HISTORY OF COMPUTING

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Summary

Computers have transformed the way people in the developed, and increasingly the developing world work, think, play, shop, and socialize. For centuries humans have designed and developed computational tools and machines to aid with calculation—from the ancient abacus (perhaps as early as 2700-2300 BC), Napier's logarithmic tables and "bones" (early 17th century), and Charles Babbage's plans for massive mechanical calculating engines (early 19th century) to sophisticated accounting machines and giant analog computers (first half of the 20th century). While these technologies were complex, meaningful, and often highly useful to individuals and organizations in particular fields and endeavors, the digital computer—first developed during World War II—evolved by the end of the 20th century to broadly and forever, change human perspectives, predilections, practices, and possibilities. It unquestionably became a machine, and more accurately a set of systems, that changed the world. In time, digital computers, and advanced programming facilitated not only unmatched number crunching accuracy and speed, but also highly versatile information processing and textual, audio, and graphical communications. As such, computers became not only a tool for various types of scientific and business data processing work, but also an

instrument of leisure that individuals and groups use for entertainment, social interaction, and other ends.

This chapter briefly surveys select pre-digital computational developments (the abacus, calculators, punch card tabulation machines, and analog computers), before focusing on the successive waves of digital computing, software, and networking technology that have so deeply influenced our infrastructural systems and ways of life. It examines the major developments and shifts within computing, and sheds light on the underlying changes, as well as continuities, associated with the development and use of these pervasive technologies.

1. Pre-digital Computer Computing Technology

For millennia humans have sought to develop tools for computation. The abacus, a technology that might date back in some form more than 4500 years, is generally recognized as the first computational tool (other than using one's hand to count). By creating or utilizing rows of indentations on sand or soil, and positioning and moving stones or other small objects within the rows, ancient abaci were used to keep track of numbers and aid humans as they made calculations. Given the materials that these individuals used, pinpointing the date and place of origin of the ancient abacus most likely will never be possible.

Some researchers have argued that the technology existed in Mesopotamia (2700 to 2300 BC)—where Sumerians may have constructed the first primitive (sand/soil and stones) abaci. Others contend that the Chinese were the first to invent the technology, with some claims to a similar time-frame. Definitive evidence (of a more modern abacus), however, only exists for a much later device. Abaci more nearly matching what we now think of as the abacus (pierced beads of some sort moved along a thin rod or wire that is held in place by a frame) are most commonly associated with the Far East. These more modern abaci were used in China in the early 13th century and the technology was transferred to Korea and Japan in the succeeding several centuries.

Of the European abaci, none are more famous than Napier's bones. John Napier was born in Scotland in 1550, though much of his early life remains a mystery. He is most famous for his invention of logarithmic tables. In 1614 Napier published *Mirifici Logarithmorum Canonis Descriptio*, a book with 57-pages on the description of relations between arithmetic and geometric series, and 90-pages of logarithmic tables. He died three years later, but in that time began collaborating with Henry Briggs, who popularized and built upon Napier's work on logarithms after Napier's death. In the latter part of his life, Napier also developed his bones—a multiplication rod abacus capable of relatively complex multiplication—that he used in his research and creation of his logarithmic tables. Napier's bones represented a different form of abacus that used a system of numbers on rods, and sequences of positioning of these rods, to multiply. It was a precursor to the slide rule—a technology developed several decades later in Great Britain. The use of actual animal bones gave the multiplication rods a name, "bones," that remained long after Napier's death. .

Today we think of the abacus—often constructed of a finished wood or plastic frame, thin metal bars or wires, and pierced, movable beads or small plastic cylinders—as a children's toy. To (possibly) the ancient Sumerians, and (definitely) the Chinese, Japanese, Koreans and others from the late Middle Ages, as well as users of Napier's bones in the 17th century, it was anything but a toy. It was an important tool to assist with various mathematical computations related to the natural world and human-developed systems, particularly those within government and commerce.

Concomitant to the abacus, mathematical tables were an idea born millennia ago that began to have profound influence during the late Middle Ages. The impact of mathematical tables only heightened in the Renaissance and beyond. Mathematical tables were fundamental to the Scientific Revolution and continued to see widespread use in the sciences (particularly astronomy and physics) as well as economics and business. Long before calculating devices became inexpensive, and with unemployment rising dramatically as a result of the Great Depression, U.S. President Franklin D. Roosevelt's Works Progress Administration's Mathematical Tables Project (initiated in 1938) put to work hundreds of unemployed individuals to develop more than two-dozen volumes of calculated tables. Gertrude Blanch was the technical director of this decade-long effort that was subsequently merged into the National Bureau of Standards' Computation Laboratory.

Blanch, and those who worked under her leadership, was one of the many human computers. Prior to World War II, the term "computer" referred to humans who computed—an occupation not a device. Unlike many occupations of the era, it was open to women. Particularly after the entrance of the U.S. into World War II, the U.S. government recruited women trained in mathematics to become human computers. Dozens of women were hired by the Army Ballistic Research Laboratory (which was collaborating with the University of Pennsylvania's Moore School of Electrical Engineering) to calculate ballistic firing tables (tables showing the coordinates for artillery trajectories given wind, atmospheric pressure, and other factors). Six of these women—Betty Snyder, Jean Bartik, Kathleen McNulty, Marilyn Westcoff, Ruth Lichterman, and Frances Bilas—commonly referred to as the "ENIAC girls," would be the first to program the pioneering Electronic Numerical Integrator and Computer (the first meaningful, general-purpose digital computer in the U.S.).

Alongside earlier developments that profoundly and directly influenced digital computing, there were also a number of computational technologies created between the 17th century and first half of the 20th century that had little direct connection to digital computers. Nevertheless some of these technologies were remarkable achievements and ones that may have influenced intermediate technologies, as well as individuals who later did have an impact on digital computing. Chief among these were Blaise Pascal's development of the mechanical calculator, Charles Babbage's designs and plans for massive mechanical calculating engines, and analog computing.

Blaise Pascal, a French mathematician, physicist, and philosopher, in 1642 invented the Pascaline, a mechanical calculator that could do addition and subtraction. Approximately 20 of these machines were produced over the succeeding decade, but they were more a novelty of wealthy individuals than a computational tool of direct, broad impact. Nevertheless, the Pascaline influenced Gottfried Leibniz's "wheel," a device introduced three decades later that could not only do addition and subtraction, but also multiplication and division. Further, the Charles Xavier Thomas de Colmar arithmometer (first produced in the 1820s and manufactured for the next four decades), and the designed calculating engines of Charles Babbage, were influenced in part the Pascaline and the Leibniz wheel.

Charles Babbage, a prominent mathematician, philosopher, economist, and inventor, is often credited as the father of computing based on his designs of the Difference Engine, and a series of technologies collectively referred to as the Analytical Engine, in the first half of the 19th century. He began work on the Difference Engine in 1822, which was abandoned by the early 1840s, and started designs for the technologies of the Analytical Engine in 1833. Neither of Babbage's two designs for the Difference Engine, nor his plans for far more complex analytical engines, resulted in built machines during his lifetime. Finances, challenges of precision manufacturing, and other factors prevented their realization (until 1991 when the Science Museum of London built a working Babbage Difference Engine from the inventor's original designs). Babbage was influenced by the "programmed" punched card instruction loom of Joseph Marie Jacquard developed in 1801, and among the plans for analytical engine technology was the concept of a stored program or instruction set. A collaborator of Babbage, Ada Lovelace, developed a program for the analytical engine, and is sometimes credited as being the world's first computer programmer (a U.S. Department of Defense-funded object-oriented, high level programming language developed by Honeywell-Bull in the late 1970s and early 1980s bears the name "Ada" in her honor).

Many analog mechanical computational devices were invented between the early 17th century and mid-to-late 20th century. These machines modeled phenomena in continuous rather than in the discrete terms (binary digits) of digital computers. They included early tide predictors of the 16th century that used dials and pointers, and representations of the position of the sun and moon in the sky, to come to rough approximations of future tide levels. William Thomson (Lord Kelvin), a prominent Belfast-born mathematician, physicist, and inventor took tide prediction and associated technology to a new level with his analysis of tidal records in the last third of the 19th century. Thomson designed a highly sophisticated tide-predicting machine utilizing pulleys to add harmonic time functions that could trace out results on a chart recorder (consisting of tracing needles and paper roll on the side of the large machine). Similar devices to Lord Kelvin's U.S. government-funded tide predictor, that was fully completed in 1911 (four years after Kelvin's death), were used for a half-century.

Lord Kelvin also sought mechanical solutions to calculating areas under a curve—using integration to solve differential equations. In fact, a number of individuals and companies attempted to use mechanical wheel mechanisms to integrate differential equations in the first-third of the 20th century. Vannevar Bush, a gifted electrical engineering professor at MIT, who would go on to propose the National Defense Research Committee (NDRC) to President Franklin D. Roosevelt and serve as director of the Office of Scientific Research and Development (OSRD), led a project at MIT to develop by far the most useful and significant pre-World War II machine to calculate differential equations: the Differential Analyzer. Bush's first Differential Analyzer was completed in 1927, and he was not aware of the unsuccessful attempts made by Lord

Kelvin to create a similar device more than two-decades earlier. Multiple copies of Bush's Differential Analyzer were built and one went to prominent British computing pioneer Douglas Hartree of Manchester University and another to the University of Pennsylvania's Moore School of Electrical Engineering. The latter was used to calculate ballistic firing tables for the U.S. Army prior to the post-World War II advent of digital computing—but aside from it being used in the same setting as the development of the ENIAC (and for the same initial purpose), it was a completely different type of computer and had no meaningful technical connection to the famous early digital computer. The time-consuming set-up of Bush's massive machine of rods and gears, its lack of exact precision with calculations, and problems associated with its mechanisms frequently getting out of alignment were all critical factors to launching the ENIAC project.

Analog computers continued to be used for certain purposes long after the advent of digital computers, though these contributions commonly are overlooked. This is likely because analog computers were quite different machines and had little technical connection to the broadly transformative digital computer technology of the post-war era.

In contrast to analog computing, pre-digital computer punched card tabulation equipment, and the firms specializing in this area (especially International Business Machines, or IBM), had a profound and continuing impact on digital computer technology. The international office machine industry, which consisted of accounting machines, cash registers, typewriters, and punch card tabulation systems, among other devices, took off in the last quarter of the 19^{th} century. Given labor shortages, a greater propensity toward automation, well-managed office machine companies, and a larger overall market than any single European nation, the U.S. became the international leader of the punch card tabulation machine industry in the first half of the 20^{th} century.

The punch card tabulation technology of engineer and inventor Herman Hollerith was used on the most demanding information processing task of the late 19^{th} century—processing U.S. Census information. Herman Hollerith, a graduate of Columbia University, invented a path breaking punch card tabulation machine that utilized electronic sensors (to detect punched holes in cards) in the mid-1880s. He formed a company in Washington, D.C. and sold his machines and services on a small scale before securing the contract for equipment to process the 1890 U.S. Census. Coupled with other census applications in the U.S. and abroad, Hollerith also successfully secured contracts with the railroad and other industries for his punch card tabulation equipment. In 1911 Hollerith retired and sold his company, then called the Tabulating Recording Company, to financier Charles Flint who merged it with two other firms, the Computing Scale Company and the International Time Recording Company. The merged entity became the Computer Tabulating Recording Company, or C-T-R. C-T-R would change its name to International Business Machines in 1924.

While IBM produced numerous successful products in the interwar period—industrial scales, time-clocks, and electric typewriters—its focus was on punch card tabulators and the standard cards used by these machines. It competed in this industry with Remington Rand (a firm resulting from the combination of Remington Typewriter Company, Powers Accounting Machine Company and Rand Kardex Company in 1927), which had a substantial, but considerably smaller, tabulating machine division. IBM benefited greatly from, and created a strong degree of customer "lock-in" with, its 80-column punch cards first introduced in 1928. These became a near standard in many industrial fields and contributed significantly to IBM's continuing success. The message that appeared on many of these cards, "Do not fold, spindle, or mutilate" is a very well known phrase to this day—despite the fact that the cards are essentially (though not entirely) obsolete.

A couple decades before the famous merger that would result in C-T-R/IBM, John Patterson's successful National Cash Register Company, the world's leading firm for cash registers, hired a young salesman, Thomas Watson. Watson would learn the art of sales from Patterson, and become the firm's leading salesman. After a falling out between Patterson and Watson, C-T-R hired Watson in 1914 to be its General Manager, and soon thereafter its president. For the next four decades Thomas Watson, Sr. would provide strong leadership for C-T-R/IBM and grow it into a corporate giant—a role that he would officially hand over to his son Thomas Watson, Jr. in 1956. Thomas Watson, Sr. daringly invested in the firm throughout the depression as his office machine competitors generally suffered more severely from the challenging times. IBM benefited substantially from the New Deal and its associated need to process ever more government information on the citizens of the United States. Also IBM's stronger financial position than its competitors was self-reinforcing. In addition to inspiring confidence that IBM would be around long-term (which was very important because customer organizations were investing in standard systems), the company was able to focus on a model of leasing as opposed to just selling its machines—at a time when many organizations could not afford to purchase capital equipment for data processing. By the start of World War II, IBM dwarfed its competitors in the punch card tabulation machine field, and it was easily the world's largest office machine producer.

Critically, IBM had far more resources to invest in research and development (R&D) than its competitors. Watson, Sr. insightfully invested aggressively in electronics during the 1940s, placing IBM in an excellent position for rapidly moving into the nascent computer industry when a market opportunity first seemed to appear in the early 1950s. IBM had by far the best sales and service infrastructure for business data processing in pre-World War II office machines. Further, the key input-output technology for digital computers was an area in which IBM was a world leader: punch cards and punch card tabulation systems. These technological (punch card and punch card tabulation) and organizational factors (size and talent of its sales force, and R&D infrastructure) represented critical organizational capabilities that helped IBM achieve computer industry dominance in the second half of the 1950s and 1960s. Absolutely fundamental was IBM's heavy investment in the late 1940s and early 1950s in electronics to strengthen its hold on the data processing machine market in the post-war era. While Watson Sr. saw electronic data processing machines as the future, he remained skeptical about computers, and did not enter into the electronic digital computing field until a clearly recognizable market demand for these machines emerged.

It was individuals and organizations funded directly (design and development contracts) or indirectly (initial customer base) by the U.S. Federal Government (and especially the

Department of Defense, or DoD), that would pioneer digital computing technology in the U.S. In Europe, universities, government laboratories, and electrical equipment firms would lead the way to comparable early achievements.

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