1.7 Historical Perspective and Further Reading

An active field of science is like an immense anthill; the individual almost vanishes into the mass of minds tumbling over each other, carrying information from place to place, passing it around at the speed of light.

Lewis Thomas, "Natural Science," in *The Lives of a Cell*, 1974

For each chapter in the text, a section devoted to a historical perspective can be found on this CD. We may trace the development of an idea through a series of machines or describe some important projects, and we provide references in case you are interested in probing further.

The historical perspective for this chapter provides a background for some of the key ideas presented in this opening chapter. Its purpose is to give you the human story behind the technological advances and to place achievements in their historical context. By understanding the past, you may be better able to understand the forces that will shape computing in the future. Each historical perspectives section ends with suggestions for further reading, which are also collected separately on this CD under the section "Further Reading."

The First Electronic Computers

J. Presper Eckert and John Mauchly at the Moore School of the University of Pennsylvania built what is widely accepted to be the world's first operational electronic, general-purpose computer. This machine, called ENIAC (Electronic Numerical Integrator and Calculator), was funded by the United States Army and became operational during World War II, but was not publicly disclosed until 1946. ENIAC was a general-purpose machine used for computing artillery firing tables. This U-shaped computer was 80 feet long by 8.5 feet high and several feet wide (Figure 1.7.1). Each of the 20 10-digit registers was 2 feet long. In total, ENIAC used 18,000 vacuum tubes.

In size, ENIAC was two orders of magnitude bigger than machines built today, yet it was more than five orders of magnitude slower, performing 1900 additions per second. ENIAC provided conditional jumps and was programmable, clearly distinguishing it from earlier calculators. Programming was done manually by plugging cables and setting switches, and data was entered on punched cards. Programming for typical calculations required from half an hour to a whole day. ENIAC was a general-purpose machine, limited primarily by a small amount of storage and tedious programming.

In 1944, John von Neumann was attracted to the ENIAC project. The group wanted to improve the way programs were entered and discussed storing programs as numbers; von Neumann helped crystallize the ideas and wrote a memo proposing a stored-program computer called EDVAC (Electronic Discrete Variable Automatic Computer). Herman Goldstine distributed the memo and put von

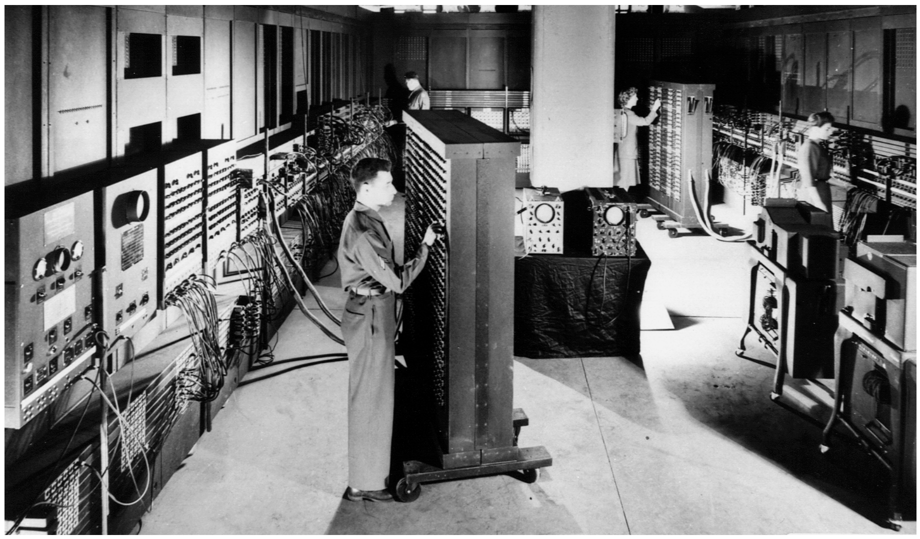

FIGURE 1.7.1 ENIAC, the world's first general-purpose electronic computer. Note the court tag in the lower-right corner; this is from the patent case mentioned on page 1.7-2.

Neumann's name on it, much to the dismay of Eckert and Mauchly, whose names were omitted. This memo has served as the basis for the commonly used term *von Neumann computer*. Several early pioneers in the computer field believe that this term gives too much credit to von Neumann, who wrote up the ideas, and too little to the engineers, Eckert and Mauchly, who worked on the machines. For this reason, the term does not appear elsewhere in this book or CD.

In 1946, Maurice Wilkes of Cambridge University visited the Moore School to attend the latter part of a series of lectures on developments in electronic computers. When he returned to Cambridge, Wilkes decided to embark on a project to build a stored-program computer named EDSAC (Electronic Delay Storage Automatic Calculator). EDSAC became operational in 1949 and was the world's first full-scale, operational, stored-program computer [Wilkes 1985]. (A small prototype called the Mark-I, built at the University of Manchester in 1948, might be called the first operational stored-program machine.) Section 2.4 in Chapter 2 explains the stored-program concept.

In 1947, Eckert and Mauchly applied for a patent on electronic computers. The dean of the Moore School, by demanding that the patent be turned over to the university, may have helped Eckert and Mauchly conclude that they should leave. Their departure crippled the EDVAC project, delaying completion until 1952.

Goldstine left to join von Neumann at the Institute for Advanced Study (IAS) at Princeton in 1946. Together with Arthur Burks, they issued a report based on the memo written earlier [Burks, Goldstine, and von Neumann 1946]. The paper was incredible for the period; reading it today, you would never guess this landmark paper was written more than 50 years ago because it discusses most of the architectural concepts seen in modern computers. This paper led to the IAS machine built by Julian Bigelow. It had a total of 1024 40-bit words and was roughly 10 times faster than ENIAC. The group thought about uses for the machine, published a set of reports, and encouraged visitors. These reports and visitors inspired the development of a number of new computers.

Recently, there has been some controversy about the work of John Atanasoff, who built a small-scale electronic computer in the early 1940s. His machine, designed at Iowa State University, was a special-purpose computer that was never completely operational. Mauchly briefly visited Atanasoff before he built ENIAC. The presence of the Atanasoff machine, together with delays in filing the ENIAC patents (the work was classified and patents could not be filed until after the war) and the distribution of von Neumann's EDVAC paper, were used to break the Eckert-Mauchly patent. Though controversy still rages over Atanasoff's role, Eckert and Mauchly are usually given credit for building the first working, general-purpose, electronic computer [Stern 1980].

Another early machine that deserves some credit was a special-purpose machine built by Konrad Zuse in Germany in the late 1930s and early 1940s. Although Zuse had the design for a programmable computer ready, the German government decided not to fund scientific investigations taking more than two years because the bureaucrats expected the war would be won by that deadline.

Across the English Channel, during World War II special-purpose electronic computers were built to decrypt the intercepted German messages. A team at Bletchley Park, including Alan Turing, built the Colossus in 1943. The machines were kept secret until 1970; after the war, the group had little impact on commercial British computers.

While work on ENIAC went forward, Howard Aiken was building an electromechanical computer called the Mark-I at Harvard (a name that Manchester later adopted for its machine). He followed the Mark-I with a relay machine, the Mark-II, and a pair of vacuum tube machines, the Mark-III and Mark-IV. In contrast to earlier machines like EDSAC, which used a single memory for instructions and data, the Mark-III and Mark-IV had separate memories for instructions and data. The machines were regarded as reactionary by the advocates of stored-program computers; the term *Harvard architecture* was coined to describe machines with separate memories. Paying respect to history, this term is used today in a different sense to describe machines with a single main memory but with separate caches for instructions and data.

The Whirlwind project was begun at MIT in 1947 and was aimed at applications in real-time radar signal processing. Although it led to several inventions, its most important innovation was magnetic core memory. Whirlwind had 2048 16-bit words of magnetic core. Magnetic cores served as the main memory technology for nearly 30 years.

Commercial Developments

In December 1947, Eckert and Mauchly formed Eckert-Mauchly Computer Corporation. Their first machine, the BINAC, was built for Northrop and was shown in August 1949. After some financial difficulties, their firm was acquired by Remington-Rand, where they built the UNIVAC I (Universal Automatic Computer), designed to be sold as a general-purpose computer (Figure 1.7.2). First delivered in June 1951, UNIVAC I sold for about $1 million and was the first successful commercial computer—48 systems were built! This early machine, along with many other fascinating pieces of computer lore, may be seen at the Computer Museum in Boston, Massachusetts, and the Computer History Center in Mountain View, California.

FIGURE 1.7.2 UNIVAC I, the first commercial computer in the United States. It correctly predicted the outcome of the 1952 presidential election, but its initial forecast was withheld from broadcast because experts doubted the use of such early results.

IBM had been in the punched card and office automation business but didn't start building computers until 1950. The first IBM computer, the IBM 701, shipped in 1952, and eventually 19 units were sold. In the early 1950s, many people were pessimistic about the future of computers, believing that the market and opportunities for these "highly specialized" machines were quite limited.

In 1964, after investing $5 billion, IBM made a bold move with the announcement of the System/360. An IBM spokesman said the following at the time:

> *We are not at all humble in this announcement. This is the most important product announcement that this corporation has ever made in its history. It's not a computer in any previous sense. It's not a product, but a line of products . . . that spans in performance from the very low part of the computer line to the very high.*

Moving the idea of the architecture abstraction into commercial reality, IBM announced six implementations of the System/360 architecture that varied in price and performance by a factor of 25. Figure 1.7.3 shows four of these models. IBM bet its company on the success of a *computer family*, and IBM won. The System/360 and its successors dominated the large computer market.

About a year later Digital Equipment Corporation (DEC) unveiled the PDP-8, the first commercial *minicomputer*. This small machine was a breakthrough in low-cost design, allowing DEC to offer a computer for under $20,000. Minicomputers were the forerunners of microprocessors, with Intel inventing the first microprocessor in 1971—the Intel 4004.

In 1963 came the announcement of the first *supercomputer*. This announcement came not from the large companies nor even from the high tech centers. Seymour Cray led the design of the Control Data Corporation CDC 6600 in Minnesota. This machine included many ideas that are beginning to be found in the latest microprocessors. Cray later left CDC to form Cray Research, Inc., in Wisconsin. In 1976 he announced the Cray-1 (Figure 1.7.4). This machine was simultaneously the fastest in the world, the most expensive, and the computer with the best cost/performance for scientific programs.

While Seymour Cray was creating the world's most expensive computer, other designers around the world were looking at using the microprocessor to create a computer so cheap that you could have it at home. There is no single fountainhead for the *personal computer*, but in 1977 the Apple II (Figure 1.7.5) of Steve Jobs and Steve Wozniak set standards for low cost, high volume, and high reliability that defined the personal computer industry. But even with a four-year head start, Apple's personal computers finished second in popularity. The IBM Personal Computer, announced in 1981, became the best-selling computer of any kind; its success gave Intel the most popular microprocessor and Microsoft the most popular operating system. Today, the most popular CD is the Microsoft operating system, even though it costs many times more than a music CD! Of course, over the more than 20 years that the IBM-compatible personal computer has existed, it has

FIGURE 1.7.3 IBM System/360 computers: models 40, 50, 65, and 75 were all introduced in 1964. These four models varied in cost and performance by a factor of almost 10; it grows to 25 if we include models 20 and 30 (not shown). The clock rate, range of memory sizes, and approximate price for only the processor and memory of average size: (a) Model 40, 1.6 MHz, 32 KB–256 KB, $225,000; (b) Model 50, 2.0 MHz, 128 KB–256 KB, $550,000; (c) Model 65, 5.0 MHz, 256 KB–1 MB, $1,200,000; and (d) Model 75, 5.1 MHz, 256 KB–1 MB, $1,900,000. Adding I/O devices typically increased the price by factors of 1.8 to 3.5, with higher factors for cheaper models.

evolved greatly. In fact, the first personal computers had 16-bit processors and 64 kilobytes of memory, and a low-density, slow floppy disk has the only nonvolatile storage! Floppy disks were originally developed by IBM for loading diagnostic programs in mainframes, but were a major I/O device in personal computers for almost 20 years before the advent of CDs and networking made them obsolete as a method for exchanging data. Of course, Intel microprocessors have also evolved since the first PC, which used a 16-bit processor with an 8-bit external interface! In Chapter 2, we will talk about the evolution of the Intel architecture.

FIGURE 1.7.4 Cray-1, the first commercial vector supercomputer, announced in 1976. This machine had the unusual distinction of being both the fastest computer for scientific applications and the computer with the best price/performance for those applications. Viewed from the top, the computer looks like the letter *C*. Seymour Cray passed away in 1996 as a result of injuries sustained in an automobile accident. At the time of his death, this 70-year-old computer pioneer was working on his vision of the next generation of supercomputers. (See *www.cray.com* for more details.)

The first personal computers were quite simple with little or no graphics capability, no pointing devices, and primitive operating systems compared to those of today. The computer that inspired many of the architectural and software concepts that characterize the modern desktop machines was the Xerox Alto, shown in Figure 1.7.6. The Alto was created as an experimental prototype of a future computer; there were several hundred Altos built, including a significant number that were donated to universities. Among the technologies incorporated in the Alto were

- a bit-mapped graphics display integrated with a computer (earlier graphics displays acted as terminals, usually connected to larger computers)
- a mouse, which was invented earlier, but included on every Alto and used extensively in the user interface
- a local area network, which became the precursor to the Ethernet

FIGURE 1.7.5 The Apple IIc Plus. Designed by Steve Wozniak, The Apple IIe set standards of cost and reliability for the industry.

- a user interface based on windows and featuring a WYSIWYG (What You See Is What You Get) editor and interactive drawing programs

In addition, both file servers and print servers were developed and interfaced via the local area network, and connections between the local area network and the wide area ARPAnet produce the first versions of Internet-style networking. The Xerox Alto was incredibly influential and clearly affected the design of a wide variety of computers and software systems, including the Apple Macintosh, the IBM-compatible PC, MacOS and Windows, and Sun and other early workstations.

The Growth of Embedded Computing

Embedded processors have been around for a very long time; in fact, the first minicomputers and the first microprocessors were originally developed for controlling functions in a laboratory or industrial application. For many years, the dominant use of embedded processors was for industrial control applications, and although this use continued to grow, the processors tended to be very cheap and the performance relatively low. For example, the best-selling processor in the world remains an 8-bit microcontroller used in cars, some home appliances, and other simple applications.

The late 1980s and early 1990s saw the emergence of new opportunities for embedded processors, ranging from more advanced video games and set-top boxes to cell phones and personal digital assistants. The rapidly increasing num-

FIGURE 1.7.6 The Xerox Alto was the primary inspiration for the modern desktop computer. It included a mouse, a bit-mapped scheme, a windows-based user interface, and a local network connection.

ber of information appliances and the growth of networking have driven dramatic increases in the number of embedded processors, as well as the performance requirements. Today, the high end of the embedded market is anywhere from 2 to 5 times slower than desktop processors, but with prices that are typically from one-fifth to one-hundredth of the price of a desktop processor.

A Half Century of Progress

Since 1951, there have been thousands of new computers using a wide range of technologies and having widely varying capabilities. Figure 1.7.7 summarizes the

Year	Name	Size (cu. ft.)	Power (watts)	Performance (adds/sec)	Memory (KB)	Price	Price-performance vs. UNIVAC	Adjusted price (2003 $)	Adjusted price-performance vs. UNIVAC
1951	UNIVAC I	1,000	125,000	2,000	48	$1,000,000	1	$6,107,600	1
1964	IBM S/360 model 50	60	10,000	500,000	64	$1,000,000	263	$4,792,300	318
1965	PDP-8	8	500	330,000	4	$16,000	10,855	$75,390	13,135
1976	Cray-1	58	60,000	166,000,000	32,000	$4,000,000	21,842	$10,756,800	51,604
1981	IBM PC	1	150	240,000	256	$3,000	42,105	$5,461	154,673
1991	HP 9000/ model 750	2	500	50,000,000	16,384	$7,400	3,556,188	$9,401	16,122,356
1996	Intel PPro PC (200 MHz)	2	500	400,000,000	16,384	$4,400	47,846,890	$4,945	239,078,908
2003	Intel Pentium 4 PC (3.0 GHz)	2	500	6,000,000,000	262,144	$1,600	1,875,000,000	$1,600	11,452,000,000

FIGURE 1.7.7 Characteristics of key commercial computers since 1950, in actual dollars and in 2003 dollars adjusted for inflation. In contrast to Figure 1.7.3, here the price of the IBM S/360 model 50 includes I/O devices. Source: The Computer Museum, Boston, and Producer Price Index for Industrial Commodities.

key characteristics of some machines mentioned in this section and shows the dramatic changes that have occurred in just over 50 years. After adjusting for inflation, price/performance has improved by about 240 million in 45 years, or about 54% per year.

Readers interested in computer history should consult *Annals of the History of Computing,* a journal devoted to the history of computing. Several books describing the early days of computing have also appeared, many written by the pioneers including Goldstine 1972; Metropolis, Howlett, and Rota 1980; and Wilkes 1985.

Further Reading

Bell, C. G. [1996]. *Computer Pioneers and Pioneer Computers,* ACM and the Computer Museum, videotapes.

Two videotapes on the history of computing, produced by Gordon and Gwen Bell, including the following machines and their inventors: Harvard Mark-I, ENIAC, EDSAC, IAS machine, and many others.

Burks, A. W., H. H. Goldstine, and J. von Neumann [1946]. "Preliminary discussion of the logical design of an electronic computing instrument," Report to the U.S. Army Ordnance Department, p. 1; also appears in *Papers of John von Neumann,* W. Aspray and A. Burks, eds., MIT Press, Cambridge, MA., and Tomash Publishers, Los Angeles, 1987, 97–146.

A classic paper explaining computer hardware and software before the first stored-program computer was built. We quote extensively from it in Chapter 3. It simultaneously explained computers to the world and was a source of controversy because the first draft did not give credit to Eckert and Mauchly.

Campbell-Kelly, M., and W. Aspray [1996]. *Computer: A History of the Information Machine*, Basic Books, New York.

Two historians chronicle the dramatic story. The New York Times *calls it well written and authoritative.*

Ceruzzi, P. F. [1998] A History of Modern Computing. MIT Press, Cambridge, MA.

Contains a good description of the later history of computing: the integrated circuit and its impact, personal computers, UNIX, and the Internet.

Goldstine, H. H. [1972]. *The Computer: From Pascal to von Neumann,* Princeton University Press, Princeton, NJ.

A personal view of computing by one of the pioneers who worked with von Neumann.

Hennessy, J. L., and D. A. Patterson [2003]. Sections 1.3 and 1.4 of *Computer Architecture: A Quantitative Approach*, third edition, Morgan Kaufmann Publishers, San Francisco.

These sections contain much more detail on the cost of integrated circuits and explain the reasons for the difference between price and cost.

B.W. Lampson. *Personal distributed computing; The Alto and Ethernet software.* In ACM Conference on the History of Personal Workstations, January 1986.

C. R Thacker. *Personal distributed computing; The Alto and Ethernet hardware.* In ACM Conference on the History of Personal Workstations, January 1986.

These two papers describe the software and hardware of the landmark Alto.

Metropolis, N., Howlett, J, and G-C Rota, eds. [1980] *A History of Computing in the Twentieth Century*, Academic Press, New York.

A collection of essays that describe the people, software, computers, and laboratories involved in the first experimental and commercial computers. Most of the authors were personally involved in the projects. An excellent bibliography of early reports concludes this interesting book.

Public Broadcasting System [1992]. *The Machine that Changed the World,* videotapes.

These five one-hour programs include rare footage and interviews with pioneers of the computer industry.

Slater, R. [1987]. *Portraits in Silicon,* MIT Press, Cambridge, MA.

Short biographies of 31 computer pioneers.

Stern, N. [1980]. "Who invented the first electronic digital computer?" *Annals of the History of Computing* 2:4 (October) 375–76.

A historian's perspective on Atanasoff vs. Eckert and Mauchly.

Wilkes, M. V. [1985]. *Memoirs of a Computer Pioneer,* MIT Press, Cambridge, MA.

A personal view of computing by one of the pioneers.