Epilog

Today we see computers almost everywhere we turn: in our banks, our schools, our factories, our offices, our homes. How this happened, and what it has to do with those technologies we have discussed in this book, are described in the following few pages. In doing so, we will argue that the computer has evolved from the long line of calculating technologies we have traced from antiquity, and that it may not be the revolutionary technology some people suppose it to be.

All computers, from the giant brains of the 1950s to the sleek microcomputers of the 1980s, have the same fundamental design. The computer is not a single device, but rather an integrated system of hardware. A control unit directs the operations of the constituent units, coordinating them to carry out the thousands or millions of small steps in the information-processing task the computer has been programmed to do. Input-output units transfer data and instructions from the user to the computer system. Memory units store data and instructions until they are needed for processing. And an arithmetic-logic unit performs the basic arithmetic operations and logical comparisons that comprise an information-processing task.

Computers are *general purpose* in the sense that they can carry out any information-processing task a programmer can break into suitable basic operations and feed to the computer in an appropriate code. Computers are *automatic* in the sense that once the instructions and data have been appropriately coded and sent to the computer through the input equipment, no human intervention is required throughout the course of the computation; the computer is able automatically to transfer information and data between various units of the system as needed, carry out the sequence of arithmetical and logical operations in the appropriate order, and even modify data and instructions in the course of a computation as the circumstances warrant. Computers are *digital* devices in the sense we discussed in Chapter 5.

There are two general features of computers that set them apart from earlier calculating technologies and help to explain why the computer has become so prevalent in contemporary western society. The widespread use of electronics makes the computer thousands of times faster than any mechanical or electromechanical calculating device. This speed advantage opens up many new computing opportunities, e.g., real-time applications, like air traffic control, in which the calculator must provide an answer as rapidly as the activity progresses, and supercomputing problems in which billions of arithmetic and logical operations may be required to achieve a single result. The use of stored programming (i.e., instructing the machine through the use of programs which the machine stores internally and modifies and executes automatically) makes practical the computer's general-purpose capability. A stored-program computer can process in rapid succession, or even simultaneously, a wide range of problems. This is accomplished, without the lengthy and tedious rewiring or replugging of the machine between problems, by simply using the input equipment to enter a string of symbols representing a new program.

For all of the design similarities among computers, the changes over the past forty years are perhaps more significant to the technology's incorporation in society. In comparison with those of even thirty years ago, today's computers are smaller and more reliable, require less maintenance, consume less power, cost considerably less, and have much better absolute performance and price-performance characteristics. The microcomputers used by today's hobbyist outperform in almost every respect the computers of the 1950s, which were affordable only to the largest organizations. These changes are explained by the rapid stream of inventions and innovations in the hardware that implement the various functions of the computer, and in the software that instructs this hardware how to operate. These innovations include the transistor, the microprocessor, virtual memory, parallel processing, operating systems, and high-level programming languages.

The implementation of these innovations widened the market for the computer. In the 1950s, only large organizations (e.g., the Census Bureau, military agencies, and aerospace and oil companies) with large computing or data processing needs could afford computers. In the 1960s, computers came within reach of many medium-sized businesses, universities, and smaller scientific organizations. In the 1970s, price-performance continued to improve so that individual research laboratories and business offices could afford their own computers. By the 1980s, the cost had declined to the point where computers appeared in the home and on the desks of individuals in the office place. These changes, which could not have occurred without continuous dramatic decreases in price, were also dependent on many other technical innovations that made the machines smaller, more powerful, more reliable, and easier to use. This whole, interrelated set of changes have enabled the computer to attain its position in what some now call the "Information Age." But it is beyond the scope of this work to trace these changes and their impacts in the detail they deserve.

Contrary to the popular perception of the computer as an entirely novel invention, it adapted to its own needs features from many different earlier calculating technologies. Many of the early American and British computer designers built directly upon their experiences building large electronic calculators, like Colossus and ENIAC. The idea of a program-controlled calculating machine was developed by Charles Babbage in the mid-nineteenth century. Inspired by Babbage, Howard Aiken built his Harvard Mark I, which would execute an arbitrary sequence of operations specified by a program. The concept of program control was carried much further forward by the invention of stored programming.

Many of the first digital computer projects had their origins in punched-card equipment or analog calculators. International Business Machines, the world leader in computer manufacturing, achieved the transition from punched-card equipment manufacture to computer manufacture partly through an intermediate technology, the Card Programmed Calculator (CPC). Built in 1948, the CPC wired together into a system an IBM 603 electronic punched card multiplier and an IBM 405 accounting machine. The University of Pennsylvania's ENIAC project, out of which grew the first plans for the modern computer, had its own origins in MIT's Rockefeller Differential Analyzer; in fact ENIAC was known originally as an electronic difference analyzer. MIT's Whirlwind computer evolved from an Air Force project to construct an analog calculating device to control an aircraft simulator.

Peripheral equipment used in prewar calculating systems was adapted to the computer. The prime example is punched-card equipment. Contrary to the prediction of MIT mathematician Norbert Wiener that computers would make punched cards obsolete, their use expanded exponentially in the 1950s and remained popular until time-sharing became commonplace in the 1970s. Paper tape, used earlier in the Harvard Mark I, Colossus, and several of the Bell Labs relay calculators, was a principal input medium of the early computers. The Flexowriter, a "smart" typewriter used in direct mailing and other applications before the Second World War, was employed as the principal output device on the Harvard Mark I and several computers of the 1950s.

Early computer designers also appropriated electronic technology from other fields. The vacuum tube flip-flop, the fundamental switching component of computers in the 1950s, was first tested and refined in cosmic ray counters of the 1930s. Mercury delay lines, used during the Second World War to store radar signals, were modified to store information in the EDVAC and several other early computers. Cathode ray tubes, developed for television and radar, served as the basis for the popular Williams tube memory of the 1950s and also as an input-output device on the Whirlwind. Magnetic tape and wire, introduced by the German broadcast industry, was pioneered as a storage medium on the first National Bureau of Standards computer, the SEAC.

This continuity in technology is mirrored in the organizations that manufactured it. The computer industry of the 1950s emerged largely from the business equipment manufacturing industry that had supplied card punches, sorters, tabulators, and desk calculators between the two world wars. National Cash Register acquired Computer Research Corporation in 1953 to update their line of retail equipment. Burroughs acquired ElectroData in 1956 in order to computerize their traditional line of banking equipment. IBM's 650 and 1401 computers of the 1950s replaced the punched-card equipment IBM had supplied for decades to insurance companies and other large businesses.

This same pattern of continuity is apparent among users. Industries that used calculating technology extensively in the 1930s became a ready market for the computer in the 1950s. For example, the aircraft manufacturers, which employed thousands of Friden and Marchant calculators and many punched-card systems in test data reduction in the 1930s and 1940s, replaced these with computers as soon as they became available. In some instances companies were not satisfied with the computing power available from commercial sources and participated in the development of the new products themselves. For example, IBM worked with Northrop Aviation to develop the Card Programmed Calculator and with United Aircraft on the first high-level programming language, Fortran.

The story is similar for government users. In the 1930s and 1940s the heaviest government users of calculating equipment were the Census Bureau and the military organizations. The first commercial computer delivered in the United States went to the Census Bureau in 1951. The Navy supported the start-up of a new firm, Engineering Research Associates, in 1946 in order to ensure that state-of-the-art computing equipment would be available for cryptanalysis. Those who founded Engineering Research Associates were some of the same engineers who built or operated cryptanalytic calculating equipment as military personnel during the war.

Scientists were among the most innovative and demanding users of calculating technology in the 1930s and the war years. Astronomers, psychologists, and agricultural statisticians found new ways of using business calculating equipment in the 1930s. Physicists from Los Alamos used desk calculators, punched-card tabulators, relay calculators, and differential analyzers on the Manhattan Project during the war. But they switched to computers as soon as they became available in the 1950s. The NORC, the MANIAC, the Institute for Advanced Study computer, and others were used heavily for research in nuclear physics, molecular biology, fluid dynamics, and many other scientific areas in the first decade of modern computing.

These remarks only suggest the rich connections between the technology we have set out in this book and the electronic, stored-program computer. Our incomplete understanding of these connections, of events that have occurred so recently that we may still speak to the participants, may seem odd to some readers. But it requires time to gain perspective, especially in a field in which most participants are too busy looking to the future to devote time to the past. Many of the advances in computing have been made in the context of government-classified or company-proprietary projects, in which information has not been shared yet with the historian. But as we learn more our appreciation for a single, continuous history of computing grows deeper. And within the next few years we should be able to present the events of the first half-century of the computer era as we have been able here to account for the development of those earlier calculating technologies.