CHAPTER THREE

Military Roots

WHEN historians examine the origins of the electronic digital computer, they usually give top billing to the pioneering efforts of the American scientists J. Presper Eckert and John W. Mauchly, who built their Electronic Numerical Integrator and Computer (ENIAC) during World War II. Eckert and Mauchly are justly and widely honored as the men whose efforts and risks led to the first machines recognizable as modern computers. They also founded the first private computer systems company. But historians now also recognize a lesser known history of the computer, one whose roots run deep into the most sensitive and secret corners of a modern military establishment.

It was no accident that the military services largely financed the postwar development of the computer in the 1950s, for computing technology had played a pivotal role in the Allied war effort. The military indirectly bankrolled even the Eckert and Mauchly computer projects, and these relatively open projects were only the tip of a much larger, and sometimes hidden, technological iceberg.

The military computer projects, as well as Eckert and Mauchly's daring bet on an as-yet nonexistent commercial market, led to the first stirrings of interest in computers in the 1950s by business and industry. Indeed the first commercial computers were direct copies or adaptations of machines developed for military users.

After the war, the commercial potential of government-sponsored research became more apparent. The first great political clashes over technology policy in the United States occurred.

Origins of the Computer

By the time war broke out in 1939, engineering and science had already made important advances in several seemingly unrelated areas . Although the war was the catalyst that drew together these advances and produced the electronic digital computer, its origins stemmed from four scientific and engineering traditions. A centuries-old history of the development of mechanical calculating machines formed the first line of activity. The construction of special purpose machines (differential analyzers) designed to approximate the mathematical solution of differential equations used in modeling various physical processes was the second and more recent type of effort. The third stream of developments resulted from rapid progress in developing new generations of electronic components during the war. Finally, a new theoretical perspective on the abstract mathematical conception of information and information processing preceded further breakthroughs in technology.

By the 1930s applied mathematicians had incorporated recent advances in electrical technology into mechanical calculators. Mechanical levers and gears were being replaced with faster and more reliable electrical relays and wheels. In the United States, George R. Stibitz at the Bell Telephone Laboratories constructed a series of electromechanical calculators in the late 1930s that stored and manipulated numbers internally in binary form.1 The machines were constructed from ordinary telephone relays, wired together in standard telephone equipment racks. They relied on teletype input and output. Larger and more powerful versions of these early relay computers were built for wartime use and continued in service well into the 1950s.

Closely related to this equipment were sophisticated punched card business machines that used electromechanical technology to tabulate, sort, add, and compare data punched into paper cards. Herman Hollerith invented such machinery, and it was first used in the U.S. Census of 1890. Although there were significant competitors, inparticular, National Cash Register (NCR) and Remington Rand, International Business Machines (IBM) dominated the U.S. market for commercial punched card machines in the 1930s . IBM had good relations with the government: the establishment of the U.S. social security system and the ensuing demand for punched card machinery to process the massive numbers of

1. See W. H. C. Higgins and others, "Electrical Computers for Fire Control," in M. D. Fagen, ed., *A History of Engineering and Science in the Bell System: National Service in War and Peace (1925-1975)* (Murray Hill, N.J.: Bell Telephone Laboratories, 1978), pp. 166-67; and George R. Stibitz, "Early Computers," in N. Metropolis, J. Howlett, and Gian-Carlo Rota, eds., *A History of Computing in the Twentieth Century: A Collection of Essays* (Academic Press, 1980), pp. 47983.

cards needed to keep the system's records was significant in helping IBM to weather the depression years.2

Technologically, both calculators and punched card equipment relied on electromechanical relays, counters, adders, comparators, and sensors. Wiring together the more sophisticated mathematical capability of the calculator with the data processing capacity of punched card equipment was a logical extension of the art. Columbia University researchers put together this type of installation with support from IBM in the late 1920s and used it for complex scientific calculations.3 By the later 1930s individual researchers had begun to experiment with circuitry using vacuum tube flip-flop switches and specialized counters, and other electronic circuits, to perform numerical computations.

Numerous efforts were under way in the United States. Inspired by the work of British physicist C. E. Wynn-Williams, who had built pioneering high-speed nuclear particle counters using thyratron tubes (a type of gas-filled electronic valve) in the early 1930s, Joseph Desch and Robert Mumma of NCR had begun working on the application of electronics to arithmetic calculations in 1938 and 1939.4 Installed in a new research lab established at NCR's Dayton, Ohio, plant, Desch and Mumma had by 1940 built a prototype electronic calculator. At MIT, NCR sponsored a parallel research effort to build a Rapid Arithmetical Machine, conceived by Vannevar Bush and supervised by his associate Samuel Caldwell. Although exotic experimental electronic circuitry was built and tested, MIT never produced a complete machined At Iowa State University, in 1940, John Vincent Atanasoff built a functional prototype electronic adder. In 1941 he demonstrated it to a visitor, John W. Mauchly.6 IBM also had a small research effort under way before

2. See Bob O. Evans, "IBM System/360," *ComputerMuseum Report,* no. 9 (Summer _984), p. 9; and William Rodgers, *Think* (Stein and Day, 1969), p. 108.

3. See Rodgers, *Think,* pp. 133-48; and Charles J. Bashe and others, *IBM's Early computers (MIT* Press, 1986), pp. 22-24.

4. See B. Randell, "The Colossus," in Metropolis and others, *A History of Computing, p.* 51. The work of Joseph Desch and Robert Mumma is described briefly in Bryon E. Phelps, "Early Electronic Computer Developments at IBM," *Annals of the History of Computing, vol.* 2 (July 1980), pp. 251-55. Unpublished interviews with Joseph Desch and Robert Mumma conducted by Henry Tropp,

January 17 and 18, 1973 available in the Smithsonian Institution, Washington, D.C.

5. Tropp interview with Desch and Mumma, January 17 and 18, 1973. Randell, 'Colossus,99 pp 80-81; Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882-1982* (MIT Press, 1985), pp. 228-35.

6. This episode ultimately led to the overthrow in 1973 of patents on the computer

the war, investigating the replacement of mechanical relays with electronic circuits.7

Even at this early stage, a key concept had already emerged. Both Stibitz and Atanasoff were using circuitry that processed numbers in digital form, as sequences of binary, on-off electrical pulses that were stored in switches and counted in adders.

The numerous "differential analyzers" built in the United States in the 1930s contributed greatly to the emerging form of the modern digital computer.8 Vannevar Bush directed most of this work, undertaken at MIT. The differential analyzer was a special purpose machine that could solve certain types of differential equations. It also used the prevailing electromechanical technology and worked by measuring physical phenomena whose behavior could be associated with an equation under study. Electrical and mechanical values were altered to mimic the effects of parameters in the equation to be solved. The U.S. War Department funded much of this work. In fact a differential analyzer was installed by the Army at its Aberdeen Proving Grounds in Maryland, where it was put to work calculating artillery firing tables. Bush's interest in achieving greater computational speeds by replacing mechanical components with electronic circuitry was one of the motivations leading MIT to work jointly with NCR on high-speed electronics.9

A new generation of superior electronic componentry was another ingredient in the technological ferment leading to the modern computer. The progress in electronic components built on new and superior vacuum tube devices developed in the 1920s and 1930s by radio engineers and on designs for new highperformance circuits dependent on these improved

filed by J. Presper Eckert and John W. Mauchly, on the basis of their work on the ENIAC machine and its successors. See Nancy Stern, *From ENIAC to UNIVAC: An AppraisaloftheEckert-Mauchly Computers* (Digital Press, 1981), pp. 33-36; and Herman H. Goldstine, *The Computer: From Pascal to von Neumann* (Princeton University Press, 1980), pp. 125-26.

7. Phelps, "Early Electronic Computer," pp. 253-58; Charles J. Bashe, "The SSEC in Historical Perspective," *Annals of the History of Computing, vol.* 4 (October 1982), pp. 298-301; and Bashe and others, *IBM's Early Computers,* pp. 36-42.

8. See Vannevar Bush, *Pieces of the Action* (William Morrow, 1970), pp. 181-85.

9. In the late 1930s it also became clear that the principles involved in the differential analyzer could be coupled with a feedback mechanism to the mechanical movement of a gunsight and used to control the fire of a weapon. See Higgins and others, "Electrical Computers," pp. 133-63. See also Jan Rajchman, "Early Research on Computers at RCA," in Metropolis and others, *A History of Computing*, pp. 465-66; and Wildes and Lindgren, *A Century of Electrical Engineering, p.* 92. The analog computers were much faster, though less accurate, than digital machines in solving these problems.

Components The biggest contribution of the new, all-electronic switching and counting circuits was the potential for orders of magnitude improvement in speed.

The research effort put into radar in the 1930s, under government sponsorship in some of the big industrial economies (the United States, Britain, Germany, and France), was crucial to the development of the electronic components used to modulate high-speed, high-frequency electrical pulses. Radar apparatus using the higher frequencies of the electromagnetic spectrum was found to have superior range and diffusion characteristicss and much effort was expended in developing parts capable of handling high pulse rates. Happily, since digital computers rely on electrical pulses, devices capable of responding to high-frequency pulses allow very fast computing. Much of the later rapid progress in computers drew heavily on the fruits of accelerated development of high-frequency electronics for radar.10

The final scientific tradition from which computers emerged was mathematical logic. In a famous and original 1936 paper, the young British mathematician Alan Turing tackled a difficult theoretical problem and in the process invented the abstract concept of a general purpose computer.11 In extending work by Czech mathematician Kurt Godel, Turing showed that there was no mechanical process by which all provable assertions could be proven.12 To do so, he invented what is now known as a Turing machine, an abstract theoretical automaton that could recognize and process symbols, including arithmetic, according to a "table of behavior" with which it was programmed. Turing's proof applied this theoretical automaton to the task of computing numbers.

Significantly, Turing's abstract conception of a machine was that it

10. J. Presper Eckert, for example, has commented that experience with electronics used in radar operatus gave him crucial experience in building high-speed circuits. See J. Presper Eckert, "ENIAC," *Computer Museum Report, vol.* 16 (Summer 1986), p. 3. Maurice Wilkes, builder of the Electronic Delay Storage Automatic Calculator (EDSAC), is also emphatic on this point. Maurice V. Wilkes, *Memoirs of a Computer Pioneer (MIT* Press, 1985), pp. 107-08. *IBM's Early Compurers* points out that Ralph L Palmer's electronics group at IBM was largely composed of engineers with wartime electronics experience in radar. See Bashe and others, *IBM's Early Computers,* pp. 60-61, 118.

11 . Alan M. Tunng, "On Computable Numbers, with an Application to the EntscheldUngsproblem," *Proceedings of the London Mathematical Society, vol.* 42 (London 1936), pp. 230-65.12 See Andrew Hodges, *Alan Turing: The Enigma* (Simon and Schuster, 1983), pp. 92-110

be universal and capable in principle of doing any logical operation that could be automated or mechanized. Furthermore, the machine should process symbols, not just numbers. Thus Turing extended the horizons of computing machinery to information processing and the manipulation and interpretation of symbolic concepts.

Turing's ideas crossed the Atlantic with him, when he accepted fellowships for the 193S37 academic years at the Institute for Advanced Study (IAS), near Princeton University. While there, he met many prominent mathematicians, including John von Neumann, who was later to figure prominently in the development of the computer in the United States. Turing turned down a position as a research assistant to von Neumann and returned to England in the summer of 1938.

While at Princeton, however, Turing became interested in applying logical techniques to codes and ciphers. He envisioned representing letters as binary numbers and multiplying them by other long numbers to encrypt messages. He went as far as building a functioning prototype of an electrical multiplier that processed binary numbers . After returning to England, Turing immediately became associated with the British Foreign Office's Government Code and Cypher School (GC & CS), which was decrypting the message traffic of foreign powers and maintaining the security of British communications.

Military Influence

Progress in computer technology exploded during and after the Second World War. Several military organizations, and organizations funded by the military, promoted the development of computer technology in the United States in the 1940s.

The U.S. Navy

The Navy's interest in the development of advanced technology on a large scale dates back to World War I. Important advances in naval warfare, including the use of mechanical directors and computers for fire control, the use of radio for communication across great distances, and the development of the attack submarine posed new technical problems for strategists. The Navy soon took the lead in applying new technology to military problems. The secretary of the Navy set up a naval consulting board, chaired by Thomas A. Edison, in 1915. Though the board largely confined its work to screening the proposals of outside inventors, it set up a laboratory facility to work on problems of antisubmarine warfare. Another of its initiatives led to the establishment of the Naval Research Laboratory in 1923. The only other significant force in American wartime research during the First World War was the civilian controlled National Research Council, associated with the private National Academy of Sciences, which had a small budget and largely served as liaison between the scientific community and research needs defined by the military.

The Navy's postwar research efforts included support for the development of radar, radio communications, and the interception and cryptanalysis of foreign communications traffic. Naval interest in these areas reflected the difficulties of communication and reconnaissance over the vast expanses of ocean on which ships operated; telephony and telegraphy, the mainstay of land-based military communications, were not an option. Because signals transmitted by radio could be intercepted much more easily than communications over land lines, cryptanalysis became an economic means of acquiring intelligence about the intentions of foreign, especially naval, military forces.

In 1921 the U.S. Navy began to build a large cryptological unit, which came to dominate the military' s codebreaking activities. During the next two decades, the Navy budgeted three to five dollars for every dollar expended for cryptological activities by the U . S . Army and by 1939 was the most significant force in U.S military communications intelligence. In 1935 the Navy's Communications Security Group, known by its designation as OP-20-G, was established to manage the security of U.S. naval communications and to attack foreign codes.13 This highly secret organization engaged in important, early American work on the digital computer.

In the early 1930s the Navy began to mechanize its cryptanalytical activities. It installed IBM punched card machinery to process code traffic.l4 During that transition, naval intelligence officers approached

13. See William F. Friedman, "A Brief History of the Signal Intelligence Service," SRH-029, June 29, 1942, declassified National Security Agency report released to the National Archives. Friedman was the top cryptanalyst in the U.S.

Army's Signal Intelligence Service (SIS) and led the team that broke the Japanese "Purple" diplomatic Code in 1940. See also "The Birthday of the Naval Security Group," SRH-150, declassified National Security Agency report released to the National Archives.

14. David Kahn, *The Codebreakers: The Story of Secret Writing* (London:

Vannevar Bush, then vice-president and dean of engineering at MIT, an acknowledged expert on machine analysis because of his leadership of the differential analyzer group at MIT.15 Bush studied the Navy's plans and concluded that punched card machinery was too slow. He wanted special machinery that was orders of magnitude faster. A small, secret research group was formed at MIT and developed a machine, which, along with those who built it, entered the Navy.16 By the end of the war, at least seven copies of this particular machine had been built and were instrumental in breaking Japanese codes. 17

The U.S. Navy also funded considerable work on servomechanisms, which use feedback to control movement, at MIT in the 1930s. Navy officers enrolled as graduate students in MIT's Servomechanisms Laboratory.*18* This work led to another set of routes to the digital computer, the analog computers developed and applied to fire control at MIT, RCA, and the Bell Telephone Laboratories during the war.

Thus two principal lines of advance toward the digital computer—rapid analytical machinery for cryptanalytical applications and analog computers for guidance and fire control—benefited from a steady pre-war diet of research support from the U.S. Navy. A third application, computers to calculate ballistics tables for projectiles fired from weapons, was to emerge from the Army funding sources that had originally supported the development of differential analyzers in the 1930s for this purpose.

A Colossus Is Built

Cryptological applications first justified large government expenditures on electronic computing machines. Through rather complex and

Weidenfield and Nicolson, 1967), p. 563, says that the Navy's first IBM machines were installed in 1932.

15. Bush describes the episode in his memoirs. See Bush, *Pieces of the Action,* pp. 192-94.

16. Bush reports that only four people at the Massachusetts Institute of Technology (MIT) knew about the project: Karl T. Compton, then president of the institute, the two young researchers who worked with Bush, and Bush himself.. Ibid., p. 193; Randell, "Colossus," pp. 80-81.

17. Bush, *Pieces of the Action, p.* 194. The unnamed machine developed in the late 1930s at MIT for the Navy was comparable in concept (though not, perhaps, in technology or performance, since it used photoelectric sensing circuitry linked to standard punched card machines) to the Heath Robinson machines built later by the British. See Randell, "Colossus," pp. 80-81.

18. See Wildes and Lindgren, *A Century of ElectricalEngineering,* pp. 213-17. One of the theses, produced before the United States entered the war, remained classified until 1972.

circuitous events, the British secret service had obtained considerable information and a working model of the encryption machinery (the so-called Enigma) used, in one variant or another, by both the Germans and Japanese for their most secret communications traffic . Turing, along with Gordon W. Welchman and others working at Bletchley Park, wartime headquarters of the GC & CS, had developed statistical and mathematical techniques and constructed an electromechanical machine, the so-called bombe, that enabled them to break the Enigma system of the German Navy during the early part of the warps The mechanization of cryptanalysis on these machines allowed vast quantities of German intercepts to be translated, and articulation of the concept of "information processing" was a logical next step.

In early 1942, however, the German Navy modified its Enigmas to effectively multiply the possible keys used to encode messages by a factor of twenty-six. This essentially halted codebreaking successes against German U-boat communications in the Atlantic, since what took a day using the old methods now took a month. It also created a willingness to invest resources in experiments with novel methods. The British began to explore speeding up the machinery by using newly developed electronic technology to replace portions of the (order of magnitude slower) electromechanical relay machinery. Experts were brought in from the radar research laboratory, the Telecommunications Research Establishment (TRE), and the Post Office Research Station (the British equivalent of the Bell Telephone labs). Initial efforts met with frustrating technical problems, and by the end of 1942, a successful electronic solution had not been found.20

The U.S. armed forces had established contacts with the British cryptanalysts well before the United States came into the war formally, and a regular program of missions exchanging technical information and coordinating codebreaking efforts was begun.21 By mid-1942, OP-20-G

19. See Hodges, *Alan Turing, p.* 181, for an inside view of the wartime breakthroughs at Bletchley Park. That the "bombe" used electromechanical punched card machinery technology is illustrated by the fact that it was constructed on the premises of British Tabulating Machinery, the punched card machinery company that was the British hcensee of IBM.

20. In the end, the boarding of a U-boat by the U.S. Navy in October 1942, and the capture of its code books, coupled with unsound German cryptographic

procedures, allowed the Allies to resume breaking U-boat communications by using "bombe" technology in late 1942.

21- For the story of these early contacts see Ronald Lewin, *The American Magic: Codes, Ciphers, and the Defeat of Japan* (Farrar, Strauss Giroux, 1982), pp. 46-47.

had developed its own, more advanced version of the British bombe and was well under way on its own attack on German naval ciphers.22

In mid-1942, at roughly the same time that U-boat signal traffic decryption was disrupted by changes in the German naval Enigma, the British began to intercept a new type of encrypted teleprinter message, produced by a cryptographic machine, code-named Fish. With others at Bletchley Park, Turing developed a general method for attacking the large number of possible keys used by this device to encrypt high-grade German Army messages.23 A group under the direction of Max M. A. Newman, a Cambridge mathematician, set out to mechanize the processing of this traffic. Very high speeds were required to break this traffic within a reasonable time, and the same group of engineers from TRE and the Post Office Research Station that had been frustrated in applying electronics to the bombe set about developing the technology to break Fish automatically.

The machine they produced was nicknamed the Heath Robinson, and it was a hybrid of electromechanical and electronic technology.24 Paper

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See also "Collection of Memoranda on Operations of SIS Intercept Activities and Dissemination, 1942-1945," SRH-145, declassified National Security Agency report released to the National Archives. Several known cryptanalytical technical exchange missions are described in the following documents: "History of the Special Branch, MIS, War Department, 1942-44," SRH-035, declassified National Security Agency report released to the National Archives; Hodges, *Alan Turing,* pp. 242-55; Lewin, *American Magic,* pp. 136-37; and Gordon Welchman, *The Hut Six Story: Breaking the Enigma Codes* (McGraw-Hill, 1982), pp. 170-79. See also Howard Campaigne, "Forward," in "The Design of Colossus," *Annals of the History of Computing, vol.* 5 (July 1983), pp. 239-40; and Joseph Blum, Robert L. Kirby, and Jack Minker, "Eloge: Walter W. Jacobs, 1914-1982," *Annals of the History of Computing, vol.* 6 (April 1984), p. 100.

22. Hodges, *Alan Turing,* pp. 235-36. The U.S. Navy proposed to attack the new complexities in the U-boat codes by building 360 copies of its bombe and wiring them together in parallel. This plan constituted a massive frontal attack on the problem—the British at that time had only 30 machines, with another 20 under construction. Ultimately, a compromise with GC & CS was reached, with

the U.S. Navy building only 100 copies of the machine. Bletchley Park became responsible for coordinating U.S.-British efforts. F. H. Hinsley and others, *British Intelligence in the Second World War: Its Influence on Strategy and Operations, vol.* 2 (New York: Cambridge University Press, 1981), pp. 55-56.

23. Hodges, *Alan Turing,* pp. 228-31; and 1. J. Good, "A Report on T. H. Flower's Lecture on Colossus," *Annals of the History Of Computing, vol.* 4 (January 1982), p. 55.

24. American engineers at OP-20-G built an improved version of this machine called "Goldberg." (Rube Goldberg, the American cartoonist, drew fantastic contraptions similar to those of the British cartoonist Heath Robinson). Telephone interview with Howard Campaigne, August 1, 1985.

tapes containing encrypted messages and keys were synchronized and used to generate electronic pulses, and logical comparisons were made. The mechanical parts of the operation were prone to breakdown, however, and difficult to synchronize.

To overcome these difficulties, many of the mechanical parts of the machine including the key tape, were replaced by electronics, and thyratron ring counter circuits were substituted for mechanical wheels. This machine, which went into operation in 1943, had 1,500 vacuum tubes and was named Colossus. A later version, the Mark II Colossus, had 2,400 vacuum tubes and 800 electromechanical relays. By the end of the war, ten of the Mark II machines were functioning in England.25

Though much smaller, Colossus was technologically and functionally comparable to the ENIAC, the American machine that was operating two years later and is often called the first modern electronic digital computer. Details of its existence were not revealed until the mid- 1970s, however. Although special purpose in nature, Colossus could theoretically be programmed to carry out conventional mathematical calculations. Because of a complete twoway exchange of technological information between the United States and British groups at the time, details of its construction and operation crossed the Atlantic in short order and influenced the engineers working on rapid analytical machinery within OP-20-G. Apparently, moreover, American engineers built relatively faithful copies of Colossus technology.26

This technology used at Bletchley Park and in U.S. naval intelligence would greatly affect the postwar development of computers. In the United States, OP-20-G's most important technology-related groups were its Washington cryptological unit, known as Communications Supplementary Activities Washington (CSAW), and its engineering facilities, the Naval Computing Machinery Laboratory (NCML), located on the facilities of the National Cash Register plant in Dayton, Ohio.

In late 1942, after the U.S. Navy had decided to build many rapid analytical machines, Joseph Desch and Robert Mumma and their electronics lab at NCR had been pulled from Army war projects and put to work on these secret Navy tasks. This lab, transformed into NCML, grew from 20 to 1,100 people at its peak. About 1,200 codebreaking

25. Good, "A Report on T. H. Flower's Lecture," p. 57.

26 B. Randell quotes American engineer Arnold 1. Dumey as saying that "the only early Improvement on Colossus was in a more compact way of holding and running the tapes." See Randell, "Colossus," p. 82.

machines, of about 140 different types, are reported to have been built at the NCR Dayton plant during the war.27

The Navy's takeover of the NCR electronics effort may even have indirectly led to the Army's decision to build the ENIAC. For by the end of 1942, the civilian electronics research at MIT and NCR had been abandoned under the pressure of more pressing wartime requirements. The MIT researchers went to work in the U.S. nuclear program.28 The NCR group had been shifted to an Army calculator project. Desch and Mumma had even produced functional electronic calculator circuits demonstrated to the Army at Aberdeen, Maryland, site of its Ballistics Research Laboratory.29

At roughly the same time as the loss of decrypted German naval traffic (because of changes in the German Enigma early in the year) pushed up Allied shipping losses in the North Atlantic to horrendous levels, OP20-G apparently generated enough pressure to take over Desch and Mumma's lab at NCR, over the protests of the Army.30 Thus the Army had to look elsewhere for its calculator and, in the end, decided to support a previously ignored proposal submitted by J. Presper Eckert and John W. Mauchly at the University of Pennsylvania.

Engineers with prewar experience in electronic circuitry, from around the country, were sent to NCR to work on cryptanalytical machinery. In particular, a few engineers from IBM, some of whom had been experimenting with the substitution of electronic circuits for slower electromechanical components in IBM punched card machines before the war, joined the staffof NCML.3' One of these IBM engineers, Ralph L. Palmer, a technical executive of ficer arriving at NCML in 1943, later steered IBM's transition to electronic technology.32

27. See B. Randell, "An Annotated Bibliography on the Origins of Computers," *Annals of the History of Computing,* vol. I (October 1979), pp. 11917, abstracting from an unpublished interview with H. Carnpaigne.

28. Wildes and Lindgren, *A Century of Electrical Engineering, p.* 231.

29. Tropp interview with Desch and Mumma, January 17 and 18, 1973.

30. Ibid.

31. Desch notes in the Tropp interview that he had quite a few IBM men in uniforin working for him during the war. They had been sent to Dayton because of their background, but they did not get access to work at the NCR labs outside of their area. Ibid.

32. See Emerson W. Pugh, *Memories That Shaped an Industry: Decisions Leading to IBM Systeml360* (MIT Press, 1984), pp. 23-25; Charles J. Bashe, "The SSEC in Historical Perspective," *Annals of the History of Computing, vol.* 4 (October 1982), pp. 301-02.

Other U.S. firms, including IBM and Eastman Kodak, were also building rapid analytical machinery for the Navy, while the Army worked with the Bell Telephone Laboratories to build electrical encryption machinery for voice and teletype data and a large special purpose relay Computer for cryptanalytical work.33 Both Army and Navy intelligence agencies used great batteries of conventional IBM punched card machines. IBM also built special purpose attachments to punched card machines for cryptological applications .34

The Navy also worked on two significant external digital computer projects during the war. The Mark I relay computer project at Harvard was designed by Howard Aiken and developed and engineered by IBM. Begun under the financial sponsorship of IBM before the war, the Mark I was taken over by the Navy after hostilities were under way. The Navy also supported the Airplane Stability and Control Analyzer (ASCA), a general purpose aircraft simulator proposed for use as a flight trainer for pilots and a flight characteristics simulator for aircraft designers. Jay W. Forrester and the MIT Servomechanisms Laboratory signed a contract with the Special Devices Division of the Navy's Bureau of Aeronautics in mid-1944 to develop the apparatus, which, though neve rbuilt, evolved into the Whirlwind computer project.35 Both the Mark I and the Whirlwind development groups helped pave the way for the technical development of the U. S. computer industry.

An Emerging National Science and Technology Policy

A vigorous debate over postwar science and technology policy began to shape up even before the war had ended .36 The massive wartime influx

33. Samuel S. Snyder, "Influence of U.S. Cryptologic Organizations on the Digital Computer Industry," SRH-003, declassified National Security Agency report released to the National Archives, p. 4. See also M. D. Fagen, *A History of Engineering and Sciences pp.* 291-317; telephone interview with Howard Campaigne, August l, 1985; RaDdeU, "Colossus," p. 80; and James Bamford, *The Puzzle Palace* (Penguin, 1983),

34. Thomas Graham Belden and Mona Robins Belden, *The Lengthening Shadow: The Life of Thomas J. Watson* (Little, Brown, 1962), p. 218; Kahn reports that the Army cryptologists use of IBM equipment, which dated to 1936, included 13 machines at Pearl Harbor, 407 by the spring of 1945. Kahn,

Codebreakers, pp. 563, 576. See also Snyder, "Influence of U.S. Cryptologic Organizations," p. 4.

3S. See Kent C. Redmond and Thomas S. Smith, *Project Whirlwind: The History* a Pioneer Computer (Digital Press, 1980), pp. 12-13.

36- James L. Pennick, Jr., and others, *The Politics of American Science: 1939 to*

of resources into research and development, leading to the prospect of further technological breakthroughs, left a permanent commitment to increased public support for research.37 Though policymakers eventually cut back government support from wartime levels, they were eager to confront new issues like the scale of dollars to be allocated to science and technology, the control of research budgets and priorities, and the types of research to support.

But there were those with a different vision of continued federal support for technology, and a political stalemate developed. In 1947 Congress passed an act establishing a National Science Foundation (NSF) organized along the lines outlined by Vannevar Bush in his 1945 report, only to have it vetoed by President Harry S. Truman over issues of accountability and control. Continued political struggles buried the prospects for action until Congress finally established the foundation in 1950.

The U.S. Navy, with congressional approval, did establish an Office of Naval Research (ONR) in 1946. It was the first U.S. government agency established specifically to oversee the task of research management, and Congress placed it in nominal control of all Navy-supported research, both intramural, as in Navy laboratories, and extramural, in external research institutions, universities, and outside defense contractors. Many supporters of the ONR, including Bush, conditioned their help on "the full understanding on the part of everyone that it was to a considerable extent a temporary program,"38 to be funded until the establishment of a National Science Foundation.

By the end of 1948, the ONR employed one thousand in-house scientists, funded about 40 percent of basic research in the United States, and was working on research contracts amounting to $43 million ($20 million of its own money, $9 million from other federal agencies, and

the Present (MIT Press, 1972); Michael S. Sherry, *Preparing for the Next War. American Plans for Postwar Defense* (Yale University Press, 1977), pp. 120-58; and

David F. Noble, *Forces of Production: A Social History of Industrial Automation* (Alfred A. Knopf, 1984), pp. 10-20.

37. Secretary of the Navy James V. Forrestal, in a February 1945 memo to President Roosevelt, wrote: "The problem which began to emerge during the 1944 fiscal year is how to establish channels through which scientists can Icontnbute to the nation's security by carrying on research] in peace as successfully as they have during the war." Quoted in Mina Rees, "The Computing Program of the Office of Naval Research, 194S 1953," *Annals of the History of Computing, vol.* 4 (April 1982), p. 103.

38. Bush is quoted in Redmond and Smith, *Project Whirlwind, p.* 106.

$14 million of university money).39 Until the early 1950s, the only other government agency that exerted a role over the external technological development of computers even remotely approaching that of ONR was the National Bureau of Standards, and its involvement had a considerably different orientation.

During the years 1946-50, as different research groups struggled to develop a workable general purpose, stored-program, electronic digital computer, ONR funded a great number and variety of computer projects . These projects included MIT's Whirlwind, Raytheon's Hurricane computer (later renamed RAYDAC), the CALDIC computer at the University of California, Berkeley, and the Harvard Mark III. Opposition from the ONR's mathematics branch, entrusted with supervision of computer research, also created diffficulties for computer projects.40

Engineering Research Associates

In mid-1945, as it became clear that the war would soon be over, technical personnel working on OP-20-G's codebreaking efforts began to plan a return to civilian life.41 The Navy, anxious to keep its technical resources intact, offered peacetime civil service appointments to its valued personnel, but they refused to accept. The Navy then tried to interest the National Cash Register Corporation in continuing to supply high-speed analytical machinery for Navy applications. It, too, refused, eager to return to its profitable prewar business in of fice equipment.

Finally, two senior reserve naval of ficers in Washington's cryptological unit (CSAW)42 approached the Navy with the idea of starting a

39. Ibid., p. 105.

40. These included Eckert and Mauchly's fledgling UNIVAC I and the MIT Whirlwind. Harry D. Huskey, "The National Bureau *of* Standards Western Automatic Computer (SWAC)," *Annals of the History of Computing, vol.* 2 (April 1980), pp.

41. This account *of* the beginnings *of* ERA draws on Erwin Tomash, "The Start *of* an ERA: Engineering Research Associates," in Metropolis and others, *A History of Computings pp* 485-95; and Arnold A. Cohen and Erwin Tomash, "The Birth of an ERA, Engineering Research Associates, Inc.," *Annals of the History of Computing* vol. I (October 1979), pp. 83-100

42. Howard T. Engstrom, who had been a professor of mathematics at Yale before the war, and research director for Communications Supplementary Activities Washington (CSAW) during the war, later left Remington Rand,

which had purchased Engineenng Research Associates (ERA), to become deputy director *of* the National Security Agency (NSA). Ralph Palmer credited Engstrom with championing the use of high technology

private business to service the computing needs of CSAW and the Navy. Top officials in the Navy encouraged Harold Engstrom and William Norris, and they were soon joined in their efforts by the wartime head of the Naval Computing Machinery Laboratory, Ralph I. Meader. Seventeen different companies and various individuals were contacted, but all declined to invest in a project with highly uncertain economic prospects. Finally, afinancial backerwith political and Navy connections was found and the newly born Engineering Research Associates, as well as the Navy's NCML, moved onto the premises of an established firm that the backer owned. Although ERA was legally ineligible to obtain large government contracts, the Navy bent the rules and issued noncompetitive contracts to ERA and the established sister firm, which shared the same facility and management in St. Paul, Minnesota. As soon as ERA had qualified as a contractor, the sister firm was dissolved.43

ERA's research and development efforts in the late 1940s focused on developing special purpose machines for cryptological applications. The company used the technology under development in the large digital computer projects then under way in the United States and Britain.44 ERA's expertise was in magnetic drum memory technology, which it developed and incorporated into many of these specialized cryptological

in naval intelligence applications. (See Pugh, *Memories, p.* 268). William Norris later became head of Remington Rand's ERA subsidiary, the UNIVAC division of Sperry Rand, and the Control Data Corporation. Rear Admiral Joseph Wenger, who as a captain had headed CSAW during the war, was the first vice-director of the NSA, having held the same position in its predecessor organization, the AFSA. Of the fiftyone members of ERA's founding technical group, forty came from CSAW, five from the Naval Computing Machinery Laboratory, three from the Naval Ordnance Laboratory, and three from research units that were predecessors to the Office of Naval Research. See Arnold A. Cohen, "Biographical Notes," in *Highspeed Computing Devices* (Los Angeles: Tomash Publishers, 1983), p. xxxiii; and Bamford, *Puzzle Palace, p.* 119.

43. A proposal for a joint enterprise by Norris and his colleagues was turned down by J. Presper Eckert. The civilians who established ERA explicitly intended to market commercial products based on the technology developed for government applications. See William Norris, "Entreprenueurism—the Past, Present, and Future of Computing in the USA," *Computer Museum Report, vol. 19* (Spring 1987), p. 12. It was not unknown for patented technology developed for defense to become the property of the developer. Nevertheless, at the time the

Navy was sensitive about the circumstances of its noncompetitive contracts with a group of ex-officers. See Tomash and Cohen, "Birth of an ERA," pp. 86-87, 90-91.

44. Samuel S. Snyder, "Computer Advances Pioneered by Cryptologic Organizations," *Annals of the History of Computing, vol.* 2 (January 1980), pp. 61-62; Snyder, "Influence of U.S. Cryptologic Organizations," pp. 5-7; and Tomash and Cohen, "Birth of an ERA," pp. 89-93.

machines, and later used in general purpose computers. Its research on magnetic drums built on captured technology developed in Germany during the war.45 The company also invented a special magnetic spray coating to improve the performance of the drum memories.46

In 1947 U.S. naval intelligence issued an order to ERA to design and construct a general purpose digital computer. The hope was that a general purpose computer could be programmed to do many of the tasks for which ERA had been building special, one-of-a-kind machines and therefore reduce the cost of code cracking. This machine, code-named Atlas, was Task 13, the thirteenth job given to ERA by the Navy, and was operating by the end of 1950.

The Atlas computer development effort drew heavily on the work of others—logical designs produced by von Neumann's computer group at IAS and engineering designs from MIT's Whirlwind computer group. Because of the priority given to the project by military sponsors, the Navy gave ERA engineers access to reports on computer work on other government projects .47 Technology flowed both ways however—another early task assigned ERA was to produce a survey of computing technology based on its investigations, and this book, published in 1950, became a standard handbook for the industry.48

The Atlas, delivered to the Navy at the beginning of December 1950 became fully operational in a week. It was the second electronic stored program computer to go into regular use in the United States.49 One year

45. Emmett Quady, who joined ERA in 1947, recalls, "I remember the very first day I went to work they had a captured German magnetic drum of some sort. They'd captured it, you know, in occupation and brought it over." Unpublished interview with Emmett Quady conducted by Robina Mapstone, May 15, 1973, available in the Smithsonian Institution, Washington, D.C. Emerson Pugh describes a special type of magnetic tape material brought over from Germany and used at ERA. Pugh, *Memories* p. 20, citing an interview with S. M. Rubens, May 30, 1980.

46. Snyder, "Computer Advances," p. 62; and Mapstone interview with Emmett Quady on May 18, 1973. Interview with James Cass by Robina Mapstone, December 18, 1972, available in the Smithsonian Institution, Washington, D.C. In 1949 ERA entered into a design project with IBM to develop a magnetic drum computer, which though never built, led to a technology transfer and cross-licensing arrangement with IBM that gave IBM access to ERA's extensive

patents on magnetic drums. Tomash and Cohen, "Birth *of* an ERA," p. 91. For an IBM perspective, see Bashe and others *IBM's Early Computers*, pp. 81-83.

47. Snyder, "Computer Advances," p. 62; and Tomash and Cohen, "Birth *of* an ERA," p. 89.

48. As Cohen, *High-speed Computing Devices, p. xix,* explains, a Russian translation published in 1952 seems to have been important in the development *of* Soviet ideas.

49. The first was the National Bureau of Standards' SEAC machine, which was

after delivery to the Navy, ERA received permission to market a commercial version of the Atlas as the ERA 1101.50 Though only one was built, a more advanced successor, the ERA 1103, also developed originally as a Navy project (the Atlas II) became the first ERA computer to go into large-scale serial production (twenty machines were built). ERA, producing an estimated 80 percent of the dollar value of computers sold in the United States through 1952, became the dominant computer company of its day.51

Because of the nature of its market, engineering considerations dominated ERA' s business orientation. The company designed and built machines to a user's specifications, then handed the hardware over to the purchaser.52 In sharp contrast with the experience of firms seeking a commercial market, ERA experienced little feedback from users and little direct contact with what remained a relatively unknown market. The emphasis on technical sophistication over marketing, it may be argued, persisted in the computer companies that the engineers brought up in ERA went on to found.

The Origins of a Commercial Industry

At the war's end, it was far from obvious that the newly developed electronic computers were going to have much practical impact on business. According to prevailing wisdom, the government might need several large electronic computers, but they would have no broader appeal. Nonetheless, as military intelligence organizations began building electronic computers during the war to assist in their cryptological work, parallel developments in computing machinery occurred in more open environments. The idea of applying electronic computers to com

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turning out mathematical work regularly in May 1950. The MIT Whirlwind's central machine was working about 1951. See Ralph J. Slutz. "Memones of the Bureau of Standards' SEAC," in Metropolis and others, *A History of Computing, p.* 476; and Robert R. Everett, "Whirlwind," in Metropolis and others, *A History of Computing,* p. 372.

50. The figure 1101 is the binary representation of the decimal number 13.

51. Pugh, *Memories, p.* 19; and Franklin M. Fisher, James W. McKie, and Richard B . Mancke, *IBM and the U.S. Data Processing Industry: An Economic History* (Praeger, 1983), p. 10.

52. The ERA 1101 was offered for sale with no documentation, no operating system, and virtually no input-output other than paper tape. Tomash and Cohen, "Birth of an ERA," p. 90.

mercial and business problems gradually became the driving force behind the spectacular rise of a computer industry.

J. Presper Eckert and John W. Mauchly were foremost among those with the visionary idea of applying computers to everyday industrial and administrative tasks. Mauchly, as a teacher of physics at Ursinus College, near Philadelphia, had begun experimenting with high-speed vacuum tube counting circuits in the late 1930s.53 Mauchly attended a training course in electronics given at the Moore School at the University of Pennsylvania in 1941 and was then invited to teach there. He soon became associated with Eckert, a graduate student and the top electronic engineer at the school . The Moore School had built a differential analyzer for the Army's Ballistic Research Laboratory (BRL) in 1939, adapted from the design of Bush's MIT machine, and was collaborating with BRL in training computing personnel for the Army. In August 1942 Mauchly submitted a proposal to the Moore School and the BRL to build a high-speed vacuum tube calculator for ballistics calculations. Both recipients ignored the proposal.

In the spring of 1943, at the initiative of BRL's representative at the Moore School, Herman H. Goldstine, Mauchly resubmitted the proposal. Unexpectedly, the Army promptly pursued it, and a contract was signed six weeks later. In retrospect, the dates suggest that the takeover by the Navy at the end of 1942 of the Desch and Mumma group at NCR, which had been working on an electronic calculator for BRL, must have influenced the Army to fund the work at the Moore School.54

The design of the machine, the ENIAC, was frozen a year later, in June 1944, and in November 1945, after the war had ended, it was ready for testing. It had most of the elements of a modern digital computer but lEked an internal program store, which allows a computer to treat its own program as data and modify the instructions it follows as they are executed. The ENIAC is often identified as the first electronic digital computer, but the Colossus, completed in great secrecy two years earlier in England, contained circuitry functionally equivalent to that found in ENIAcs though on a considerably smaller scale.

53. The descnption of J. Presper Eckert and John W. Mauchly draws heavily from Stcrn, *From ENIAC to UNIVAC.*

54. This point has not been made in the literature on Eckert and Mauchly, perhaps because there is essentially no published information on the work of Desch and Mumma for the Army's Ballistic Research Laboratory at National

Cash Register Corporation; the dates given in their unpublished interview with Tropp on September 17 and 18 1972, do support this inference, however.

The ENIAC was a massive machine, occupying 1,800 square feet. It contained almost 18,000 tubes and consumed 174 kilowatts of power. The system cost almost $800,000 to build.

The decision to build the ENIAC resulted from the Army's pressing wartime needs. The established scientific computing community within the government's Of fice of Scientific Research and Development, headed by Vannevar Bush, fiercely opposed the Eckert-Mauchly project. At issue were both the digital design of their proposal (an advanced analog differential analyzer was being built at MIT at the time) and their proposed use of electronic circuit elements. Samuel H. Caldwell, Bush's MIT colleague, wrote, "The reliability of electronic equipment required great improvement before it could be used with confidence for computation purposes."55 Stibitz, at the Bell labs, expressed similar sentiments and suggested using electromechanical relay technology.

After the war, when Eckert and Mauchly turned to more advanced designs, opposition from established figures in computing continued. Howard Aiken, who had struggled at Harvard before the war to seek support for constructing a large electromechanical calculator, opposed their projects, suggesting, "There will never be enough problems, enough work, for more than one or two of these computers...."56 Thus the Army' s willingness to gamble on a radically new approach, and Eckert and Mauchly's stubborn defiance of the scientific establishment led to the birth of the first all-electronic computers. Their achievement in engineering a reliable system composed of eighteen thousand inherently unreliable components must not be understated.

Well before ENIAC was finished, Eckert and Mauchly's group began thinking about a new and improved machine. Two principal shortcomings of the original ENIAC—limited memory available for use in calculation and a complex and difficult procedure for programming calculations using manual switches—were becoming increasingly obvious. Ideas for improving ENIAC revolved around these problems. In August 1944 the concept of an improved machine was broached to the Ballistics Research Laboratory, and by October, a contract had been issued to the Moore School.

By then, an important addition to the Moore School team had been made. The famous mathematician John von Neumann had learned of the existence of the project and had immediately begun regular visits.

55. This letter is cited in Stern, *From ENIAC to UNIVAC, p. 20.*

56. Stern, quoting Edward Cannon of the NBS. Ibid., p. 111.

Von Neumann, a superb mathematician, had become a powerful voice in the scientific establishment that ran the U.S. war effort' s research and development program. His most important project at the time was his work on the development of nuclear weapons at Los Alamos National Laboratory, a task requiring tedious and time-consuming numerical calculations He had also had personal contact with Turing at Princeton before the war and was familiar with Turing's abstract formalization of a computing machine.57

Von Neumann's presence stimulated a more formal and rigorous approach to the design of the successor machine, dubbed the Electronic Discrete Variable Automatic Computer (EDVAC). Over the ensuing months of discussion, ideas like the need for more memory and the concept of the stored program gained impetus. In April 1945 von Neumann composed a working draft based on these discussions, and the resulting "First Draft of a Report on the EDVAC" circulated widely among the scientific community.58 The ideas on the logical design of a computer contained in that document were the basis for machine design well into the 1950s, and the essential architecture for a computer system set out in that report, the so-called von Neumann architecture, is today the basic design of all but experimental or special purpose computers.

Even before the EDVAC report was written, von Neumann had been working on setting up his own computer project at IAS. The nascent conflict over credit for the EDVAC ideas, as well as an overture to RCA to support the construction of an IAS computer, and a failed attempt to lure Eckert to the Princeton project, led to worsening relations with Eckert and Mauchly.

The publication of the EDVAC report, and the public dedication of the ENIAC machine in February 1946, had put the United States at the **f**orefront of computing technology. Even before ENIAC had been completeds streams of visitors were pouring through the Moore School,

S7. Hodges, *Alan Turing, p.* 145.

58. Only von Neumann's name was on the report, though it contained many ideas worked out by the entire Eckert-Mauchly group at the Moore School. This has led to an acrimonious historical debate about whether or not von Neumann was primarily responsible for the concept of the stored program, the key dividing line between special purpose digital electronic computing machines like ENIAC or Colossus, and the general pupose electronic digital computer. See Stern, *From ENIAC to UNIVAC,* pp. 74-78 and lames E. Tomayko, "The

StoredProgram Concept: National Computer Conference, Houston, Texas, June 9, 1982," *Technology and Culture, vol.* 24 (October 1983), pp. 660-63.

eager to hear how the newly developed electronics technology applied to problems of numerical calculation. In contrast to the Navy's ultrasecret work on cryptological machines, information on the ENIAC and EDVAC was widely accessible.

In early 1946 Eckert and Mauchly were pressured to sign a patent release giving the Moore School rights to the technology developed on the EDVAC project, just getting under way. After resisting similar pressures, they had retained rights to patents filed for the ENIAC technology and were clearly interested in commercial applications. In the spring of 1946, they resigned and set up their own firm, intending to manufacture an electronic computer for commercial use. After further wrangling over patent rights on the EDVAC (to which von Neumann also made a claim based on his authorship of the EDVAC report), the Army's patent lawyers ruled that because of the time elapsed since publication of the EDVAC report, the concepts related to EDVAC-type machines were in the public domain. Other groups would use these ideas in designing their computers over the next few years.

Many from the Moore School computer project left after Eckert and Mauchly's departure. Some engineers joined the new commercial venture, and others joined von Neumann's project at the IAS in Princeton. The Moore School's research director left shortly thereafter to start a computer division at Burroughs. Though a prototype was put into fitful operation, the EDVAC project was never fully completed.

Improvement of computer technology owed a great deal to the EDVAC. Its widely circulated design was used in many other computers, and lectures by the Moore School staff were critically important in getting other computer groups started. The presentations given by the Eckert-Mauchly group at a conference held at MIT in 1945 were important in steering the Whirlwind project at MIT toward digital computer technology.[59] A six-week course at the Moore School in the summer of 1946 got the Navy's cryptological establishment interested in general purpose digital computers.[60] This course greatly influenced others, including Maurice Wilkes, who began the Electronic Delay

59. See Redmond and Smith, *Project Whirlwind, p.* 33; and Stern, *From ENUC to UNIVAC, p.* 55.

60. Snyder, "Influence of U.S. Cryptologic Organizations," p. 7, credits James T. Pendergrass of the Navy's Communications Supplementary Activities

Washington, who attended this conference, with promoting Navy interest in general purpose digital computers.

Storage Automatic Calculator (EDSAC) project in England. The EDSAC was explicitly modeled on the EDVAC design and was probably the first full-scale stored-program digital computer to begin operation. Thus, even as the EDVAC project withered on the vine, its seeds were scattered widely.

Eckert and Mauchly, now having ruptured their ties to the academic world, faced serious difficulties. The scientific community was generally negative about their computer project; funding and customers were scarce. Before they had left the Moore School, Eckert and Mauchly had interested the Census Bureau in funding the development of an electronic computer for computation work through the Commerce Department's National Bureau of Standards, and only the NBS continued to actively support them.

Even the NBS could give only minimal backing in the short run, and Eckert and Mauchly were forced to scramble for funding. The Northrop Aircraft Company, in California, approached them about constructing a digital computer to be used for guidance of the Snark missile, then under development for the Air Force. Desperate for cash, Eckert and Mauchly agreed to an arrangement with 80 percent of the contract prepaid, and used this small computer, the Binary Automatic Computer (BINAC), as a development vehicle for the larger commercial machine they sought to market.

The BINAC passed performance trials at Eckert and Mauchly's Philadelphia lab in 1949, the first stored-program computer to function successfully in the United States. It was not well constructed, however, and never performed adequately when moved to California. Development costs, which amounted to $278,000, exceeded the fixed $100,000 fee negotiated with Northrop,[61] and the financial condition of the Eckert-Mauchly operation worsened. Finally, in early 1950, in desperate financial straits, Eckert and Mauchly sold out to Remington Rand.

In 1951 the first Universal Automatic Calculator (UNIVAC) built by Eckert and Mauchly was delivered to the Census Bureau. The UNIVAC became a great commercial success and propelled Remington Rand to market leadership in the early 1950s. By the end of 1952, three had been delivered to the government, and ultimately, forty-six UNIVAC's were built.[62]

61. Stern, *From ENIAC to UNIVAC*, pp. 122-24.
62. Jean E. Sammett, "Answers to Self-Study Questions," *Annals of the History of Computingn vol.* 6 (October 1984), pp. 406-07.

The Institute for Advanced Study

Von Neumann started his computer project in 1945, securing funding from the Army and Navy ordnance departments and the IAS. RCA entered a joint contract with the IAS to develop a tube-based memory device called the Selectron for the IAS computer system. Beginning in 1946, the logical design of the IAS machine was published in a series of papers by von Neumann and his associates. Although financial support came from the military, and later, the Atomic Energy Commission, there were few security complications, and the reports were widely circulated. Unlike other military projects, working drawings and preliminary designs for the IAS computer were to be distributed to five other development centers, at the University of Illinois, the Oak Ridge National Laboratory, the Los Alamos National Laboratory, the Argonne National Laboratory, and the Rand Corporation, where copies of the machine were to be built.63

The influence of the IAS project in the early years of U.S. computer technology was therefore extensive, even before its completion in 1951. As the published design circulated widely, joint projects with other research institutions on subsystems for the Princeton computer were undertaken (with RCA on the Selectron tube storage system, with the Washington laboratories of NBS for controllers for serial-type inputoutput devices). Other collaborating institutions built copies of the basic design.

These copies included those built at the five laboratories officially designated in the funding contracts for the IAS system—the ILLIAC I built for the Army at the University of Illinois, ORDVAC at Aberdeen Proving Grounds in Maryland, MANIAC I at Los Alamos, the AVIDAC at Argonne, the Oak Ridge ORACLE, and the JOHNNIAC at Rand. Many unofficial "bootleg" copies were also built—the BESK and SMIL machines in Sweden, the BESM in Moscow, the WEIZAC in Israel, the Australian SILLIAC and CSIRAC computers, and the MSUDC at Michigan State.64 Many pioneers of the computer industry cut their teeth on these projects.

The IAS computer also greatly influenced the logical design of IBM's

63. Julian Bigelow, "Computer Development at the Institute for Advanced Study," in Metropolis and others, *A History of Computing, p. 292*.

64. Goldstine, *Computer*, pp. 306-07; and C. Gordon Bell and Allen Newell, *Computer Structures: Readings and Examples* (McGraw-Hill, 1971), p. 89.

early 700 and 7000 series scientific computers, which evolved from the IAS architecture. Von Neumann started consulting for IBM on a thirty days-per-year basis in 1951, and key IAS computer group members joined IBM in the late 1950s, when the Princeton computer group disbanded.65

MIT and the Whirlwind

Another important influence on the nascent computer industry in the late 1940s was MIT's Whirlwind computer. Like the IAS computer, Whirlwind was built by a university-based group of engineers who carefully documented the machine's development and distributed widely read progress reports on its construction. Whirlwind also had the distinction of being by far the most costly of the early U.S. computer projects. Bitter fights over Whirlwind funding characterized the debates over U.S. research policy affecting computer development in the late 1940s and early 1950s.66 Whirlwind had started life as the MIT ASCA project in 1944, intended to supply the Navy with a general purpose flight simulator, provide inexpensive training for pilots of a broad range of aircraft, and supply data on pilot-airplane interaction useful in aircraft design. The project, headed by Jay W. Forrester, an electrical engineering graduate student in MIT's Servomechanisms Laboratory, was largely staffed with young MIT graduate students.

In 1944 the Navy approved a preliminary design study for the ASCA, for $75,000. A full-scale eighteen-month development project, to cost $875,000 was initiated. Originally the project was to use an analog computer, employing the electromechanical differential analyzer technology pioneered at MIT, to control the machine. By the fall of 1945, the war had ended, and Forrester and his colleagues had run into serious design problems in their attempts to build an analog computer sufficiently fast and flexible to handle the real-time control of an aircraft simulator.

At that point, in October 1945, the Archibald conference, an early and important conference on advanced computation techniques, was held at MIT, and the MIT ASCA group learned of the electronic digital

65. Goldstine, *Computer, p.* 346; and Cuthbert C. Hurd, "Computer Development at IBM," in Metropolis and others, *A History of Computing*, pp. 401-02.
66. Unless otherwise noted, this section draws on Redmond and Smith, *Project Whirlwind* .

computers, the ENIAC and EDVAC, being built at the Moore School. After further research, the MIT group quickly decided to switch to a digital electronic computer to control its simulator. By the spring of 1946, the MIT group had submitted a revised proposal calling for the construction of a digital computer, the Whirlwind, and a simulator using that computer, to be built by 1950 at a total cost of about $2.4 million. The Navy accepted the proposal and funded it at $1.2 million through mid-1948. 67
Whirlwind had been funded by the Special Devices Division of the Navy, however, and at the end of 1948, conflicts over funding of the project began to surface. For one thing, the newly born Of fice of Naval Research had begun to exert authority over all Navy research projects, and the Whirlwind project had been transferred to the mathematics branch of ONR in 1948. For another thing, costs on the Whirlwind computer continued to climb—by early 1948, another $600,000 had been authorized by the Navy, which also extended the original contract another year. When MIT requested another $1.8 million from ONR to cover the fifteen months from June 1948 to September 1949, the matter blew up into a major flap over research policy.

To put it most baldly, MIT's funding requests for Whirlwind for fiscal 1949, now almost $1.5 million, amounted to roughly 80 percent of the 1949 ONR budget for mathematics research, and about 10 percent of the entire ONR budget for contract research.68

At that time, the mathematics branch of ONR funded most of the computer projects under way in the United States, and Whirlwind ' s total funding requests were now running almost five times greater than the projected costs of another of ONR's most ambitious projects, the IAS computer, projected in 1950 to cost a total of about $650,000. MIT mobilized to defend the project, and as part of that defense, Forrester and his associates outlined a sweeping vision of military applications of computers to command and control tasks, including air traffic control, fire and combat control, and missile guidance, as well as to scientific calculations and logistics. The estimated cost of this program was put at $2 billion, over fifteen years *,69* The originaljustification for the computer, as the controller for a flight simulator, was rapidly replaced by the

67. Ibid., p. 43.
68. Ibid., pp. 110-11.
69. Ibid., p. 166.

broader concept of a computerized real-time command and control system.

MIT's conflict with ONR touched on various sensitive issues. One unstated issue must certainly have been the large fraction of public research funds for computers going to MIT. During World War II, MIT had expanded enormously, as research projects funded by the OSRD, largely run by professionals with MIT connections, had poured into the institute. MIT was the largest single recipient of wartime research contracts; its $56.0 million in contracts with the OSRD ran about 20 percent of the nearly $0.25 billion in wartime research conducted by educational institutions and was a significant fraction of the $1.0 billion going to industrial firms.[70] It must have been especially galling to established members of academic mathematical circles to be in a close competition for research dollars with a group of young, largely unknown MIT engineers, with no real finished product to show for their efforts yet.

Top MIT scientists and administrators lobbied for the Whirlwind project with the Navy, but, finally, ONR restrained the funding. The final appropriation for fiscal 1949 was $1.2 million, and the fiscal 1950 budget was trimmed back to $750,000. By this time, MIT had turned to the Air Force with its vision of an air traffic control system, and the Whirlwind project had been given a smaller $ 122,000 study grant in 1949. A special ad hoc panel reviewed the MIT project and concluded in 1950 that the Whirlwind computer, its original flight simulator objective all but forgotten, lacked a suitable mission.

The Russian thermonuclear test of 1949 had occurred by this time, however, and the Air Force was alarmed about the possibility of a Soviet bomber attack on the United States. The outbreak of the Korean War in 1950 had made the perceived need for an air defense system even more urgent, and the Air Force stepped in to support the Whirlwind project just as the Navy phased out its funding. Of the fiscal 1951 expenditures of more than $900,000, about $600,000 came from the Air Force, the remainder from the Navy. From this time forward, the Air Force's air defense needs dominated computer development at MIT.[71]

70. Penick and others, *Politics of American Science, p.* 100.

71. The Navy continued promoting the development of computer science at MIT well into the 1950s, though. MIT had established a Center for Machine

Computation, directed by Professor Philip M. Morse, to supervise the use of computing machines at MIT, which included Whirlwind, when it was not being used for air defense studies.

In the atmosphere of crisis prevailing in 1951, the Air Force commissioned Project Charles, a study at MIT of the feasibility of a continental air defense system against long-range bombers. The report issued in the fall of 1950 supported the concept, and MIT set up Project Lincoln, or the Lincoln Laboratories, as a semiautonomous72 large-scale research and development facility, dedicated to the development of an air defense system. The Whirlwind computer development team was absorbed into this lab and moved away from the MIT campus shortly thereafter, though the original Whirlwind remained on campus . The computer work became a component of the Semi-Automated Ground Environment air defense system (SAGE) developed during the 1950s, and the Lincoln/MIT/IBM SAGE computers contributed greatly to the technological development of the infant U.S. computer industry.

Subsystems of Whirlwind gradually began coming to life in 1949, and by 1951 the entire central machine was functioning.73 The Whirlwind machine pushed computer technology forward in several, important areas. The development of high-speed electronic logic made the Whirlwind much faster than other machines of its day and a big influence on other computer projects. Its developers devised techniques for checking the integrity of vacuum tube circuit components that vastly increased the reliability of systems using tubes. Graphic display technology was pioneered in devices employing cathode ray tubes (CRTs) that tracked the aircraft position data pouring in and out of the machine. New types of digital switches, including the supercooled cryotron, were developed as a by-product of the research effort.74

The center received $650,000 from ONR in 1951, $250,000 in 1952, and $285,000 in 1953. Later allocations were much smaller, although the National Science Foundation began to fund computer facilities and research at MIT after these grants were phased out. See Redmond and Smith, *Project Whirlwind,* pp. 156-58.

MIT had also begun another computer project funded by the Rockefeller Foundation after the war, apparently to draw Norbert Wiener, who refused to work on military research after the war, into computer development. When Wiener showed little interest, MIT returned the funds and concentrated on the Whirlwind project. Karl L. Wildes, "Electrical Engineering at the Massachusetts Institute of Technology," unpublished manuscript, chap. 5, pp. 127-31.

72. Located in Lincoln, Massachusetts, the laboratories were far from MlT's home base in Cambridge.

73. See Everett, "Whirlwind," p. 372.

74. The cryotron, invented by Dudley Buck while working on Project Whirlwind, was the direct forerunner of work on supercooled circuit elements that led to the invention and development of the Josephson Junction. See Redmond and Smith, *Project*

Perhaps the most important development emerging from Whirlwind was the ferrite core memory. A fast and reliable technology for storing data to be accessed frequently by the main processing unit of a computer, so-called primary memory, was a principal goal of early technology development efforts . Eckert and Mauchly and others building "EDVAC-type" serial computers used mercury acoustic delay lines for primary memorY, but these were slow and prone to breakdown.75 Attention then turned to using some form of cathode ray tube for storage, which would have the advantage of making stored data accessible randomly, that is, without having to move through successive locations in memory to reach a desired storage location, as was the case with acoustic delay lines.76

As part of its collaboration with Princeton on the IAS computer, RCA developed a special cathode ray tube to be used as a random access memory. Though the project was closely related to RCA's principal postwar research focus, color television, the work was difficult and progress slow; RCA's Selectron memory tube was not produced in quantity until 1951.77 F. C. Williams, at Manchester University, however, devised a technique for using an ordinary CRT as a storage device in 1947, and variants on the "Williams tube" soon showed up in designs for computer memories, and finally, in the IAS computer. Forrester's group at MIT had devised its own rather complex variant on a CRT memory, but it, like Williams' design, suffered from problems with reliability.

Whirlwind, p. 216; Pugh, *Memories, p.* 216; and Snyder, "Influence of U.S. Cryptologic Orgaluzations," pp. 25-27. The NSA funded a $25 million electronics research effort in the late 1950s known as Project Lightning, which included continued work on supercooled switching devices. Later research at IBM on the Josephson Junction was also partially funded by NSA. See Snyder, "Computer Advances," pp. 67-69.

75. William Shockley, who later developed the transistor and shared in the Nobel Prize awarded for its invention, invented the acoustic delay line during the war. The line was used as a temporary storage device for radar data being displayed on a CRT. Eckert and Mauchly were introduced to the concept of a delay line through Eckert's work on a Moore School subcontract from MlT's Radiation Laboratories, which supervised wartime radar work in the United States. See Stern, *From ENIAC to UNIVAC, p.* 60; Hodges, *Alan Turing, p.* 315; and Arthur W. Burks, "From ENIAC to the Stored-Program Computer: Two

Revolutions in Computers," in Metropolis and others, *A History of Computing, p.* 336.

76. A random access memory (RAM) is now commonly and cheaply implemented in semiconductor integrated circuits.

77. See Jan Rajchman, "Early Research on Computers at RCA," in Metropolis and others, *A History of Computing, p.* 468; see also Hodges, *Alan Turing, p.* 321; and Pugh, *Memories*, pp. 35-37

In 1949 Forrester had begun to work on alternatives to CRT memories, in particular, on a memory device using rings (or cores) of ferromagnetic material, where a binary digit would be stored by setting the magnetic flux of the ring.78 Forrester was not the only one investigating this idea; An Wang, working on Howard Aiken's computer project at Harvard, had set out a description of a storage device using this principle in late 1949, and Jan A. Rajchman had explored similar concepts at RCA that same year. 79 Forrester' s concept was technically superior to the others, however, and was developed and improved as the memory for Whirlwind's successors, the SAGE air defense computers.80

Core memories were the technology of choice for fast primary memory for a long time—from the mid-1950s through the early 1970s, when semiconductor integrated circuits began to be used on a large scale. To this day, they continue to be used in extreme environments or when power supplies are liable to be interrupted, as in defense systems. This great advance in computer technology was perhaps the most important legacy of Whirlwind.

Howard Aiken and the Harvard Computers

MIT was not the only influence on computer technology with headquarters in Cambridge, Massachusetts. Harvard University had been involved since 1939. A young instructor of physics, Howard Aiken, had worked with IBM on a project to build an electromechanical programmable calculator, which came to be known as the Harvard Mark I. Aiken was responsible for the overall architecture of the machine, while IBM developed its components and did the systems engineering; the machine was to be donated to Harvard by IBM.

78. The material used in the femte cores, called Deltamaxs was developed in Germany during the war and brought back to the United States by the military along with the machinery and tooling used to produce it. See Pugh, *Memories,*

pp. 39-40. As was true for the magnetic drum memory, German technology contributed to U.S. advances in ferromagnetics in the late 1940s. See Jan Rajchman, "Recollections of Memones from RCA in the Fifties," *Computer Museum Report, vol.* 13 (Summer 1985), PP- 1l-13.

79 Pugh, *Memories,* pp. 39, 81-89; and Rajchman, "Early Research," p. 46569.

80. Pugh, *Memories*, pp. 34-57, describes how early core memories were developed and improved upon in many places, including IBM, in the early 1950s. Eventually, MIT and IBM jointly produced core memories on the SAGE project. Ibid., pp. 93-128.

Construction dragged on well beyond the estimated two years and $100,000 originally budgeted. After the war started, Aiken was inducted into the Navy and put to work on the Navy's computational needs. IBM delivered the machine to Harvard in 1944, where it was taken over by Aiken and the Navy. But relations between Aiken and IBM's president, Thomas J . Watson, Sr., had deteriorated over issues of credit and public claims to the invention of the machine, and IBM and Aiken parted company in a cloud of acrimony.

Aiken went on to design more programmable calculators and computers in his Harvard laboratory after the war. From 1945 to 1947 he built the Mark II for the Navy; it was installed at the Naval Proving Ground in Dahlgren, Virginia, and used in ballistics research. In 1949 the Mark III was finished and again installed in the Navy's Dahlgren research facility. In 1952 the last of this series of machines was finished, though the Mark IV was paid for by and delivered to the U.S. Air Force.81

The Harvard Mark series of machines had a fairly small impact on contemporary computer technology. Aiken, conservative in his designs, stressed reliability and the use of proven technologies. Thus both the Mark I and II were electromechanical machines, using relays and rotating counters. The Mark III used a magnetic drum and introduced some electronic circuitry. The Mark IV made use of ferrite core memories, electronic tubes and diodes, as well as relays. Because of the technological conservatism, though, all these machines were slow, even by the standards of the day.

Aiken had a larger impact on computer design and use, however, because of the great number of his graduate students and associates who went on from Harvard to other computer activities. With ONR support, Aiken offered a graduate training course in computing machinery in 1947 and 1948, held symposia, and produced books on scientific computing.82

The students and associates of Aiken had a particularly important effect. An Wang, who had worked on ferrite core memories in Aiken's lab at Harvard, after receiving his Ph.D. in 1948, left to start Wang Laboratories in 1951, now a significant force in the U.S. computer

81. M. R. Williams, "Howard Aiken and the Harvard Computation Laboratory," *Annals of the History of Computing, vol.* 6 (April 1984), pp. 157-61.
82. See Mina Rees, "The Computing Program of the Office of Naval Research, 1946-1953," *Annals of the History of Computing,* vol. 4 (April 1982), pp. 10506.

tors for the Aberdeen and Dahlgren ballistics laboratories during and after the war that were faster than the Mark I, but smaller in capacity.89 The SSEC was designed to be both bigger and faster than the Mark I— IBM press releases pointed out that arithmetic operations on the SSEC were at least 250 times faster than on the Mark I.90

A former assistant of Aiken's, Rex R. Seeber, heavily influenced the SSEC's architecture. Seeber had left the Mark I project after a dispute with Aiken over Seeber's proposal that future models from the Harvard labs be designed to modify their own programming while running, which Aiken had thought unnecessary. Seeber joined IBM and successfully promoted the idea, so the SSEC consequently became the first calculating machine with a dynamically modifiable program.91 Although the arithmetic unit of the SSEC did incorporate some of the new ideas about electronic circuits, in order to gain computational speed, the bulk of the machine used the older electromechanical wheels and relays technology. The SSEC was more in the tradition of the Mark I than an electronic digital computer as conceived by Eckert, Mauchly, and von Neumann. Inaugurated in 1948, newer technologies soon eclipsed the SSEC and it was dismantled in 1952 to make room for the Model 701, IBM's first true electronic digital computer.

IBM's 701 grew out of a different set of circumstances. After the war, Ralph L. Palmer had returned to IBM from NCML, where he had worked in engineering electronic cryptological machinery for the Navy and had been exposed to the same state-of-the-art electronics technology that had inspired the founders of ERA to go into the computer business.92

89. Hurd, "Computer Development at IBM," p. 397; and Bashe, "The SSEC," p. 302. See Niemann, *Dahigren's Participation,* pp. 3-4.
90. Pugh, *Memories, p.* 7; and Hurd, "Computer Development at IBM," p. 397.
91. R. Moreau, *The Computer Comes of Age: The People, the Hardware, and the Software* (MIT Press, 1984), pp. 39-41, and Bashe, "The SSEC," pp. 310-11, argue that the SSEC was the first computing machine with an internally stored program. Hurd is less generous in his analysis. Hurd, "Computer Development at IBM," p. 397. See also Pugh, *Memories,* pp. 7-11. Since the SSEC generally read in its programming from paper tape, it could punch out tapes and then read in as a program what it had just punched. This is not quite what most analysts

have in mind when they refer to an internally stored program. Its electronic and relay memory was limited, and though instructions stored internally were modifiable (and therefore can be considered an internally stored program), the machine operated principally from its externally stored (on paper tape or cards) program.

92. Another key IBM engineer, Stephen W. Dunwell, had worked for OP-20-G's counterpart in the Army Signal Corps. Dunwell also was a leader in IBM's efforts in electronics, and later he directed the development of IBM's Stretch supercomputer in

During the war, IBM had started a small laboratory and factory in Poughkeepsie, New York, to build equipment for "a government need."93 In this small lab, and not in IBM's main research facility in Endicott, Palmer began to build an electronics group for IBM after he was mustered out of the service. While the engineers in IBM's main Endicott facility, who were well versed in the older electromechanical technology, worked at building the newer relay computers, including the SSEC, and improving IBM's traditional line of accounting machinery, Palmer's development group in Poughkeepsie worked on perfecting electronic circuitry and introducing it into traditional business machines. A series of electronic calculating machines introduced by IBM in the late 1940s resulted from this effort.94

In 1948 Palmer's Poughkeepsie lab began aggressive recruiting; the crop of young engineers who joined IBM over the next several years were the technical leadership that propelled IBM into its place as a computing power in the 1950s and 1960s. Palmer's electronics group more than doubled in size in 1949 alone.95

IBM's entry into computer production was delayed, however. The company viewed its natural area of concentration as electric accounting machines, which were quite profitable. Managers saw no commercial market for computers. Top engineering management, when evaluating

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the late 1950s. See Bashe and others, *IBM's Early Computers*, pp. 60, 61, 174. Other prominent IBM engineers exposed to wartime advances in military cryptology included Max Femmer, David Crawford, and Philip Fox. See Erich Bloch, "Remarks," presented at the Computer Museum, Boston, June 15, 1986, p. 36; and Pugh, *Memories, p.* 35.

93. Hurd, "Computer Development at IBM," p. 402.

94. The first electronic calculator produced by IBM, the IBM 603, was the fruit of the small electronics research effort that had been started before the war. It was produced in limited quantities, then replaced by the IBM 604, designed at Poughkeepsie. The plug-programmable 604 was introduced in 1948. The electronic calculator line **reached** a new level of functionality with the introduction of the Card-Programmed Calculator (CPC), in 1949, which consisted of a 604 tied to an IBM 405 accounting machine. The CPC, in effect a cardprogrammable version of the 604, was engineered by IBM at Endicott in response to a request from the Northrop Aircraft Company. The CPC was a success; about 250 were installed during the 1949-52 period. See ibid., p. 400;

Phelps, "Early Electronic Computer," pp. 258-64: and Bashe and others, "IBM's Early Computers," pp. 34, 44-72.

95. Among the young recruits joining IBM over this period were Charles J. Bashe, who headed the engineering team on the IBM 702 computer, Nathaniel Rochester, who came to IBM from the MIT Whirlwind project and was a key figure in the 701 design, Gene Amdahl, chief designer of the System 360, Erich Bloch, who headed the Stretch design team, and Bob O. Evans, head of the 360 project and later IBM's chief engineer. See Bashe and others, *IBM's Early Computers, p.* 118.

the possibility of constructing electronic computers for the NBS computer program, urged management not to enter the activity, on the grounds that it might endanger IBM's patent position. Instead, they counseled the head of the company, Thomas J. Watson, Sr., to maintain enough of a development effort to recognize significant external innovations when they occurred and to adopt them quickly in IBM products.96

Within the company, though, Watson, Sr.'s heir apparent, Thomas Watson, Jr., pushed for IBM's entry into electronic computers. IBM produced the 603 calculator, its first postwar electronic machine, as a direct result of the younger Watson's persistent advocacy of electronics. Watson, Jr., and the young engineers Palmer had brought into the company had struggled to gain approval for a high-speed computer project, using magnetic tape for input and output and electronic memory. This experimental project, called the Tape Processing Machine (TPM), became IBM's first computer project at the end of 1949.97

In 1950, when the Korean War began, Watson, Sr., pledged the company's resources to support the war effort. After IBM personnel had surveyed the government's computing needs, Watson, Jr., convinced his father that enough government demand existed to support the production of twenty special purpose computing machines for the war effort. Engineers were then pulled from the TPM project and assigned to what came to be known as the IBM Defense Calculator, later renamed the 701. The 701, funded by IBM in anticipation of a healthy volume of government sales, was completed in under a year and a half and was demonstrated in the spring of 1952.

The 701 used important parts of the TPM technology and was modeled on the logical structure of the IAS computer. Other important influences came from the MIT Whirlwind project and the English computer groups.98 Nineteen 701 s were built by 1954.

They were rented for $20,000 a month, when the monthly rate for other IBM machines was $300 or so.99 The first 701s came out after Eckert and Mauchly's UNIVAC computers were already attracting commercial interest. Racing to catch up, IBM under Watson, Jr., poured resources into the development of its computer business.

96. Pugh, *Memories, p.* 26.
97. Ibid., pp. 27-29; and Phelps, "Early Electronic Computer," pp. 264-65.
98. Phelps, "Early Electronic Computer," pp. 265-66; and C. J. Bashe and others, "The Architecture of IBM's Early Computers," *IBM Journal of Research and Development, vol.* 25 (September 1981), p. 363.
99. Evans, "IBM System / 360," p. 10.

The TPM became the IBM 702, IBM' s first business-oriented machine, delivered in 1954, and heavily influenced by the IAS computer. Its overall performance was generally considered inferior to that of the UNIVAC, and an improved model, the 705, was announced that same year. An improved version of the scientifically oriented 701 also entered the commercial market as the 704 in 1954. Both these lines of development came from the Poughkeepsie lab. The Endicott lab meanwhile developed a design for a small business-oriented machine, the IBM 650, announced in 1953. The 650 was the first mass-produced computer—more than a thousand were sold. Even for the 650, the most purely "commercial" of the first generation of computers, projected governmental demand played a crucial role in the decision to produce the machine.100 The Endicott laboratory continued to lead in designing small, cheap computers, including the IBM 1401, "the Model T of the computer industry, " of which more than twelve thousand were eventually shipped after 1958.101

The West Coast Computer Industry

The aerospace firms of Southern California were the last major group in industry significant in the early development of computers. 102 Aircraft design had, and has, enormous computational requirements, which make it a prime customer for leading-edge scientific computers. The new computing technology was also applied to command and control applications—aircraft and missile guidance and interception, in particular. In the late 1940s these activities centered on Northrop Aircraft, which needed a guidance computer for its Snark missile, and Raytheon, which was testing a control computer at the Navy's facilities at Point Mugu, California.

100. Hurd, "Computer Development at IBM," p. 408, notes that a pledge by IBM's Washington office to sell fifty machines to government users greatly helped to launch the product.

101. Evans, "IBM System / 360," pp. 11-12. The 650 was a magnetic drum computer and relied on the magnetic drum concepts developed at ERA and licensed to IBM as part of the technology interchange discussed earlier.

102. This discussion draws heavily on Richard E. Sprague, "A Westem View of Computer History," *Communications of the Association for Computing ANachinery,* vol. 15 (July 1972), pp. 686-94; Fred J. Gruenberger, "A Short History of Digital Computing in Southem Califomia," *Annals of the History of Computing, vol.* 2 (July 1980), pp. 246-50; and Lutze, "Fommation," pp. 79-81. Unpublished interviews with John Alrich, James Cass, Stanley Frankel, Jerry Mendelson, and Emmett

Quady by Robina Mapstone in 1972 and 1973, found in the Smithsonian Institution, were also consulted.

The design group was located on the premises at Northrop, which had contracted outside with Eckert and Mauchly for the illstarred BINAC computer. The computer group within Northrop designed a series of digital differential analyzers to solve the equations required for missile guidance and contracted with a small California firm named Hewlett-Packard to build the devices. In 1950 a large group of these engineers, after unsuccessfully attempting to get Northrop to set up a computer division, left the company and formed the Computer Research Corporation (CRC). With aerospace company and Air Force funding, this group designed and built general purpose magnetic drum computers in the early 1950s.

Like many of the small technology-based companies just described, CRC eventually ran into financial difficulties. In 1953 it was sold to NCR, which after initial hesitation, had become interested in producing computers for the business market. By 1955 most of the original founders of CRC had left to work in other small high-tech start-ups.

Northrop eventually sold its remaining computer operations to Bendix Aviation, which produced the popular, small G-15 computer. Bendix benefited not only from acquisition of Northrop's computer operations, but also from association with a computer research group at UCLA headed by Harry Huskey, who had worked on both the ENIAC and a British computer project and designed the G-15. After a short time, many of the original Northrop personnel left to start their own computer firm, Logistics Research Corporation, which designed and built its ALWAC line of small magnetic drum computers. Logistics Research, in turn, was sold to El-Tronics. Another group left Bendix to form Packard-Bell computers in the mid-1950s, andfromthese roots, inturn, came Scientific Data Systems, one of the main developers of the minicomputer. *103*

Yet another group of computer designers in close contact with the Northrop group worked at Caltech in the late 1940s, under partial ONR sponsorship. A Caltech researcher designed the MINAC, a design renamed the LGP-30 and built by the Librascope division of General Precision in 1956.l°4 Like the Bendix G-15, the LGP-30 was one of the

103. Lutze, "Formation," pp. 129-30; Reminiscences of Jerry Mendelson for Henry Tropp, December 18, 1972, available in the Smithsonian Institution, Washington, D.C.; interview with Mendelson by Robina Mapstone, September 6, 1972, available in the Smithsonian Institution, Washington, D.C.

104. The designer of the MINAC/LGP-30 was Stanley Frankel. Interview with James Cass by Robina Mapstone, December 18, 1972, available in the Smithsonian Institution, Washington, D.C. Librascope's involvement in computing began when it devised a

early small computers in quantity production whose success inspired the minicomputer—more than five hundred of the LGP30s were built. 105 Control Data acquired both Bendix and Librascope in the early 1960s, and these products were important in Control Data' s minicomputer line .

Another firm in California, the Consolidated Electrodynamics Corporation (CEC) formed a computer division in the early 1950s. Drawing on the services of a Norwegian researcher at Caltech who had worked on computer projects, at IAS and in England, CEC designed and built a significant series of computers in the middle of the 1950s.'°6 CEC's Electrodata computer division was bought out by Burroughs in 1956, and a computer designed at CEC, the Datatron 205, became the Burroughs 205, the first solid commercial success to make Burroughs influential in the computer business. 107

Several other companies on the West Coast participated in important computer developments. Hughes Aircraft built military computers before quitting the business in the mid-1950s, and the Rand Corporation built a version of the IAS computer, the JOHNNIAC (named in honor of von Neumann). North American Aviation's Autonetics division, United Aircraft's computer division, and TRW were also participants. The key element in these efforts was the fluid movement of talented engineers from one aerospace patron to another and into start-ups that often survived only long enough to be acquired by a larger firm. In the

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replacement for the electromechanical computing equipment used in the Norden bombsight.

105. Interview with Cass by Robina Mapstone, December 18, 1972. One major use for these machines was in early process control applications. See Alvin J. Harman, *The International Computer Industry: Innovation and Comparative Advantage* (Harvard University Press, 1971), p. 11.

106. The first CEC Datatron was a fairly advanced computer. The Datatron had index registers, floating-point arithmetic, and magnetic tape input and output. See Moreau, *Computer, p.* 62. IBM thought the Datatron significant competition for its model 650 when it first came on the market. Hurd, "Computer Development at IBM," pp. 407-08. The designer of the original CEC Datatron computer was Norwegian scientist Ernst Selmer, who did the work while on a guest lectureship at Caltech. Selmer apparently was inspired to put index registers in his design through a conversation with Harry Huskey. Interview with John Alrich by Robina Mapstone, February 9, 1973, available in the Smithsonian Institution, Washington, D.C.; and interview with Stanley Frankel

by Robina Mapstone, October 5, 1972, available in the Smithsonian Institution, Washington, D.C.

107. See Moreau, *Computer, p.* 62; Fisher and others, *IBM and the U.S. Data Processing Industry, pp.* 79-81; and Barbara Goody Katz and Almann Philips, "The Computer Industry," in Richard R. Nelson, ed., *Government and Techmcal Progress: A Cross-lndustry Anslysis* (Pergamon Press, 1982), pp. 162-232.

Longer run, the activities of these aerospace-based firms led to the development of the minicomputer.

The aerospace companies, and the military services that procured their products, were the key customers for the early commercial compruter manufacturers building large-scale mainframe computers. A request from the computer group at Northrop, for example, led IBM to build the Card-Programmed Calculator (CPC) in 1948.108 These engineers also made advances in software that were a critical part of the general a dvance in computing technology in the 1950s. Aerospace industry users of the IBM 701 formed the predecessor to the SHARE IBM users organization and contributed much to the development of a useful software base for scientific and engineering applications.

Battling over National Policy: The National Bureau of Standards

Conflict over a new and emerging American concern— organizing and rnanaging investments in the development of science and technology— appeared on many fronts in the late 1940s. Key players in the military first tried to convince established businesses and investment bankers that a new and potentially profitable business opportunity was presenting itself. They did not succeed, and, consequently, the Defense Department committed itself to financing an enormously expensive development program for new technologies—like the electronic computer—in which the military had a special interest.

Another skirmish was fought by those who dwelled on the connection between public investment in technology and private profit. During the wartime scientific mobilization, Senator Harley Kilgore of West Virginia had begun arguing in Congress that federal research funds should be Distributed more evenly among researchers. He also believed that the entire nation "owned" research paid for by federal funds. Many supporters of the New Deal embraced a corollary to Kilgore's "populist" position by arguing that the results of federal research programs should be made available widely and quickly, particularly to smaller businesses.

Within the executive branch, the populist vision of American science policy found a home in the Commerce Department and its new secretary, Henry A. Wallace, during the last days of the war. Within the Commerce Department, the National Bureau of Standards (NBS) attempted to

108. See Phelps. "Early Electronic Computer Developments at IBM," p. 264.

transform its role from a traditional position as arbiter of weights, measures, and other standards to a new position as manager of a broad industrial research program designed to assist American industry in exploiting wartime advances in science and technology. Eventually, NBS would become directly involved in the birth of the computer.

Like most of the American scientific community, the NBS laboratories were drafted into weapons development during the war. 109 After the war, NBS, using funds transferred to it by the Defense Department, continued to do a great deal of weapons-related research. Its involvement in computers initially began at the instigation of the Navy.110 Under the sponsorship of the Army Ordnance Department, NBS had also started a program to develop improved components for digital computers . 111 In 1946 NBS had assisted the newly formed U.S. Of fice of Naval Research in contracting with Raytheon to build a machine for Navy use. The NBS laboratories also began development of input-output equipment for the IAS project during this period. 112

The fledgling NBS computer development effort was institutionalized in 1947 with the establishment of the National Applied Mathematics Laboratory (NAML) within its ranks. The first chief of the NAML, John Curtiss, rapidly involved the lab in diverse activities supporting the drive to build electronic computers.

In 1948 one of the first official tasks of the NAML was to evaluate Eckert and Mauchly's proposal to build a computer for the Census Bureau. NBS was given the responsibilities for selecting a supplier for the Census machine and supervising its development. NBS approved the purchase from Eckert and Mauchly, as well as the acquisition of two more UNIVACs, one for the Air Force's Air Materiel Command, and one for the NAML's own facilities. When the Eckert-Mauchly Corporation failed a security clearance in 1948,113 and the Air Materiel Com

109. See Rexmond C. Cochrane, *Measures for Progress: A History of the National Bureau of Standards, U.S.* Department of Commerce, National Bureau of Standards (GPO, 1966), p. 431.

110. See Harry D. Huskey, "The SWAC: The National Bureau of Standards Western Automatic Computer," in Metropolis and others, *A History of Computing, p.* 419; and Huskey, "The National Bureau of Standards," pp. 111-12.

111. S. N. Alexander, "Introduction," in *Computer Development (SEAC and DYSEAc) at the National Bureau of Standards,* NBS Circular 551 (GPO, 1955), pp. 1—3 .
112. Slutz, "Memories of the Bureau," p. 472.
113. Huskey, "The National Bureau of Standards," p. 112. Stern, *From ENIAC to*

mand declined to support the Eckert-Mauchly purchase, NBS began negotiations with Raytheon to supply a version of the computer Raytheon was building for the Navy in its place. In the late 1 940s NBS also assisted the Army Security Agency in designing and constructing ABNER, a cryptological computer, and in negotiating UNIVAC purchases for the Air Comptroller's Of fice and the Army Map Service. 114

Around 1948 it became clear that the continual delays in the various computer projects going at that time, which included the machines being developed by Eckert and Mauchly, the EDVAC at the Moore School, the MIT Whirlwind, the IAS computer at Princeton, Raytheon' s project, and the machines that ERA was known to be working on, were making them fall further and further behind schedule, with no completion date in sight. At that point, at the urging of George Dantzig, who was developing applications of linear programming to economic problems for the Air Force, the Of fice of the Air Comptroller decided to fund the development of an interim computer as a stopgap measure. 115 Thus was born the NBS Interim Computer, renamed the Standards Eastern Automatic Computer (SEAC) when it became the first operational electronic digital stored-program computer in regular operation in the United States in the spring of 1950.116

Shortly thereafter, another decision was made to build a second NBS computer, using odd scraps of leftover funding, at the Institute of Numerical Analysis at the University of California, Los Angeles, which was being set up as one of the four divisions of the NAML. An explicit objective was to test completely different design concepts in this second

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UNIVAC, pp. 112-14. Eckert and Mauchly were cleared, but only after losing the chance to land several important government contracts.
114. Snyder, "Influence of U.S. Cryptologic Organizations," p. 10. It is worth noting the apparent difference in internal technological capability between the U.S. Navy codebreakers, who had invested heavily in internal development of new technology during the war, and the U.S. Army cryptologists, who had largely relied on off-theshelf punched card machinery and special devices built by IBM and the Bell labs. When the emerging role of computers in cryptology became clear at the end of the war, the Army had to rely on outside consultants

in developing its most secret apparatus. See Stern, *From ENIAC to UNIVAC, p.* 113; and Huskey, "The National Bureau of Standards," p. 112.

115. Alexander, *Computer Development (SEAC and DYSEAC), p. I;* and Slutz, "Memories of the Bureau," p. 473.

116. This claim ignores the Eckert-Mauchly BINAC, which passed initial factory tests in 1949 but never functioned in a satisfactory manner at its final installation site. Stern, *From ENIAC to UNIVAC, p.* 129.

computers which came to be known as the Standards Western Automatic Computer (SWAC)

After SEAC was built, new additions to the machine were constantly being devised and attached to the existing structures. The NBS used the SEAC program as a vehicle for designing and testing a whole series of experimental computers and peripherals, including the first magnetic disk drive.117 Ambitious plans were in the works when the NBS was forced to halt its rapid expansion in 1953.

The NBS computing program was caught up in the political debate over postwar science policy, and seemingly minor incidents used to demolish its ambitious industrial research agenda. Troubles had begun in 1947, when the head of the NBS, Dr. Edward V. Condon, who had been active in the Manhattan project and the MIT Radiation Laboratories during the war, had come under attack from individuals on the House Committee on Un-American Activities for associating with alleged Soviet espionage agents.118 Condon resigned in 1951 and joined the private sector as director of research at Corning Glass. John Curtiss, head of the NAML, also came under attack during this period and was forced out in 1953.119

The incident that finally destroyed the NBS computer program, **ironically,** had nothing to do with computers or any other technical issue. The NBS had been aggressively expanding its functions in testing the claims of products to be used by government agencies. In this tradition, the bureau from time to time would issue circulars summarizing the results of its efforts and making them available to the taxpayer. In 1949, ffler testing battery additives (which it found worthless), an official of the NBS identified one additive, "AD-X2," by name in a letter to the

117. Designed by Jacob Rabinow, the NBS magnetic disk assembly inspired the later development of the first commercial disk storage system at IBM's San Jose laboratorjes. See Bashe and others, *IBM's Early Computers, pp.* 279-80. Other notable examples included the input-output systems built for the IAS computer, the DYSEAC process-cOntrOI computer, which was fitted into two mobile vans and pioneered the use of external interrupts; the AMOS IV weather forecasting computer; the unfinished multiple processor "Pilot" computer, and the FOSDIC optical character scanning machine. See A. L. Leiner, S. N. Alexander, and R. P. Witt, "DYSEAC," in Alexander, *Computer Development (SEAC and DYSEAC), pp.* 39-40; and Martin H. Weik, Jr., *A Third Survey of Domestic Electronic Digital*

Computing Systems, BRL Report 1115 (Aberdeen, Md.: Aberdeen Proving Grounds, 1961), *pp.* 28, 234, 258.
118. Cochrane, *Measures for Progress, pp.* 485, 491-92.
119. John Todd, "John Hamilton Curtiss, 1909-1977," *Annals of the History of Computing, vol.* 2 (April 1980), *pp.* 107-08. See also Rees, "The Computing Program of the Office of Naval Research," pp. 100-03.

Better Business Bureau of Oakland, California.120 The outraged manufacturer mounted a major political campaign in Congress and commissioned a study at MIT that appeared to support the claims made.121
The incoming Eisenhower administration temporarily suspended the acting director of the NBS and hastily ordered two advisory reports from the National Academy of Sciences—one on the merits of AD-X2, the other on the nature, organization, and funding of the bureau' s expanded activities.
The latter report was issued first, in October 1953, and recommended the removal of all DOD-funded programs from the bureau and a reorientation of the bureau away from applied and developmental work, to basic research on physical constants and testing procedures. The secretary of commerce, Sinclair Weeks, immediately ordered the transfer of four major divisions of the bureau, including important electronics laboratories, to the ordnance laboratories of the armed forces. In subsequent months many other programs, including support for the NBS-supported computer group at the Institute for Numerical Analysis at UCLA, were ended . l22

Since most of the computer work had been supported by funds transferred to NBS by the military services, and these were abruptly ended, computer development at the bureau suffered a traumatic blow from which it never recovered. In fiscal 1954, the NBS budget had been roughly halved and its staff cut from 4,600 to 2,800, the approximate level at which it was held through the remainder of the decade . 123

The report on AD-X2, which was released in November of 1953, vindicated the bureau's work and concluded that the MIT tests were deficient in their design.124 By this time, however, the reorganization of the NBS was well under way.

In retrospect the fundamental issue at stake in these proceedings had little to do with either the merits of battery additives or the acquaintance

120. The bureau later informed Congress that it had identified AD-X2 by name because its producers had claimed that previous statements by NBS did not apply to their product.

121. Cochrane, *Measures for Progress, pp.* 483-87.

122. Ibid., p. 497.

123. Ibid., p. 497, app. F. By 1959 the full-time staff had recovered only slightly, to 2,960. See National Research Council of the National Academy of Sciences, *The Role of the Department of Commerce in Science and Technology*, report to the secretary of commerce by a special advisory committee of the National Academy of Sciences (National Academy of Sciences, 1960), p. 83.

124. Cochrane, *Measures for Progress, pp.* 486-87.

of top NBS scientists with Russian and left-leaning American colleagues . The bureau had vastly expanded its research activities, explicitly intending to produce technological information to be used by small business and to stimulate the formation of new enterprises by popularizing the technical advances made during the war. In the computer contracts it had supervised for the government, the NBS had promoted the small and innovative start-ups dedicated to producing leading-edge technological products, particularly ERA and Eckert-Mauchly, over the slowermoving established industrial firms. 125

From the viewpoint of Commerce Secretary Weeks, and the incoming administration, these activities meant too much meddling with the normal outcome of free market forces.126 When Weeks had suspended the director of the NBS in the spring of 1953, he was quoted as saying, "The National Bureau of Standards has not been sufficiently objective because they discount entirely the play of the marketplace."127

Perhaps more important, at the time of these events, the first commercial computers (Eckert and Mauchly's UNIVAC, the ERA 1103, the IBM 701) were finally beginning to be offered in the marketplace. Pressures from the military services for a technical czar to push the development of the new machines for the use of the military establishment had subsided somewhat. Computerresearch at the NBS, decimated by these changes, struggled on with a meager budgetary diet. It was not until the late 1970s that the NBS began once more to build a significant computer research division, this time with a more explicit standardization agenda. 128

Before losing the political fight, though, the NBS computer program

125. In a 1946 letter to the head of the A. C. Nielsen Company, which was interested in automating tabulation activities, John Curtiss had suggested that Nielsen "could send [his] men directly to two concerns whom I consider now the best ones to bet on among the small electronics outfits with brains (and I think such outfits may win the race). The Electronic Control Corp. (Eckert and Mauchly's firm) and Engineering Research Associates, Inc., St. Paul, Minn." Stern, *From ENIAC to UNIVAC, pp.* 142-43.

126. Weeks, a Massachusetts industrialist, had appointed the president of the Scheaffer Pen Company, Craig R. Scheaffer, as assistant secretary for domestic affairs. Scheaffer had reason for personal concern over the activities of the bureau. Relying on NBS tests, the Federal Trade Commission forced his firm to

stop claiming that a Scheaffer pen lasted a lifetime. Cochrane, *Measures for Progress, p.* 485.
127. Ibid.
128. The fiscal 1979 budget for the NBS Institute for Computer Science and Technology (ICST) more than doubled the $4.5 million 1978 budget. But it has remained flat, at the $10 million, through the mid-1980s, and NBS continues to fight chronic attempts to trim back the ICST budget.

made some notable contributions to the state of the art. The SEAC built heavily on the components research that had been ongoing at the NBS in the previous few years. The objective was to get a simple, easily constructed machine with minimal complications in place as quickly as possible. It was based on the simple, serial EDVAC design, used mercury delay line memory—then the most reliable and tested memory technology—and adopted the general logical structure being used on the EDVAC project. Key engineers with experience on other projects were hired.l29 However, the circuit and logic design, and componentry, were entirely the product of the NBS.

The SEAC, besides being the first operational von Neumann-type storedprogram computer in the United States, pioneered important technology concepts. All of the logic was implemented with newly developed germanium diodes (10,000 were used); the vacuum tubes within (750) were only for providing power and electrical pulse-shaping circuitry.130 The computer also used standardized, replaceable circuit modules, an innovation soon adopted throughout the industry. Thus the first computer to use solid state logic was also the first modern computer to be completed in the United States . 131

The SWAC, built under the direction of Harry Huskey was a higherperformance parallel computer with a Williams tube memory .132 SWAC ran into trouble with its delicate and finicky CRT memory. It was switched to a magnetic drum unit as it was completed and was not fully operational until the middle of 1953.

Both SEAC and SWAC were built on budgetary shoestrings. SEAC was built in only two years, at an estimated cost of $188,000, while SWAC was budgeted at $170,000.'33 The other major computer projects described costs from three to ten times these magnitudes.

SEAC technology and design ideas influenced the construction of

129. Ralph J. Slutz was brought in from the IAS project, and Samuel Lubkin came from the EDVAC group. See Slutz, "Memones of the Bureau," *pp.* 427-73; and Huskey, "The National Bureau of Standards," *pp.* 419—31.
130. Slutz, "Memories of the Bureau," p. 473.
131. SEAC also seems to have been far more reliant on solid state circuitry than the more complex machines that followed. Martin H. Weik, A *Third Survey, pp.* 1072-75.
132. For a more complete account of the origins of the SWAC, see Huskey, "The SWAC," *pp.* 419-32; and Huskey, "The National Bureau of Standards," pp. 112-17.
133. These were the 1950 cost estimates reported by an ad hoc panel of the Defense Department's Research and Development Board, cited in Redmond and Smith, *Project Whirlwind, p. 166.*

other larger computers. These machines included the FLAC computer, built at the Air Force Missile Test Center in Florida, and the MIDAC computer at the Willow Run Research Center of the University of Michigan. 134 Computer designers in Europe and Japan also made use of the SEAC logic designs and architecture.

Both SEAC and SWAC had some influence on the development of the commercial computer industry, notably in the development of smaller scientific computers . Research projects organized around these two computers planted the first seeds of other important technologies—magnetic disk memories, parallel multiprocessor computer designs, optical character recognition, and the application of computers to practical, industrial mathematics. One group of NBS personnel left the SEAC project to develop a medium-sized computer that became the basis for the Underwood business machine firm's computers.135 Harry Huskey, chief architect of the SWAC, designed the Bendix G- 15, the first small scientific computer produced in reasonable volume and a precursor of the minicomputer. l36 Other veterans of the SEAC project joined IBM. 137

Summary

During and after the war, for the sake of national security, the government made unprecedented investments in computer technology developed by civilians and private companies (table 3-1). Through the early 1950s the continued reluctance of commercial firms, like IBM and NCR, to invest large sums in risky research and development projects with uncertain markets, forced the government to continue sponsoring the new technology. The cold war, with its ensuing technological military competition, heightened government interest.

134. Alexander, *Computer Development, p.* 3.

135. See Lutze, "Formation," p. 45; and Arthur D. Little, Inc., with the White, Weld & Co. research department, *The Electronic Data Processing Industry: Present Equipment, Technological Trends, Potential Markets* (New York: White, Weld, & Co.
1956), *pp.* 80-81. The Electronic Computer Corporation (Elecom) founded by Samuei Lubkin and Murray Pfefferman of the SEAC design team, eventuaily became a division of Underwood and built a few scientific computers in the mid1950s.

136. Lutze, "Formation," p. 45. The Bendix G-15A computer, priced at $45,000, was a small magnetic drum machine that first became operational in 1956. More than 300 were sold. See Martin H. Weik, Jr., *A Fourth Survey of Domestic Electronic Digital Computing Systems,* BRL Report 1227 (Aberdeen, Md.: Aberdeen Proving Ground 1964), p. 316; and Arthur D. Little, Inc., *Electronic Data Processing Industry, p.* 53.
137. Interview with Richard B. Thomas, Washington, D.C., August 1, 1984.
[FIGURE 3.1]

Eventually, the commercial applications of the research sponsored by the government became clearer. Some industry leaders, like IBM's Thomas Watson, Jr., managed to lead their companies into new ventures in computer technology, buoyed by healthy doses of government support.

This pattern of government-funded research leading to private commercial benefit became more prominent, and the debate over federal technology policy grew. Indeed the debate had begun even before the war was over. Those who opposed any government intervention in the marketplace clashed with those who favored public support for the development of industrial technology.

By the mid-1950s participants in the conflict had devised a uniquely American formula for technology policy. Basic research in universities would be accepted as a legitimate public good to be undertaken by economically disinterested professors in academia. Government support for applied research and development would be acceptable only if aimed at a noneconomic objective, like national security or health. Congress explicitly established the National Science Foundation to support basic research efforts. But because computer science did not mature as a separate academic discipline until the mid-1960s, the foundation largely excluded computer research from support in the first decades after the birth of the computer. Fortunately for the U.S. computer industry, however, the military establishment guaranteed support to the industry for the sake of national security.
The United States military sponsored by far the largest and broadest program for developing computer technology found anywhere in the world during the first decades of the digital computer. Even a partial list of computer projects funded during the late 1940s and early 1950s is impressive for the number, diversity, and cost of projects included (table 3-1). By 1950 the United States was directly funding computer R&D at roughly $15 million to $20 million (current) a year. 138

Perhaps more important, the many start-up computer firms entering

138. In the late 1940s and early 1950, MlT's Whirlwind project was budgeted at $1.5 million to $2.0 million a year. See Redmond and Smith, *Project Whirlwind,* pp. 118, 120, 126-28, 191. ERA was estimated to be operating with three times the budget and staff of Project Whirlwind. (Jay Forrester is quoted to this effect, ibid., p. 154.) A conservative estimate might be that these two projects accounted for half of all military funding of computer research, an upper limit would be perhaps a third of the total, yielding an estimate of funding in the range of $14 million to $21 million.

the U.S. industry in the early and middle 1950s were chasing after a reasonably large market, dominated by military demand. For almost all of these producers, the military was the first, and generally, the best customer. About eighty different organizations, including numerous small start-ups that later merged with larger producers or disappeared, produced computers in the United States during the 1950s.139 The U.S. military, or defense contractors, paid for or purchased the first machines made by most of these groups.140 In later years, military users of the technology continued to take a broad view of activities considered relevant to defense.

139. A 1960 survey of U.S. computers lists sixty-five U.S. manufacturers, this list does not include several well-known computer groups and omits manufacturers who had dropped out of the market. Weik, A *Third Survey*, pp. 1038-42.
140. A quick review of the installations data cited in Weik, A *Third Survey*, supports this contention, as does the detailed analysis of U.S. computers installed before 1956 in John Varick Wells, "The Origins of the Computer Industry: A Case Study in Radical Technological Change" (Ph.D. dissertation, Yale University, 1978), pp. 266-78.