ERA was a private company but was also captive to the Navy, from which it had sprung. (The propriety of this arrangement would on occasion cause problems, but none serious.) The Navy assigned it a number of jobs, or "tasks," that ERA carried out. Most of these were highly classified and related to the business of breaking codes. Task 13, assigned in August 1947, was for a general-purpose electronic computer. ERA completed the machine, code-named "Atlas," and asked the Navy to clear them for an unclassified version they could sell on the open market. In December 1951 they announced it as Model "1101": "13" in binary notation.[83]

As might be expected from a company like ERA, the 1101 was intended for scientific or engineering customers, and its design reflected that. Before it could begin delivering systems, however, ERA found itself needing much more capital than its founders could provide, and like the Eckert–Mauchly Computer Corporation, was purchased by Remington Rand. By mid-1952 Remington Rand could offer not one but two well-designed and capable computer systems, one optimized for science and engineering, the other for commercial use. Installations of the 1103, its successor, began in the fall of 1953. Around twenty were built. As with the IBM 701, most went to military agencies or aerospace companies.

In 1954 the company delivered an 1103 to the National Advisory Committee for Aeronautics (NACA) that employed magnetic core in place of the Williams Tube memory. This was perhaps the first use of core in a commercial machine. The 1103 used binary arithmetic, a 36-bit word length, and operated on all the bits of a word at a time. Primary memory of 1,024 words was supplied by Williams tubes, with an ERA-designed drum, and four magnetic tape units for secondary storage.[84]

Following NACA's advice, ERA modified the machine's instruction set to include an "interrupt" facility—another first in computer design. (Core and interrupts will be discussed in detail in the next chapter.) These enhancements were later marketed as standard features of the 1103-A model.[85] Another aerospace customer, Convair, developed a CRT tube display for the 1103, which they called the Charactron. This 7-inch tube was capable of displaying a 6 × 6 array of characters, which also affected the course of computer history.[86] Overall, the 1103 competed well with the IBM 701, although its I/O facilities were judged somewhat inferior.

The Drum Machines

In the late 1930s, in what may have been the first attempt to build an electronic digital computer, J. V. Atanasoff conceived of a memory device consisting of a rotating drum on which 1,600 capacitors were placed, arrayed in 32 rows.[87] His work influenced the developments of the next decade, although those who followed him did not ultimately adopt his method. In the following years several people continued to work on the idea of rotating magnetic devices for data storage, for example, Perry O. Crawford, who described such a device in his master's thesis at MIT.[88]

After the War, the drum emerged as a reliable, rugged, inexpensive, but slow memory device. Drawing on wartime research on magnetic recording in both the United States and Germany, designers rediscovered and perfected the drum, this time using magnetic rather than capacitive techniques.

The leader in this effort was Engineering Research Associates. Before they were assigned "Task 13," they were asked to research available memory technologies. By 1947 they had made some significant advances in recording speeds and densities, using a drum on which they had glued oxide-coated paper (figure 1.4).[89] Within two years ERA was building drums that ranged from 4.3 to 34 inches in diameter, with capacities of up to two million bits, or 65,000 30-bit words. Access time ranged from 8 to 64 milliseconds.[90] ERA used drums in the 1101; they also advertised the technology for sale to others.

CRC 102A

One of the first to take advantage of magnetic drums was was Computer Research Corporation of Hawthorne, California. This company was

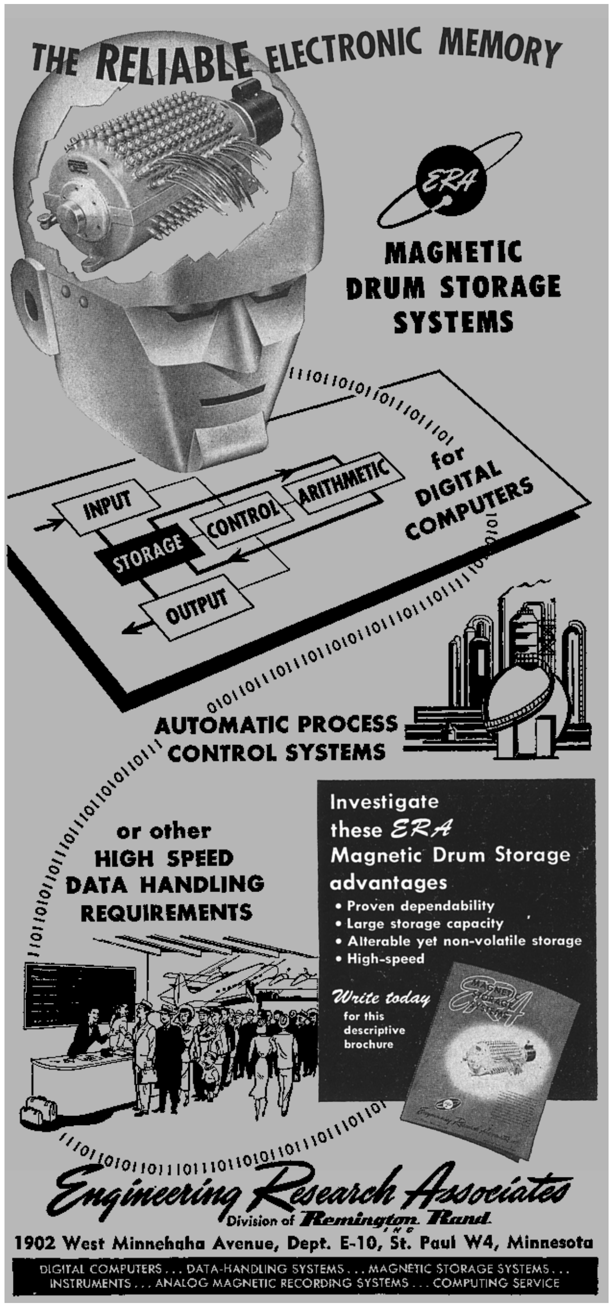


Figure 1.4

Advertisement for magnetic drum memory units, from ERA. (*Source*: *Electronics Magazine* [April 1953]: 397.)

founded by former employees of Northrop Aircraft Company, the company that had built the Card-Programmed Calculator described above. In 1953 they began selling the CRC-102A, a production version of a computer called CADAC that had been built for the Air Force. It was a stored-program, general-purpose computer based on a drum memory. The 102A had a simple design, using binary arithmetic, but a decimal version (CRC 102D) was offered in 1954.[91] In some of the published descriptions, engineers describe its design as based directly on logic states derived from statements of Boolean algebra. This so-called West Coast design was seen as distinct from the designs of Eckert and Mauchly, who thought in terms not of logic states, but of current pulses gated through various parts of a machine. As computer engineering matured, elements of both design approaches merged, and the distinction eventually vanished.[92]

The 102A's drum memory stored 1,024 42-bit words; average access time was 12.5 msec. A magnetic tape system stored an additional 100,000 words. The principal input and output device was the Flexowriter, a typewriter-like device that could store or read keystrokes on strips of paper tape. It operated at about the speeds of an ordinary electric typewriter, from which it was derived. In keeping with its aerospace roots, Computer Research Corporation also offered a converter to enter graphical or other analog data into the machine.[93] It was also possible to connect an IBM card reader or punch to the computer. The computer's operating speed was estimated at about eleven multiplications per second.[94] The 102A was a well-balanced computer and sold in modest numbers. In 1954 the National Cash Register Company purchased CRC, and the 102 formed the basis of NCR's entry into the computer business.[95]

Computer Research's experience was repeated with only minor variations between 1950 and 1954. Typically, a small engineering company would design a computer around a drum memory. I/O would be handled by a standard Flexowriter, or by punched card machines leased from IBM. The company would then announce the new machine at one of the Joint Computer Conferences of the Institute of Radio Engineers/Association for Computing Machinery. They would then get a few orders or development funds from the Air Force or another military agency. Even though that would lead to some civilian orders and modest productions runs, the company would still lack the resources to gear up for greater volume or advanced follow-on designs. Finally, a large, established company would buy the struggling firm, which would then serve as the larger company's entree into computing.

Many of these computers performed well and represented a good value for the money, but there was no getting around the inherent slowness of the drum memory. Their input/output facilities also presented a dilemma. The Flexowriter was cheap, but slow. Attaching punched card equipment meant that a significant portion of the profits would go directly to IBM, and not to the struggling new computer company.

As mentioned, National Cash Register bought CRC. Electronic Computer Corporation, founded by Samuel Lubkin of the original UNIVAC team, merged with Underwood Corporation, known for its typewriters. (Underwood left the computer business in 1957.) Consolidated Engineering of Pasadena, California, was absorbed by Burroughs in 1956. The principal legacy of the drum computers may have been their role as the vehicle by which many of the business machine companies entered the computer business.

Table 1.2 lists several other magnetic drum computers announced or available by mid-1952. For each of these systems, the basic cost was from

Table 1.2
Commercially available small computers, ca. mid-1952

Computer	Word length	Memory capacity (words)	Speed (mult./sec.)	Manufacturer
CE 30-201	10 dec.	4000	118	Consolidated Engineering Pasadena, CA
Circle	40 bits	1024	20	Hogan Labs New York, NY
Elecom 100	30 bits	512	20	Electronic Computer Corp Brooklyn, NY
MINIAC	10 dec.	4096	73	Physical Research Labs Pasadena, CA
MONROBOT	20 dec.	100	2	Monroe Calculating Machine Co Orange, NJ

Source: Data from U.S. Navy, Navy Mathematical Computing Advisory Panel, *Symposium on Commercially Available General-Purpose Electronic Digital Computers of Moderate Price* (Washington, DC, 14 May 1952).

$65,000 to $85,000 for a basic system exclusive of added memory, installation, or auxiliary I/O equipment.

Later Drum Machines, 1953–1956

LGP-30

In the mid-1950s a second wave of better-engineered drum computers appeared, and these sold in much larger quantities. They provided a practical and serious alternative for many customers who had neither the need nor the resources to buy or lease a large electronic computer.

The Librascope/General Precision LGP-30, delivered in 1956, represented a minimum design for a stored-program computer, at least until the minicomputer appeared ten years later. It was a binary machine, with a 30-bit word length and a repertoire of only sixteen instructions. Its drum held 4,096 words, with an average access time of around 2.3 msec. Input and output was through a Flexowriter.

The LGP-30 had only 113 vacuum tubes and 1,350 diodes (unlike the UNIVAC's 5,400 tubes and 18,000 diodes), and looked like an oversized office desk. At $30,000 for a basic but complete system, it was also one of the cheapest early computers ever offered. About 400 were produced and sold.[96] It was not the direct ancestor of the minicomputer, which revolutionized computing in the late 1960s, but many minicomputer pioneers knew of the LGP-30. Librascope offered a transistorized version in 1962, but soon abandoned the general-purpose field and turned to specialized guidance-and-control computers for aerospace and defense customers.

Bendix G-15

The G-15, designed by Harry Huskey and built by Bendix, was perhaps the only computer built in the United States to have been significantly influenced by the design ideas of Alan Turing rather than John von Neumann. Both advocated the stored-program principle, with a provision for conditional branching of instructions based on previously calculated results. For von Neumann, however, the fundamental concept was of a steady linear stream of instructions that occasionally branched based on a conditional test. Turing, on the other hand, felt that there was no fundamental linear order to instructions; for him, *every* order represented a transfer of control of some sort.[97]

Turing's concept (much simplified here) was more subtle than the linear model, and fit well with the nature of drum-based computers.

Turing's model required that every instruction have with it the address where the next instruction was located, rather than assuming that the next instruction would be found in the very next address location. In a drum computer, it was not practical to have instructions arranged one right after the other, since that might require almost a full revolution of the drum before the next one appeared under the read head. Programmers of drum computers often developed complicated ''minimum latency coding'' schemes to scatter instructions around the drum surface, to ensure that the next instruction would be close to the read head when it was needed. (Note that none of this was required if a memory that took the same amount of time to access each piece of data was used.)

Harry Huskey, who had worked with Turing in 1947 on the ACE project at the National Physical Laboratory in England, designed what became the G-15 while at Wayne State University in Detroit in 1953. First deliveries were in 1956, at a basic price of $45,000. It was regarded as difficult to program, but for those who could program it, it was very fast. Bendix sold more than four-hundred machines, but the G-15's success was not sufficient to establish Bendix as a major player in the computer field.[98] Control Data Corporation later took over Bendix's computer business, and Bendix continued to supply only avionics and defense electronics systems.

IBM 650

Along with the Defense Calculator (a.k.a. IBM 701), IBM was working on a more modest electronic computer. This machine had its origins in proposals for extensions of punched card equipment, which IBM had been developing at its Endicott, New York, plant. IBM's internal management was hesitant about this project, nor was there agreement as to what kind of machine it would be. One proposal, dubbed ''Wooden Wheel,'' was for a plug-programmed machine like the 604 Multiplier.[99] In the course of its development, the design shifted to a general-purpose, stored-program computer that used a magnetic drum for primary memory. (IBM's acquisition, in 1949, of drum-memory technology from Engineering Research Associates was a key element in this shift.[100]) The machine, called the 650, was delivered in 1954 and proved very successful, with eventually around a thousand installations at a rental of around $3,500 a month.[101]

By the time of its announcement, the 650 had to compete with many other inexpensive drum machines. It outsold them all, in part because of

IBM's reputation and large customer base of punched card users, and in part because the 650 was perceived as easier to program and more reliable than its competitors. IBM salesmen were also quick to point out that the 650's drum had a faster access time (2.4 msec) than other drum machines (except the Bendix G-15).[102]

The 650 was positioned as a business machine and continued IBM's policy of offering two distinct lines of products for business and scientific customers. Ironically, it had less impact among business customers, for whom it was intended, than it had at universities. Thomas Watson Jr. directed that IBM allow universities to acquire a 650 at up to a 60 percent discount, if the university agreed to offer courses in business data processing or scientific computing. Many universities took up this offer, making the 650 the first machine available to nascent "computer science" departments in the late 1950s.[103]

Summary

> Very few of these machines of anybody's manufacture were *sold* during the period we are talking about. Most of them, and I would guess 80 percent at least, were *bought* by the customer who made the buy, not the salesman who made the sale, although the salesman might get the commission.[104]
>
> —Lancelot Armstrong

The "first generation" began with the introduction of commercial computers manufactured and sold in modest quantities. This phase began around 1950 and lasted through the decade. Computers of this era stored their programs internally and used vacuum tubes as their switching technology, but beyond that there were few other things they had in common. The internal design of the processors varied widely. Whether to code each decimal digit in binary or operate entirely in the binary system internally remained an unsettled question. The greatest variation was found in the devices used for memory: delay line, Williams tube, or drum. Because in one way or another all these techniques were unsatisfactory, a variety of machines that favored one design approach over another were built.

The Institute for Advanced Study's reports, written by Arthur Burks, Herman Goldstine, and John von Neumann, emphasized the advantages of a pure binary design, with a parallel memory that could read and write all the bits of a word at once, using a storage device designed at RCA called the Selectron. By the time RCA was able to produce sufficient quantities of Selectrons, however, core memory was being introduced, and the Selectron no longer looked so attractive. Only the Johnniac, built at the RAND Corporation, used it. Most of the other parallel-word computers used Williams Tubes.[105] In practice, these tubes were plagued by reliability problems.[106]

The result was that memory devices that accessed bits one at a time, serially, were used in most first-generation computers. The fastest computers used mercury delay lines, but the most popular device was the rotating magnetic drum. A drum is fundamentally an electromechanical device and by nature slow, but its reliability and low cost made it the technology of choice for small-scale machines.

Commercial computing got off to a shaky start in the early 1950s. Eckert and Mauchly, who had a clear vision of its potential, had to sell their business to Remington Rand to survive, as did Engineering Research Associates. Remington Rand, however, did not fully understand what it had bought. IBM knew that computers were something to be involved with, but it was not sure how these expensive and complex machines might fit into its successful line of tabulating equipment. Customers took the initiative and sought out suppliers, perhaps after attending the Moore School session in 1946 or visiting a university where a von Neumann type machine was being built. These customers, from a variety of backgrounds, clamored for computers, in spite of a reluctance among UNIVAC or IBM salesmen to sell them.

The UNIVAC and the IBM 701 inaugurated the era of commercial stored-program computing. Each had its drawbacks, but overall they met the expectations of the customers who ordered them. The UNIVAC's memory was reliable but slow; the 701's was less reliable but faster. Each machine worked well enough to establish the viability of large computers. Drum technology was providing storage at a lower cost per bit, but its speed was two orders of magnitude slower, closer to the speeds of the Card-Programmed Calculator (which was capable of reading 125 instruction cards per minute), which had been available since the late 1940s from IBM. Given the speed penalty, drum-based computers would never be able to compete with the others, regardless of price. The many benefits promised in the 1940s by the stored-program electronic computer architecture required high-capacity, high-speed memory to match electronic processing. With the advent of ferrite cores—and techniques for manufacturing them in large quantities—the memory problem that characterized the first generation was effectively solved.

Table 1.3
Selected characteristics of early commercial computers

Computer	Word length	Memory capacity (words)	Access time (microseconds)	Multiplications/ second
CRC-102	9 dec.	1024	12,500	65
ERA 1103	36 bits	1024	10	2500–8000
G-15	29 bits	2160	1,700 avg.	600
LGP-30	30 bits	4096	8,500 avg.	60
IBM 650	10 dec.	1000–2000	2,400 avg.	50–450
IBM 701	36 bits	2048	48	2000
UNIVAC	11 dec.	1000	400 max.	465

Source: Data from Martin Weik, ''A Survey of Electronic Digital Computing Systems,'' Ballistic Research Laboratories Report #971 (Aberdeen Proving Ground, Maryland, December 1955).

Table 1.3 lists memory and processor characteristics of the major computers of this era.