

THIRD EDITION

COMPUTER

*A History of the
Information Machine*

STUDENT ECONOMY EDITION

Martin Campbell-Kelly, William Aspray,
Nathan Ensmenger, Jeffrey R. Yost

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THE SLOAN TECHNOLOGY SERIES

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Martin Campbell-Kelly
William Aspray
Nathan Ensmenger
Jeffrey R. Yost



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PREFACE TO THE THIRD EDITION

SINCE THE appearance of the second edition in 2004, computing has continued to evolve rapidly. Most obviously, the Internet has grown to maturity such that it is now an integral part of most people's lives in the developed world. Although computing was widely diffused by the end of the twentieth century, it has become truly ubiquitous only in the present century—a transition brought about by Internet commerce, consumer computing in the form of smartphones and tablet computers, and social networking.

The study of the history of computing has also matured as an academic enterprise. When the first edition of this book appeared in 1996, the history of computing had only recently begun to attract the attention of the academy, and research on this topic tended to be quite technically oriented. Since that time many new scholars with different perspectives have joined the field, and it is rare to find a science, technology, or business history conference that does not discuss developments in, and impacts of, computing technology. In short, the user experience and business applications of computing have become central to much of the historical discourse. To harness these new perspectives in our narrative we have been joined by two additional authors, Nathan Ensmenger and Jeffrey Yost—both scholars from the rising generation.

As always in a new edition, we have sparingly revised the text to reflect changing perspectives and updated the bibliography to incorporate the growing literature of the history of computing. We have also introduced some substantial new material. In Chapter 3, which focuses on the precomputer era, we have added a section on Alan Turing. The year 2012 saw the centenary of the birth of Turing, whom many consider both a gay icon and the true inventor of the computer. Turing was indeed a key influence in the development of theoretical computer science, but we believe his influence on the invention of the computer has been overstated and have tried to give a measured assessment. In Chapter 6, on the maturing of the mainframe computer, we have condensed material on the computer industry in order to make space for a discussion of the diffusion of computing in government and business organizations and the development of the computer professions. In Chapter 7, on real-time computing, we have taken advantage of a new strand of literature to discuss the development of online consumer banking. In Chapters 8, 9, 10, and 11 we

have made substantial additions to exploit the growing literature on the software professions, the semiconductor industry, pre-Internet networking, and the manufacture of computers.

Unsurprisingly, Chapter 12, on the development of the Internet, is the most changed. The chapter has been extended and divided into two parts: the creation of the Internet, and the World Wide Web and its consequences. The latter part includes new material on e-commerce, mobile and consumer computing, social networking, and the politics of the Internet. It is extraordinary to think that when we were writing the first edition of this book in the early 1990s, the web had only just been conceived and its current ubiquity was beyond our imagining.

With these changes we hope that, for the next several years, the third edition of *Computer* will continue to serve as an authoritative, semi-popular history of computing.

INTRODUCTION

IN JANUARY 1983, *Time* magazine selected the personal computer as its Man of the Year, and public fascination with the computer has continued to grow ever since. That year was not, however, the beginning of the computer age. Nor was it even the first time that *Time* had featured a computer on its cover. Thirty-three years earlier, in January 1950, the cover had sported an anthropomorphized image of a computer wearing a navy captain's hat to draw readers' attention to the feature story, about a calculator built at Harvard University for the US Navy. Sixty years before that, in August 1890, another popular American magazine, *Scientific American*, devoted its cover to a montage of the equipment constituting the new punched-card tabulating system for processing the US Census. As these magazine covers indicate, the computer has a long and rich history, and we aim to tell it in this book.

In the 1970s, when scholars began to investigate the history of computing, they were attracted to the large one-of-a-kind computers built a quarter-century earlier, sometimes now referred to as the "dinosaurs." These were the first machines to resemble in any way what we now recognize as computers: they were the first calculating systems to be readily programmed and the first to work with the lightning speed of electronics. Most of them were devoted to scientific and military applications, which meant that they were bred for their sheer number-crunching power. Searching for the prehistory of these machines, historians mapped out a line of desktop calculating machines originating in models built by the philosophers Blaise Pascal and Gottfried Leibniz in the seventeenth century and culminating in the formation of a desk calculator industry in the late nineteenth century. According to these histories, the desk calculators were followed in the period between the world wars by analog computers and electromechanical calculators for special scientific and engineering applications; the drive to improve the speed of calculating machines during World War II led directly to the modern computer.

Although correct in the main, this account is not complete. Today, research scientists and atomic weapons designers still use computers extensively, but the vast majority of computers in organizations are employed for other purposes, such as word processing and keeping business records. How did this come to pass? To

answer that question, we must take a broader view of the history of the computer as the history of the information machine.

This history begins in the early nineteenth century. Because of the increasing population and urbanization in the West resulting from the Industrial Revolution, the scale of business and government expanded, and with it grew the scale of information collection, processing, and communication needs. Governments began to have trouble enumerating their populations, telegraph companies could not keep pace with their message traffic, and insurance agencies had trouble processing policies for the masses of workers.

Novel and effective systems were developed for handling this increase in information. For example, the Prudential Assurance Company of England developed a highly effective system for processing insurance policies on an industrial scale using special-purpose buildings, rationalization of process, and division of labor. But by the last quarter of the century, large organizations had turned increasingly to technology as the solution to their information-processing needs. On the heels of the first large American corporations came a business-machine industry to supply them with typewriters, filing systems, and duplication and accounting equipment.

The desk calculator industry was part of this business-machine movement. For the previous two hundred years, desk calculators had merely been handmade curiosities for the wealthy. But by the end of the nineteenth century, these machines were being mass-produced and installed as standard office equipment, first in large corporations and later in progressively smaller offices and retail establishments. Similarly, the punched-card tabulating system developed to enable the US government to cope with its 1890 census data gained wide commercial use in the first half of the twentieth century, and was in fact the origin of IBM.

Also beginning in the nineteenth century and reaching maturity in the 1920s and 1930s was a separate tradition of analog computing. Engineers built simplified physical models of their problems and measured the values they needed to calculate. Analog computers were used extensively and effectively in the design of electric power networks, dams, and aircraft.

Although the calculating technologies available through the 1930s served business and scientific users well, during World War II they were not up to the demands of the military, which wanted to break codes, prepare firing tables for new guns, and design atomic weapons. The old technologies had three shortcomings: they were too slow in doing their calculations, they required human intervention in the course of a computation, and many of the most advanced calculating systems were special-purpose rather than general-purpose devices.

Because of the exigencies of the war, the military was willing to pay whatever it would take to develop the kinds of calculating machines it needed. Millions of dollars were spent, resulting in the production of the first electronic, stored-program

computers—although, ironically, none of them was completed in time for war work. The military and scientific research value of these computers was nevertheless appreciated, and by the time of the Korean War a small number had been built and placed in operation in military facilities, atomic energy laboratories, aerospace manufacturers, and research universities.

Although the computer had been developed for number crunching, several groups recognized its potential as a data-processing and accounting machine. The developers of the most important wartime computer, the ENIAC, left their university posts to start a business building computers for the scientific and business markets. Other electrical manufacturers and business-machine companies, including IBM, also turned to this enterprise. The computer makers found a ready market in government agencies, insurance companies, and large manufacturers.

The basic functional specifications of the computer were set out in a report written by John von Neumann in 1945, and these specifications are still largely followed today. However, decades of continuous innovation have followed the original conception. These innovations are of two types. One is the improvement in components, leading to faster processing speed, greater information-storage capacity, improved price/performance, better reliability, less required maintenance, and the like: today's computers are literally millions of times better than the first computers on almost all measures of this kind. These innovations were made predominantly by the firms that manufactured computers.

The second type of innovation was in the mode of operation, but here the agent for change was most often the academic sector, backed by government financing. In most cases, these innovations became a standard part of computing only through their refinement and incorporation into standard products by the computer manufacturers. There are five notable examples of this kind of innovation: high-level programming languages, real-time computing, time-sharing, networking, and graphically oriented human-computer interfaces.

While the basic structure of the computer remained unchanged, these new components and modes of operation revolutionized our human experiences with computers. Elements that we take for granted today—such as having a computer on our own desk, equipped with a mouse, monitor, and disk drive—were not even conceivable until the 1970s. At that time, most computers cost hundreds of thousands, or even millions, of dollars and filled a large room. Users would seldom touch or even see the computer itself. Instead, they would bring a stack of punched cards representing their program to an authorized computer operator and return hours or days later to pick up a printout of their results. As the mainframe became more refined, the punched cards were replaced by remote terminals, and response time from the computer became almost immediate—but still only the privileged few had access to the computer. All of this changed with the

development of the personal computer and the growth of the Internet. The mainframe has not died out, as many have predicted, but computing is now available to the masses.

As computer technology became increasingly less expensive and more portable, new and previously unanticipated uses for computers were discovered—or invented. Today, for example, the digital devices that many of us carry in our briefcases, backpacks, purses, or pockets serve simultaneously as portable computers, communications tools, entertainment platforms, digital cameras, monitoring devices, and conduits to increasingly omnipresent social networks. The history of the computer has become inextricably intertwined with the history of communications and mass media, as our discussion of the personal computer and the Internet clearly illustrates. But it is important to keep in mind that even in cutting-edge companies like Facebook and Google, multiple forms and meaning of the computer continue to coexist, from the massive mainframes and server farms that store and analyze data to the personal computers used by programmers to develop software to the mobile devices and applications with which users create and consume content. As the computer itself continues to evolve and acquire new meanings, so does our understanding of its relevant history. But it is important to remember that these new understandings do not refute or supersede these earlier histories but rather extend, deepen, and make them even more relevant.

WE HAVE ORGANIZED the book in four parts. The first covers the way computing was handled before the arrival of electronic computers. The next two parts describe the mainframe computer era, roughly from 1945 to 1980, with one part devoted to the computer's creation and the other to its evolution. The final part discusses the origins of personal computing and the Internet.

Part One, on the early history of computing, includes three chapters. Chapter 1 discusses manual information processing and early technologies. People often suppose that information processing is a twentieth-century phenomenon; this is not so, and the first chapter shows that sophisticated information processing could be done with or without machines—slower in the latter case, but equally well. Chapter 2 describes the origins of office machinery and the business-machine industry. To understand the post–World War II computer industry, we need to realize that its leading firms—including IBM—were established as business-machine manufacturers in the last decades of the nineteenth century and were major innovators between the two world wars. Chapter 3 describes Charles Babbage's failed attempt to build a calculating engine in the 1830s and its realization by Harvard University and IBM a century later. We also briefly discuss the theoretical developments associated with Alan Turing.

Part Two of the book describes the development of the electronic computer, from its invention during World War II up to the establishment of IBM as the

dominant mainframe computer manufacturer in the mid-1960s. Chapter 4 covers the development of the ENIAC at the University of Pennsylvania during the war and its successor, the EDVAC, which was the blueprint for almost all subsequent computers up to the present day. Chapter 5 describes the early development of the computer industry, which transformed the computer from a scientific instrument for mathematical computation into a machine for business data processing. In Chapter 6 we examine the development of the mainframe computer industry, focusing on the IBM System/360 range of computers, which created the first stable industry standard and established IBM's dominance.

Part Three presents a selective history of some key computer innovations in the quarter-century between the invention of the computer at the end of the war and the development of the first personal computers. Chapter 7 is a study of one of the key technologies of computing, real time. We examine this subject in the context of commonly experienced applications, such as airline reservations, banking and ATMs, and supermarket bar codes. Chapter 8 describes the development of software technology, the professionalization of programming, and the emergence of a software industry. Chapter 9 covers the development of some of the key features of the computing environment at the end of the 1960s: time-sharing, minicomputers, and microelectronics. The purpose of the chapter is, in part, to redress the commonly held notion that the computer transformed from the mainframe to the personal computer in one giant leap.

Part Four gives a history of the developments of the last forty years that brought the computer to most people's desktops and into their personal lives. Chapter 10 describes the development of the microcomputer from the first hobby computers in the mid-1970s up to its transformation into the familiar personal computer by the end of the decade. Chapter 11's focus is on the personal-computer environment of the 1980s, when the key innovations were user-friendliness and the delivery of "content," by means of CD-ROM storage and consumer networks. This decade was characterized by the extraordinary rise of Microsoft and the other personal-computer software companies. The book concludes with a discussion of the Internet. The focus is on the World Wide Web, its precedents in the information sciences, and its ever-evolving commercial and social applications.

We have included notes at the end of the book. These indicate the exact sources of our quotations and lead the interested reader to some of the major literature on the history of computing.



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Part One

BEFORE THE COMPUTER



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1

WHEN COMPUTERS WERE PEOPLE

THE WORD *computer* is a misleading name for the ubiquitous machine that sits on our desks. If we go back to the Victorian period, or even to the World War II era, the word meant an occupation, defined in the *Oxford English Dictionary* as “one who computes; a calculator, reckoner; *specifically* a person employed to make calculations in an observatory, in surveying, etc.”

In fact, although the modern computer can work with numbers, its main use is for storing and manipulating information—that is, for doing the kinds of jobs performed by a clerk, defined in the *Oxford English Dictionary* as “one employed in a subordinate position in a public or private office, shop, warehouse, etc., to make written entries, keep accounts, make fair copies of documents, do the mechanical work of correspondence and similar ‘clerkly’ work.”

The electronic computer can be said to combine the roles of the human computer and the human clerk.

LOGARITHMS AND MATHEMATICAL TABLES

The first attempt to organize information processing on a large scale using human computers was for the production of mathematical tables, such as logarithmic and trigonometric tables. Logarithmic tables revolutionized mathematical computation in the sixteenth and seventeenth centuries by enabling time-consuming arithmetic operations, such as multiplication and division and the extraction of roots, to be performed using only the simple operations of addition and subtraction. Trigonometric tables enabled a similar speeding up of calculations of angles and areas in connection with surveying and astronomy. However, logarithmic and trigonometric tables were merely the best-known general-purpose tables. By the late eighteenth

century, specialized tables were being produced for several different occupations: navigational tables for mariners, star tables for astronomers, life insurance tables for actuaries, civil engineering tables for architects, and so on. All these tables were produced by human computers, without any mechanical aid.

For a maritime nation such as Great Britain, and later the United States, the timely production of reliable navigation tables free of error was of major economic importance. In 1766 the British government sanctioned the astronomer royal, Nevil Maskelyne, to produce each year a set of navigational tables to be known as the *Nautical Almanac*. This was the first permanent table-making project to be established in the world. Often known as the Seaman's Bible, the *Nautical Almanac* dramatically improved navigational accuracy. It has been published without a break every year since 1766.

The *Nautical Almanac* was not computed directly by the Royal Observatory, but by a number of freelance human computers dotted around Great Britain. The calculations were performed twice, independently, by two computers and checked by a third "comparator." Many of these human computers were retired clerks or clergymen with a facility for figures and a reputation for reliability who worked from home. We know almost nothing of these anonymous drudges. Probably the only one to escape oblivion was the Reverend Malachy Hitchins, an eighteenth-century Cornish clergyman who was a computer and comparator for the *Nautical Almanac* for a period of forty years. A lifetime of computational dedication earned him a place in the *Dictionary of National Biography*. When Maskelyne died in 1811—Hitchins had died two years previously—the *Nautical Almanac* "fell on evil days for about 20 years, and even became notorious for its errors."

CHARLES BABBAGE AND TABLE MAKING

During this period Charles Babbage became interested in the problem of table making and the elimination of errors in tables. Born in 1791, the son of a wealthy London banker, Babbage spent his childhood in Totnes, Devon, a country town in the west of England. He experienced indifferent schooling but succeeded in teaching himself mathematics to a considerable level. He went to Trinity College, Cambridge University, in 1810, where he studied mathematics. Cambridge was the leading English university for mathematics, and Babbage was dismayed to discover that he already knew more than his tutors. Realizing that Cambridge (and England) had become a mathematical backwater compared to continental Europe, Babbage and two fellow students organized the Analytical Society, which succeeded in making major reforms of mathematics in Cambridge and eventually the whole of England. Even as a young man, Babbage was a talented propagandist.

Babbage left Cambridge in 1814, married, and settled in Regency London to lead the life of a gentleman philosopher. His researches were mainly mathematical,

and in 1816 his achievements were recognized by his election to the Royal Society, the leading scientific organization in Britain. He was then twenty-five—an enfant terrible with a growing scientific reputation.

In 1819 Babbage made the first of several visits to Paris, where he met a number of the leading members of the French Scientific Academy, such as the mathematicians Pierre-Simon Laplace and Joseph Fourier, with whom he formed lasting friendships. It was probably during this visit that Babbage learned of the great French table-making project organized by Baron Gaspard de Prony. This project would show Babbage a vision that would determine the future course of his life.

De Prony began the project in 1790, shortly after the French Revolution. The new government planned to reform many of France's ancient institutions and, in particular, to establish a fair system of property taxation. To achieve this, up-to-date maps of France were needed. De Prony was charged with this task and was appointed head of the Bureau du Cadastre, the French ordinance survey office. His task was made more complex by the fact that the government had simultaneously decided to reform the old imperial system of weights and measures by introducing the new rational metric system. This created within the bureau the job of making a complete new set of decimal tables, to be known as the *tables du cadastre*. It was by far the largest table-making project the world had ever known, and de Prony decided to organize it much as one would organize a factory.

De Prony took as his starting point the most famous economics text of his day, Adam Smith's *Wealth of Nations*, published in 1776. It was Smith who first advocated the principle of division of labor, which he illustrated by means of a pin-making factory. In this famous example, Smith explained how the making of a pin could be divided into several distinct operations: cutting the short lengths of wire to make the pins, forming the pin head, sharpening the points, polishing the pins, packing them, and so on. If a worker specialized in a single operation, the output would be vastly greater than if a single worker performed all the operations that went into making a pin. De Prony "conceived all of a sudden the idea of applying the same method to the immense work with which I had been burdened, and to manufacture logarithms as one manufactures pins."

De Prony organized his table-making "factory" into three sections. The first section consisted of half a dozen eminent mathematicians, including Adrien-Marie Legendre and Lazare Carnot, who decided on the mathematical formulas to be used in the calculations. Beneath them was another small section—a kind of middle management—that, given the mathematical formulas to be used, organized the computations and compiled the results ready for printing. Finally, the third and largest section, which consisted of sixty to eighty human computers, did the actual computation. The computers used the "method of differences," which required only the two basic operations of addition and subtraction, and not the more demanding operations of multiplication and division. Hence the computers were not, and did not need to be, educated

beyond basic numeracy and literacy. In fact, most of them were hairdressers who had lost their jobs because “one of the most hated symbols of the ancient regime was the hairstyles of the aristocracy.”

Although the Bureau was producing mathematical tables, the operation was not itself mathematical. It was fundamentally the application of an organizational technology, probably for the first time outside a manufacturing or military context, to the production of information. Its like would not be seen again for another forty years.

The whole project lasted about a decade, and by 1801 the tables existed in manuscript form all ready for printing. Unfortunately, for the next several decades, France was wracked by one financial and political crisis after another, so that the large sum of money needed to print the tables was never found. Hence, when Babbage learned of the project in 1819, all there was to show of it was the manuscript tables in the library of the French Scientific Academy.

In 1820, back in England, Babbage gained some firsthand experience of table making while preparing a set of star tables for the Astronomical Society, a scientific society that he and a group of like-minded amateur scientists had established the same year. Babbage and his friend John Herschel were supervising the construction of the star tables, which were being computed in the manner of the *Nautical Almanac* by freelance computers. Babbage’s and Herschel’s roles were to check the accuracy of the calculations and to supervise the compilation and printing of the results. Babbage complained about the difficulty of table making, finding it error-prone and tedious; and if he found it tedious just supervising the table making, so much the worse for those who did the actual computing.

Babbage’s unique role in nineteenth-century information processing was due to the fact that he was in equal measure a mathematician and an economist. The mathematician in him recognized the need for reliable tables and knew how to make them, but it was the economist in him that saw the significance of de Prony’s organizational technology and had the ability to carry the idea further.

De Prony had devised his table-making operation using the principles of mass production at a time when factory organization involved manual labor using very simple tools. But in the thirty years since de Prony’s project, best practice in factories had itself moved on, and a new age of mass-production machinery was beginning to dawn. The laborers in Adam Smith’s pin-making factory would soon be replaced by a pin-making machine. Babbage decided that rather than emulate de Prony’s labor-intensive and expensive manual table-making organization, he would ride the wave of the emerging mass-production technology and invent a machine for making tables.

Babbage called his machine a Difference Engine because it would use the same method of differences that de Prony and others used in table making. Babbage knew, however, that most errors in tables came not from calculating them but from

printing them, so he designed his engine to set the type ready for printing as well. Conceptually, the Difference Engine was very simple: it consisted of a set of adding mechanisms to do the calculations and a printing part.

Babbage applied his considerable skills as a publicist to promote the idea of the Difference Engine. He began his campaign by writing an open letter to the president of the Royal Society, Sir Humphrey Davy, in 1822, proposing that the government finance him to build the engine. Babbage argued that high-quality tables were essential for a maritime and industrial nation, and that his Difference Engine would be far cheaper than the nearly one hundred overseers and human computers in de Prony's table-making project. He had the letter printed at his own expense and ensured that it got into the hands of people of influence. As a result, in 1823 he obtained government funding of £1,500 to build the Difference Engine, with the understanding that more money would be provided if necessary.

Babbage managed to rally much of the scientific community to support his project. His boosters invariably argued that the merit of his Difference Engine was that it would eliminate the possibility of errors in tables "through the unerring certainty of mechanism." It was also darkly hinted that the errors in the *Nautical Almanac* and other tables might "render the navigator liable to be led into difficulties, if not danger." Babbage's friend Herschel went a step further, writing: "An undetected error in a logarithmic table is like a sunken rock at sea yet undiscovered, upon which it is impossible to say what wrecks may have taken place." Gradually the danger of errors in tables grew into lurid tales that "navigational tables were full of errors which continually led to ships being wrecked." Historians have found no evidence for this claim, although reliable tables certainly helped Britain's maritime activity run smoothly.

Unfortunately, the engineering was more complicated than the conceptualization. Babbage completely underestimated the financial and technical resources he would need to build his engine. He was at the cutting edge of production technology, for although relatively crude machines such as steam engines and power looms were in widespread use, sophisticated devices such as pin-making machines were still a novelty. By the 1850s such machinery would be commonplace, and there would exist a mechanical-engineering infrastructure that made building them relatively easy. While building the Difference Engine in the 1820s was not in any sense impossible, Babbage was paying the price of being a first mover; it was rather like building the first computers in the mid-1940s: difficult and extremely expensive.

Babbage was now battling on two fronts: first, designing the Difference Engine and, second, developing the technology to build it. Although the Difference Engine was conceptually simple, its design was mechanically complex. In the London Science Museum today, one can see evidence of this complexity in hundreds of Babbage's machine drawings for the engines and in thousands of pages of his notebooks. During the 1820s, Babbage scoured the factories of Europe seeking gadgets

and technology that he could use in the Difference Engine. Not many of his discoveries found their way into the Difference Engine, but he succeeded in turning himself into the most knowledgeable economist of manufacturing of his day. In 1832 he published his most important book, an economics classic titled *Economy of Machinery and Manufactures*, which ran to four editions and was translated into five languages. In the history of economics, Babbage is a seminal figure who connects Adam Smith's *Wealth of Nations* to the Scientific Management movement, founded in America by Frederick Winslow Taylor in the 1880s.

The government continued to advance Babbage money during the 1820s and early 1830s, eventually totaling £17,000; and Babbage claimed to have spent much the same again from his own pocket. These would be very large sums in today's money. By 1833, Babbage had produced a beautifully engineered prototype Difference Engine that was too small for real table making and lacked a printing unit, but showed beyond any question the feasibility of his concept. (It is still on permanent exhibit in the London Science Museum, and it works as perfectly today as it did then.)

To develop a full-scale machine Babbage needed even more money, which he requested in a letter in 1834 to the prime minister, the Duke of Wellington. Unfortunately, at that time, Babbage had an idea of such stunning originality that he just could not keep quiet about it: a new kind of engine that would do all the Difference Engine could do but much more—it would be capable of performing *any* calculation that a human could specify for it. This machine he called the Analytical Engine. In almost all important respects, it had the same logical organization as the modern electronic computer. In his letter to the Duke of Wellington, Babbage hinted that instead of completing the Difference Engine he should be allowed to build the Analytical Engine. Raising the specter of the Analytical Engine was the most spectacular political misjudgment of Babbage's career; it fatally undermined the government's confidence in his project, and he never obtained another penny. In fact, by this time, Babbage was so thoroughly immersed in his calculating-engine project that he had completely lost sight of the original objective: to make tables. The engines had become an end in themselves, as we shall see in Chapter 3.

CLEARING HOUSES AND TELEGRAPHS

While Babbage was struggling with his Difference Engine, the idea of large-scale information processing was highly unusual—whether it was organized manually or used machinery. The volume of activity in ordinary offices of the 1820s simply did not call for large clerical staffs. Nor was there any office machinery to be had; even adding machines were little more than a scientific novelty at this date, and the typewriter had yet to be invented. For example, the Equitable Society of London—

then the largest life insurance office in the world—was entirely managed by an office staff of eight clerks, equipped with nothing more than quill pens and writing paper.

In the whole of England there was just one large-scale data-processing organization that had an organizational technology comparable with de Prony's table-making project. This was the Bankers' Clearing House in the City of London, and Babbage wrote the only contemporary published account of it.

The Bankers' Clearing House was an organization that processed the rapidly increasing number of checks being used in commerce. When the use of checks became popular in the eighteenth century, a bank clerk physically had to take a check deposited by a customer to the bank that issued it to have it exchanged for cash. As the use of checks gained in popularity in the middle of the eighteenth century, each of the London banks employed a "walk clerk," whose function was to make a tour of all the other banks in the City, the financial district of London, exchanging checks for cash. In the 1770s, this arrangement was simplified by having all the clerks meet at the same time in the Five Bells Public House on Lombard Street. There they performed all the exchanging of checks and cash in one "clearing room." This obviously saved a lot of walking time and avoided the danger of robbery. It also brought to light that if two banks had checks drawn on each other, the amount of cash needed for settlement was simply the difference between the two amounts owed, which was usually far less than the total amount of all the checks. As the volume of business expanded, the clearing room outgrew its premises and moved several times. Eventually, in the early 1830s, the London banks jointly built a Bankers' Clearing House at 10 Lombard Street, in the heart of London's financial center.

The Bankers' Clearing House was a secretive organization that shunned visitors and publicity. This was because the established banks wanted to exclude the many banks newly formed in the 1820s (which the Clearing House succeeded in doing until the 1850s). Babbage, however, was fascinated by the clearing house concept and pulled strings to gain entry. The secretary of the Bankers' Clearing House was a remarkable man by the name of John Lubbock, who, besides being a leading figure in the City, was also an influential amateur scientist and vice president of the Royal Society. Babbage wrote to Lubbock in October 1832 asking if it were "possible that a stranger be permitted as a spectator." Lubbock replied, "*You* can be taken to the clearing house . . . but we wish it not to be mentioned, so that the public may fancy they can have access to the sanctum sanctorum of banking, and we wish of course not to be named." Babbage was captivated by Lubbock's scientifically organized system, which, despite Lubbock's proscription, he described in glowing terms in the *Economy of Manufactures*:

In a large room in Lombard Street, about thirty clerks from the several London bankers take their stations, in alphabetical order, at desks placed round the room;

each having a small open box by his side, and the name of the firm to which he belongs in large characters on the wall above his head. From time to time other clerks from every house enter the room, and, passing along, drop into the box the checks due by that firm to the house from which this distributor is sent.

Most of the day was spent by clerks exchanging checks with one another and entering the details in ledgers. At four o'clock in the afternoon, the settlements between the banks would begin. The clerk for each bank would total all the checks received from other banks for payment and all the checks presented for payment to other banks. The difference between these two numbers would then be either paid out or collected.

At five o'clock, the inspector of the clearing house took his seat on a rostrum in the center of the room. Then, the clerks from all the banks who owed money on that day paid the amount due in cash to the inspector. Next, the clerks of all the banks that were owed money collected their cash from the inspector. Assuming that no mistakes had been made (and an elaborate accounting system using preprinted forms ensured this did not happen very often), the inspector was left with a cash balance of exactly zero.

The amount of money flowing through the Bankers' Clearing House was staggering. In the year 1839, £954 million was cleared—the equivalent of several hundred billion dollars in today's money. On the busiest single day more than £6 million was cleared, and about half a million pounds in bank notes were used for the settlement. Eventually, the need for cash was eliminated altogether through an arrangement by which each bank and the Clearing House had an account with the Bank of England. Settlements were then made simply by transferring an amount from a bank's account to that of the Clearing House, or vice versa.

Babbage clearly recognized the significance of the Bankers' Clearing House as an example of the "division of mental labor," comparable with de Prony's table-making project and his own Difference Engine. He remained deeply interested in large-scale information processing all his life. For example, in 1837 he applied unsuccessfully to become registrar general and director of the English population census. But by the time really big information-processing organizations came along in the 1850s and 1860s—such as the great savings banks and industrial insurance companies—Babbage was an aging man who had ceased to have any influence.

The Bankers' Clearing House was an early example of what would today be called financial infrastructure. The Victorian period was the great age of physical and financial infrastructure investment. Between 1840 and 1870, Britain's investment in rail track grew from 1,500 to over 13,000 miles. Alongside this physical and highly visible transport infrastructure grew a parallel, unseen information infrastructure known as the Railway Clearing House, which was modeled very closely on the Bankers' Clearing House. Established in 1842, the Railway Clearing House

rapidly became one of the largest data-processing bureaucracies in the world. By 1870 there were over 1,300 clerks processing nearly 5 million transactions a year.

Another vital part of the Victorian information infrastructure was the telegraph, which began to compete with the ordinary postal system in the 1860s. Telegrams were expensive—one shilling for a twenty-word message compared with as much as you could want to write in a letter for one penny—but very fast. A telegram would speed across the country in an instant and arrive at its final destination in as little as an hour, hand-delivered by a telegraph boy.

Rather like the Internet in our own time, the telegraph did not originate as a planned communications system. Instead it began as a solution to a communications problem in the early rail system. There was a widely held fear among the public of a passenger train entering a section of track while another was heading in the opposite direction (in practice there were very few such accidents, but this did not diminish public concern). To solve the problem, inventive engineers strung up an electrical communication system alongside the track so that the signalmen at each end could communicate. Now a train could not enter a single-track section until two human operators agreed that it was safe to do so. Of course, it was not long before a commercial use was found for the new electrical signaling method. Newspapers and commercial organizations were willing to pay for news and market information ahead of their competitors. Suddenly, telegraph poles sprang up alongside railway tracks; some systems were owned by the railway companies, some by newly formed telegraph companies. Although messages were sent by electricity, the telegraph still needed a large clerical labor force to operate the machines that transmitted the messages. Much of the labor was female—the first time that female clerical labor had been used on any scale in Britain. The reason for this was that telegraph instruments were rather delicate and it was believed that women—especially seamstresses familiar with sewing machines—would have more dexterity than men.

By the mid-1860s there were over 75,000 miles of telegraph lines in Britain, operated by six main companies. However, each system operated independently and it was difficult for a telegram originating in one network to make use of another. In 1870, the British government stepped in to integrate the systems into a national telegraph network. Once this was done, telegraph usage simply exploded. More telegraph lines were erected and old ones were renewed. Telegraph offices were established in every significant town. Telegraph schools were set up in London and the provinces to train young men and women in Morse telegraphy. The cost of a telegram fell to sixpence for a dozen words.

The transmission of telegrams presented some interesting technical problems. Chief among these was the need to send telegrams between locations that were not directly connected by a telegraph line. Consider the problem of a cigar manufacturer in Edinburgh, Scotland, negotiating with a tobacco importer in Bristol,

England, some 350 miles south. There was no direct connection between these two great cities. Instead the telegram had to be passed, rather like a baton in a relay race, through the telegraph offices of intermediate cities: Edinburgh to Newcastle, Newcastle to York, York to Manchester, Manchester to Birmingham, and finally Birmingham to Bristol. At each intervening telegraph office the message was received by a telegraphist on a Morse sounder and written out in longhand. The message would then be resent by another telegraphist to the next telegraph office in the chain. Although labor-intensive, the system was very resilient. If the telegraph lines between York and Manchester, say, were storm-damaged or simply very busy, the operator might send the message via Sheffield, which was not too much of a diversion. Sheffield would then send the message on its southerly route. Telegraphists needed to have a good knowledge of national geography.

After the government took over the telegraph system, and because London was the political and commercial center of Britain, it made sense for all major cities to have direct lines into the capital. In 1874 a central hub, the Central Telegraph Office, was established with a direct connection to “every town of importance in the United Kingdom.” The Central Telegraph Office occupied a purpose-built structure in St. Martin’s Le Grand, sited between Parliament, on the one hand, and the financial district and newspaper offices in Fleet Street, on the other. The office was the epitome of scientific modernity and featured in illustrated books and magazines. From the day it began operations, the great majority of national telegraph traffic passed through it: now our cigar manufacturer in Edinburgh could communicate with his tobacco importer in Bristol with just a single hop. This was faster, cheaper, and less likely to introduce transcription errors in the message.

In 1874, the *Illustrated London News* produced a full-page engraving of a gallery in the Central Telegraph Office. The image shows an information factory frozen in time: row upon row of young men and women are operating telegraph instruments, supervisors (generally just a little older than their charges) organize the work from a massive sorting table at the front of the room, while messenger boys (mostly fresh out of elementary school) run up and down the rows of telegraph stations collecting messages as they are transcribed and distributing them for onward transmission. The writer of the article explained—in words that spoke not only of the telegraph but of the times in which he lived:

It is a cheerful scene of orderly industry, and it is, of course, not the less pleasing because the majority of the persons here are young women, looking brisk and happy, not to say pretty, and certainly quite at home. Each has her own instrument on the desk before her. She is either just now actually busied in working off or in reading some message, or else, for the moment she awaits the signal, from a distant station, to announce a message for her reception. Boys move here and there about the galleries, with the forms of telegrams, which have been received

in one part of the instrument-room, and which have to be signaled from another, but which have first to be conveyed, for record, to the nearest check-tables and sorting-tables in the centre.

The journalist—evidently a man with a taste for statistics—noted that there were 1,200 telegraphists, of whom 740 were female, and 270 boy messengers. Each day between 17,000 and 18,000 messages were transmitted between provincial telegraph offices, while nearly as many again were transmitted within London. But this was only the beginning. By the turn of the century, the Central Telegraph Office employed no fewer than 4,500 clerks and transmitted between 120,000 and 165,000 telegrams a day. It was the largest office in the world.

HERMAN HOLLERITH AND THE 1890 CENSUS

Compared to Europe, the United States was a latecomer to large-scale data processing. That's because it lagged twenty or thirty years behind Europe in its economic development. When Britain, Germany, and France were industrializing in the 1830s, the United States was still primarily an agricultural country. It was not until after the Civil War that US businesses began to develop big offices, but this delay enabled them to take full advantage of the newly emerging office technologies.

Before the Civil War the only American data-processing bureaucracy of major importance was the Bureau of the Census in Washington, DC. The population census was established by an act of Congress in 1790 to determine the "apportionment" of members of the House of Representatives. The first census in 1790 estimated the population of the United States at 3.9 million and consequently established that there should be an apportionment of one representative for each 33,000 people, or 105 representatives. The early census data processing was very small scale, and no records exist as to how it was organized. Even by 1840, when the population was 17.1 million, there were still only 28 clerks in the Bureau of the Census. Twenty years later, however, by the 1860 census, a major bureaucracy was in place that employed 184 clerks to count a population of 31.4 million. For the 1870 census, there were 438 clerks, and the census reports amounted to 3,473 pages.

After that, the growth of the census was simply explosive. The census of 1880 probably represented a high point in manual data processing in the United States, when no fewer than 1,495 clerks were employed to process the census data. The data-processing method in use then was known as the "tally system." This can best be understood by an example. One of the reports produced by the census was a table of the age structure of the population for each of the states, and the major cities and towns (that is, the number of males and females, in their ethnic categories, of each age). A tally clerk was provided with a large tally sheet, ruled into a

grid, with a dozen columns and many rows. Each pair of columns corresponded to males and females of a particular ethnic group. The rows corresponded to the age of an individual—under one year of age, one year of age, two years of age, and so on, up to a hundred years of age and over. The tally clerk would take a stack of census forms from an “enumeration district” (representing about a hundred families) and would proceed to examine the age, sex, and ethnic origin of each person on each form, putting a check mark in the appropriate cell of the grid. When the pile of forms had been processed in this way, the clerk would count the number of check marks in each of the cells and write the result at the side in red ink. This would be repeated for every enumeration district in the city. Finally, another clerk would total all the red-inked numbers on all the tally sheets for a city, entering the results onto a consolidation sheet, which would eventually become one of the tables in the census report.

The work of the census clerks was tedious beyond belief, prompting a journalist of the period to write: “The only wonder . . . is, that many of the clerks who toiled at the irritating slips of tally paper in the census of 1880 did not go blind and crazy.” More than twenty-one thousand pages of census reports were produced for the 1880 census, which took some seven years to process. This unreasonably long time provided a strong motive to speed up the census by mechanization or any other means that could be devised.

One person who was acutely aware of the census problem was a remarkable young engineer by the name of Herman Hollerith (1859–1929). He later developed a mechanical system for census data processing, commercialized his invention by establishing the Tabulating Machine Company in 1896, and laid the foundations of IBM. Along with Babbage, Hollerith is regarded as one of the seminal nineteenth-century figures in the development of information processing. Though Hollerith was not a deep thinker like the polymath Babbage, he was practical where Babbage was not. Hollerith also had a strong entrepreneurial flair, so that he was able to exploit his inventions and establish a major industry.

Hollerith grew up in New York and attended Columbia University, where one of his professors was an adviser to the Bureau of the Census in Washington. He invited the newly graduated Hollerith to become his assistant. While with the Census Bureau, Hollerith saw for himself the extraordinary scale of clerical activity—there was nothing else in the country to compare with it at the time. This familiarity with census operations enabled him to devise an electrical tabulating system that would mechanize much of the clerical drudgery.

Hollerith’s key idea was to record the census return for each individual as a pattern of holes on punched paper tape or a set of punched cards, similar to the way music was recorded on a string of punched cards on fairground organettes of the period. It would then be possible to use a machine to automatically count the holes and produce the tabulations. In later years Hollerith would reminisce on the

origins of the idea: "I was traveling in the West and I had a ticket with what I think was called a punch photograph. [The conductor] punched out a description of the individual, as light hair, dark eyes, large nose, etc. So you see, I only made a punch photograph of each person."

In 1888 the preparations for the 1890 census had begun under the direction of a newly appointed superintendent of the census, Robert P. Porter. Porter, an English-born naturalized American, was a charismatic individual. He was a diplomat, an economist, and a journalist; founder and editor of the *New York Press*; an industrial pundit; and a well-known exponent on statistics. As soon as he was appointed superintendent, he set up a commission to select by competition an alternative to the system of tally sheets used in the 1880 and previous censuses. He was already an enthusiast for Hollerith's system; as a journalist he had written an article about it, and would later become chairman of the British Tabulating Machine Company (the ancestor of International Computers, which became Europe's largest computer company). But to ensure a fair contest, he disallowed himself from being a judge of the competition.

Three inventors entered the competition, including Hollerith, and all of them proposed using cards or slips of paper in place of the old tally sheets. One of Hollerith's rivals proposed transcribing the census return for each individual onto a slip of paper, using inks of different colors for the different questions, so that the data could be easily identified and rapidly counted and sorted by hand. The second competitor had much the same idea but used ordinary ink and cards of different colors, which would then be easy to identify and arrange by hand. These two systems were entirely manual and were similar to the card-based record systems that were beginning to emerge ad hoc in big commercial offices. The great advantage of the Hollerith system over these others was that once the cards had been punched, all the sorting and counting would be handled mechanically.

In the fall of 1889, the three competitors were required to demonstrate their systems by processing the 10,491 returns of the 1880 population census for the district of St. Louis. The trial involved both recording the returns on the cards or paper slips and tabulating them to produce the required statistical tables. So far as recording the data on cards was concerned, the Hollerith system proved little faster than the competing manual systems. But in the tabulation phase it came into its own, proving up to ten times as fast as the rival systems. Moreover, once the cards had been punched, the more tabulations that were required the more cost-effective the Hollerith system would prove. The commission was unanimous in recommending that the Hollerith Electric Tabulating System be adopted for the 1890 census.

As preparations for the eleventh United States population census got into high gear, Superintendent Porter "rounded up what appeared to be every square foot of empty office and loft space in downtown Washington." At the same time, Hollerith

made the transition from inventor to supervising manufacturer and subcontracted Western Electric to assemble his census machines. He also negotiated with paper manufacturers to supply the 60 million-plus manila cards that would be needed for the census.

On 1 June 1890, an army of forty-five thousand census enumerators swept the nation, preparing the schedules for the 13 million households and dispatching them to Washington. At the Census Bureau two thousand clerks were assembled in readiness, and on 1 July they began to process the greatest and most complete census the world had ever seen. It was a moment for the American people to “feel their nation’s muscle.”

On 16 August 1890, six weeks into the processing of the census, the grand total of 62,622,250 was announced. But this was not what the allegedly fastest-growing nation in the world wanted to hear:

The statement by Mr. Porter that the population of this great republic was only 62,622,250 sent into spasms of indignation a great many people who had made up their minds that the dignity of the republic could only be supported on a total of 75,000,000. Hence there was a howl, not of “deep-mouthed welcome,” but of frantic disappointment. And then the publication of the figures of New York! Rachel weeping for her lost children and refusing to be comforted was a mere puppet-show compared with some of our New York politicians over the strayed and stolen of Manhattan Island citizens.

The press loved the story. In an article headlined “Useless Machines,” the *Boston Herald* roasted Porter and Hollerith; “Slip Shod Work Has Spoiled the Census,” exclaimed the *New York Herald*; and the other papers soon took up the story. But Hollerith and Porter never had any real doubts about the system.

After the rough count was over and the initial flurry of public interest had subsided, the Census Bureau settled into a routine. Recording all the data onto the cards was a task that kept the seven hundred card punches in almost constant operation. A punching clerk—doing what was optimistically described as “vastly interesting” work—could punch an average of seven hundred cards in a six-and-a-half-hour day. Female labor was heavily used for the first time in the census, which a male journalist noted “augurs well for its conscientious performance” because “women show a moral sense of responsibility that is still beyond the average.” More than 62 million cards were punched, one for each citizen.

The cards then were processed by the census machines, each of which could do the work of twenty of the former tally clerks. Even so, the original fifty-six census machines eventually had to be increased to a hundred (and the extra rentals significantly added to Hollerith’s income). Each census machine consisted of two parts: a

tabulating machine, which could count the holes in a batch of cards, and the sorting box, into which cards were placed by the operator ready for the next tabulating operation. A census machine operator processed the cards one by one, by reading the information using a “press” that consisted of a plate of 288 retractable spring-loaded pins. When the press was forced down on the card, a pin meeting the solid material was pushed back into the press and had no effect. But a pin encountering a hole passed straight through, dipped into a mercury cup, and completed an electrical circuit. This circuit would then be used to add unity to one of forty counters on the front of the census machine. The circuit could also cause the lid of one of the twenty-four compartments of the sorting box to fly open—into which the operator would place the card so that it would be ready for the next phase of the tabulation.

Thus, if one counter of the tabulating machine and one sorting box compartment were wired up for a male subject and another counter and compartment were wired up for a female subject, the census machine—by reading a batch of cards—could determine the number of males and females represented and then separate the cards accordingly. In practice, counts were much more complicated than this, in order to extract as much information as possible from the cards. Counts were designed to use all forty counters on the census machine and as many as possible of the twenty-four compartments in the sorting box.

At any one time there would be upward of eighty clerks operating the machines. Each operator processed at least a thousand cards an hour. In a typical day the combined operation would eat through nearly half a million cards: “In other words, the force was piercing its way through the mass at the rate of 500 feet daily, and handling a stack of cards nearly as high as the Washington Monument.” As each card was read, the census machine gave a ring of a bell to indicate that it had been correctly sensed. The floor full of machines ringing away made a sound “for all the world like that of sleighing,” commented a journalist. It was an awe-inspiring sight and sound; and, as the same journalist noted, “the apparatus works as unerringly as the mills of the Gods, but beats them hollow as to speed.” Hollerith personally supervised the whole operation, combating both natural and unnatural mechanical breakdowns. One veteran of the census recounted:

Herman Hollerith used to visit the premises frequently. I remember him as very tall and dark. Mechanics were there frequently too, to get ailing machines back in operation and loafing employees back at work. The trouble was usually that somebody had extracted the mercury from one of the little cups with an eye-dropper and squirted it into a spittoon, just to get some unneeded rest.

The 1890 census was processed in two and a half years, compared with the seven years of the previous census. Altogether, the census reports totaled 26,408 pages.

The total cost was \$11.5 million, and estimates indicated that without the Hollerith system it would have cost \$5 million more. For those with eyes to see, the Hollerith machines had opened up a whole new vista of mechanized information processing.

AMERICA'S LOVE AFFAIR WITH OFFICE MACHINERY

While the Hollerith system was the most visible use of mechanical information processing in the United States, it was really only one of many examples of what we now call "information technology" that developed in the twenty years following the Civil War. The Hollerith system was not in any sense typical of this information technology. Most office machines were much more humdrum: typewriters, record-keeping systems, and adding machines. Even more humdrum were the many varieties of office supplies available to American business: a hundred different types and grades of pencil; dozens of makes of fountain pens; paper clips, fasteners, and staplers of every conceivable variety; patented check-cutting machines to prevent fraud; cashier's coin trays and gadgets for sorting cash; carbon paper and typewriter sundries; loose-leaf ledgers and filing cabinets; wooden desks equipped with pigeonholes. The list goes on and on.

In the closing decades of the nineteenth century, office equipment, in both its most advanced and its least sophisticated forms, was almost entirely an American phenomenon. Its like would not be seen in Europe until the new century and, in many businesses, not until after World War I.

There were two main reasons for America's affinity for office machinery. First, because of the American office's late start compared with Europe, it did not carry the albatross of old-fashioned offices and entrenched archaic working methods. For example, back in England, the British Prudential Assurance Company had been established in the 1850s with Victorian data-processing methods that it could not shake off because redesigning the office system to make use of typewriters, adding machines, or modern card index systems was never cost-effective. Indeed, there was not a single typewriter in the Prudential before the turn of the century, and it was not until 1915 that any advanced office machinery was introduced. By contrast, the American Prudential Company in New York, which was established twenty years after the British company, immediately made use of any office appliances on the market and became a recognized leader in utilizing office technology—a reputation it sustained right into the 1950s, when it was one of the first American offices to computerize. Similarly, while the British clearing houses were unmechanized until well into the new century, their American counterparts became massive users of Comptometers and Burroughs adding machines during the 1890s.

But no simple economic explanation can fully account for America's love affair with office machinery. The fact is that America was gadget-happy and was caught up by the glamour of the mechanical office. American firms often bought office appliances simply because they were perceived as modern—much as American firms bought the first computers in the 1950s. This attitude was reinforced by the rhetoric of the office-systems movement.

Just as Frederick W. Taylor was pioneering scientific management in American industry in the 1880s, focusing on the shop floor, a new breed of scientific manager—or “systematizer”—was beginning to revolutionize the American office. As an early systematizer puffed to his audience in 1886:

Now, administration without records is like music without notes—by ear. Good as far as it goes which is but a little way—it bequeathes nothing to the future. . . . Under rational management the accumulation of experience, and its systematic use and application, form the first fighting line.

Systematizers set about restructuring the office, introducing typewriters and adding machines, designing multipart business forms and loose-leaf filing systems, replacing old-fashioned accounting ledgers with machine billing systems, and so on. The office systematizer was the ancestor of today's information-technology consultant.

Powered by the fad for office rationalization, the United States was the first country in the world to adopt office machinery on a large scale. This early start enabled the United States to become the leading producer of information-technology goods, a position it has sustained to the present day. In turn, the United States dominated the typewriter, record-keeping, and adding-machine industries for most of their histories; it dominated the accounting-machine industry between the two world wars; it established the computer industry after World War II; and it leads the industry to this day. There is thus an unbroken line of descent from the giant office-machine firms of the 1890s to the computer makers of today.



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THE MECHANICAL OFFICE

IN 1928 THE WORLD'S top four office-machine suppliers were Remington Rand, with annual sales of \$60 million; National Cash Register (NCR), with sales of \$50 million; the Burroughs Adding Machine Company, with \$32 million worth of business; and—trailing the three leaders by a considerable margin—IBM, with an income of \$20 million. Forty years later those same firms were among the top-ten computer manufacturers, and of the four, IBM, whose sales exceeded those of the other three combined, was the third-largest corporation in the world, with annual revenues of \$21 billion and a workforce of a third of a million people.

To understand the development of the computer industry, and how this apparently new industry was shaped by the past, one must understand the rise of the office-machine giants in the years around the turn of the twentieth century. This understanding is necessary, above all, to appreciate how IBM's managerial style, sales ethos, and technologies combined to make it perfectly adapted to shape and then dominate the computer industry.

Today, we use computers in the office for three main tasks. There is document preparation: for example, using a word-processing program to produce letters and reports. There is information storage: for example, using a database program to store names and addresses, or inventories. And there is financial analysis and accounting: for example, using a spreadsheet program for financial forecasting, or using a computer to organize a company's payroll.

These were precisely the three key office activities that the business-machine companies of the late nineteenth century were established to serve. Remington Rand was the leading supplier of typewriters for document preparation and filing systems for information storage. Burroughs dominated the market for adding machines used for simple calculations. IBM dominated the market for punched-card accounting machines. And NCR, having started out making cash registers in the 1880s, also became a major supplier of accounting machines.